American Journal of Physics and Applications
2025, Vol. 13, No. 5, pp. 115-124
https://doi.org/10.11648/j.ajpa.20251305.11

SciencePG
Science Publishing Group

Research Article

Impact of Enthalpy on the Exergo-environmental and Energy Performance of a Biomass Power Plant

Ghislain Junior Bangoup Ntegmi[1,*], Francois Lanzetta[2], Bernard Bali Tamegue[3], Wandji William Nyamsi[1], Mahamat Hassane Babikir[4], René Tchinda[5]

[1]Department of Physics, University of Yaounde I, Yaounde, Cameroon
[2]FEMTO-ST Institute, University of Bourgogne Franche-Comte, Belfort, France
[3]Department of Physics, University of Adam Barka d'Abeche, Adam Barka d'Abeche, Chad
[4]Department of Physics, University of Ndjamena, Ndjamena, Chad
[5]Deparment of Physics, University of Dschang, Dschang, Cameroon

Abstract

Among green energy sources, biomass has significant advantages over fossil fuels in terms of cost and environmental impact. However, the presence of a high moisture content in biomass negatively affects its combustion energy, resulting in a lower flame temperature and an increase in the production of undesirable gaseous compounds, which can lead to operational and environmental problems. The biomass must therefore be dehydrated before it can be burnt to produce electricity. To optimise energy efficiency and minimise the costs associated with drying, it is essential to design an efficient thermal integration between the steam power plant and the biomass dehydration stage. In this study, enthalpy analyses are carried out on a biomass power plant that uses agricultural waste (dried banana peel) as fuel, with a view to assessing the energy efficiency, exergy and CO_2 emissions produced. The Rankine-Hirn cycle was used to model the biomass power plant through exergy and environmental analysis. A custom code was designed in Matlab to obtain our results. The results of this study show that the optimal output enthalpy of the pump is 450 $KJ.Kg^{-1}$ for a maximum value of the exergy efficiency of the biomass plant of 41%; the optimum enthalpy at the turbine outlet is 200 KJ/Kg for an energy efficiency of 95%; the maximum energy efficiency is 88%, when the enthalpy at the turbine inlet reaches its optimal value at 3400 $kJ.Kg^{-1}$. This system can be used to generate electricity in areas where access is limited.

Keywords

CO_2 Emissions, Biomass Power Plant, Rankine-hirn Cycle, Energy Efficiency

1. Introduction

Biomass is organic matter that can be converted into energy using conversion techniques that exploit the thermodynamic and kinetic properties of chemical reactions, such as anaerobic/aerobic digestion, combustion, pyrolysis and gasi-

*Corresponding author: ghislain.bangoup@facsciences-uy1.cm (Ghislain Junior Bangoup Ntegmi)

Received: 19 May 2025; **Accepted:** 3 June 2025; **Published:** 19 September 2025

Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

fication, which are governed by the principles of thermochemistry and biochemistry. Biomass encompasses a diverse range of organic materials, including specific energy crops and wastes such as forestry residues (cotton stalks, paddy straw, rice husks, sawdust), as well as various agricultural and industrial by-products that can be recovered for energy production. Direct combustion is an exothermic thermochemical step that converts solid fuels into heat and steam. It is well suited to biomass because of its low cost and reliability, and is essential for producing electricity in biomass power plants [1]. The steam produced can be used for industrial applications or to generate electricity. The design of a biomass combustion plant depends on the properties of the fuel, environmental regulations, costs and energy and production capacity requirements for efficient, environmentally-friendly operation [2]. The physico-chemical properties of the fuel have a significant impact on the selection and design parameters of the combustion system. In particular, the moisture content of the fuel is a critical factor that significantly influences combustion efficiency and stability. The physico-chemical properties of the fuel, in particular the moisture content, have a considerable influence on combustion efficiency and stability, thus affecting system selection and design parameters. Modern biomass combustion systems require a specific moisture content range for the fuel to ensure emissions and efficiency meet standards. Using fuel outside this range can cause the system to shut down automatically to prevent malfunctions [3]. Biomass has a wide range of moisture content, from 10% for cereal straw to 50-70% for forestry waste, depending on its origin and composition [4]. Industrial sludge and fresh microalgae have a high moisture content, in excess of 90% respectively [5]. The use of dried fuels in combustion plants optimises thermal efficiency, intensifies steam generation, minimises energy expenditure, reduces atmospheric emissions and improves the performance of steam generators [6]. Research is exploring the synergy between a wood processing unit, a pellet manufacturing plant and a hybrid energy installation using organic residues in a specialised thermal system [7]. The analyses reveal that up to 18% of the organic residues generated by the wood processing unit can be recovered using a synergistic production approach. The study presents an energy and economic assessment of various biomass cogeneration plants, comparing the performance of different technologies: organic Rankine cycle (ORC), Stirling engine, steam engine, steam turbine and gas engine, as described in [8]. The assessment reveals that, in the Serbian context, the implementation of cogeneration systems in small-scale wood processing units (around 10,000 m^3/year) is not financially viable. Diversified organic resources, particularly forest residues, can be used to power decentralised hybrid energy systems. One study proposes an innovative hybrid energy plant combining a variety of biomass (wood waste, wood chips) and concentrated solar energy via parabolic trough collectors, as described in [9]. A hybrid energy plant combining photovoltaic solar energy and bioenergy resources is analysed in [10].

A similar principle should be applied to optimise the yield of a biomass energy plant. Using steam to dry the biomass minimises energy losses in the boiler and condenser, improving the overall efficiency of the system. In what follows, the use of dried banana peels to study the impact of enthalpy on improving the energy efficiency of a biomass power plant is carried out. After drying, banana peels have a moderate moisture content of 10% to 12%.

The important and current contributions of the present study to biomass power plant research are:

1) Integrated Energy + Exergy + Environment approach: This enables us to better identify the major sources of useful energy wastage and optimize cycle design (Rankine, ORC, etc.).
2) Environmental assessment based on lost exergy: Reduce biomass consumption for the same production.
3) Support for energy transition and decarbonization: A better understanding of exergo-environmental performance helps to reduce the ecological impact and improve the competitiveness of these power plants.

2. Materials and Methods

2.1. Description of the Plant

The fundamental concept of a cogeneration plant is based on the recovery and use of the thermal waste generated by the electricity production equipment, which requires a sufficiently high discharge temperature to enable this residual energy to be used efficiently. Many cogeneration plants generally use gas turbines, steam turbines or internal combustion engines to generate electricity. New technologies, such as fuel cells, are also being developed and can be integrated into cogeneration systems. The diagram in Figure 1 illustrates the main energy flows and highlights three key areas of energy conversion in a steam turbine cogeneration plant.

1. Recovery of the high-temperature heat contained in the exhaust gases at boiler level, which will make steam available at the end of the process.
2. Transformation of the thermal energy of superheated steam into mechanical energy at the turbine, thanks to the steam which undergoes expansion through the turbine wheels available on the rotor.
3. The conversion of mechanical energy from the turbine rotor into electrical energy at the generator, which is then transmitted to the grid or to an isolated load.

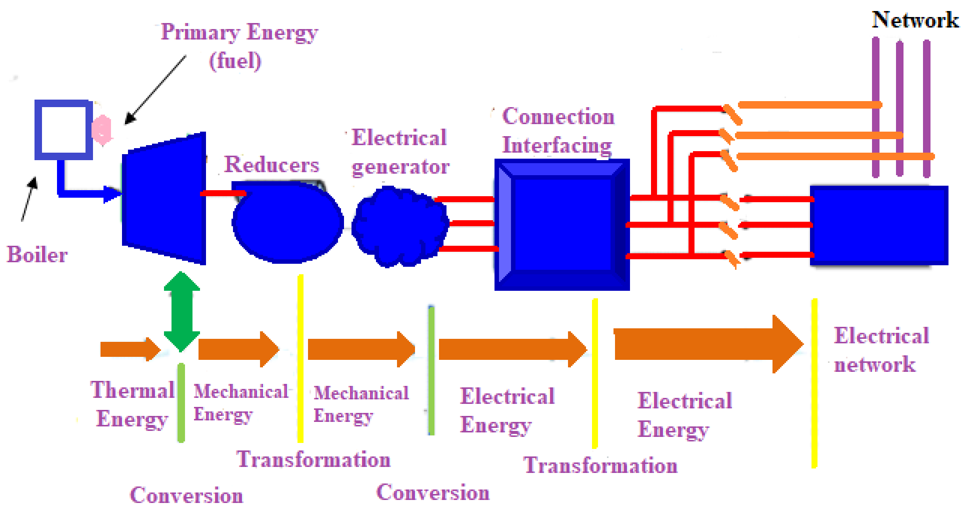

Figure 1. *Energy transformation chains in a cogeneration plant.*

2.2. Mathematical Modelling

2.2.1. Energo-exergetic Analysis

1). Rankine Cycle or Ideal Rankine Cycle

The theoretical Rankine cycle, named after the Scottish physicist William J. Rankine, serves as a fundamental model for thermal and nuclear energy installations, where water is used as a transfer agent to convert thermal energy into mechanical work. In a theoretical framework, turbines are treated as operating in an isentropic cycle, which means a reversible adiabatic transformation. In practice, machines can never achieve perfection, and efficiency coefficients will be built in later to take account of this. The thermodynamic cycle represented in the (T-S) diagram, known as the Rankine cycle, is illustrated in Figure 2. The 4 stages of the cycle are as follows:

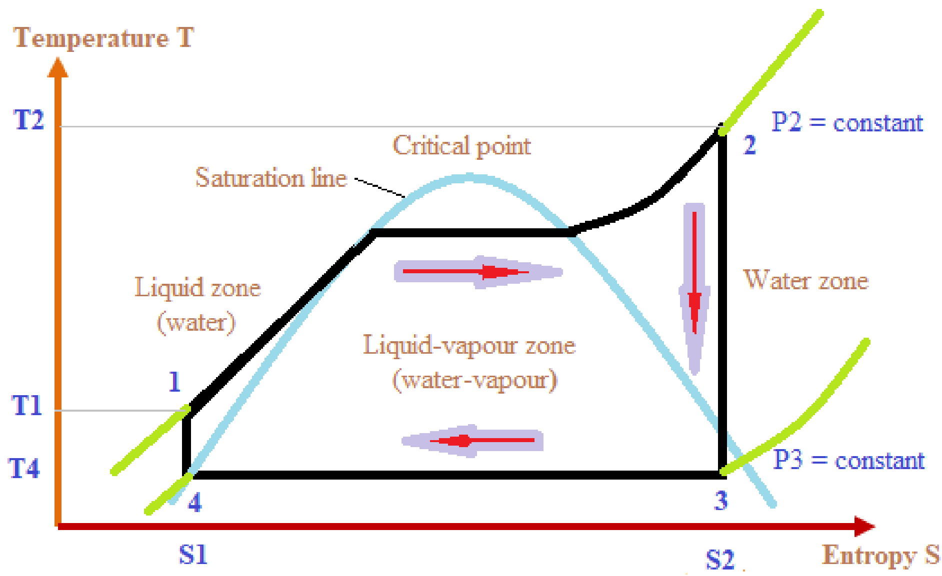

Figure 2. *Ideal Rankine cycle with superheating of the steam produced.*

Process (1-2): Heat transfer to the fluid. Heat is produced by a fuel. Water enters the boiler, absorbs the heat produced and exits as superheated steam.

Process (2 -3): Expansion. The steam passes through the turbine, losing its pressure. The enthalpy lost by the steam is transformed into work by the rotating turbine.

Process (3 - 4): Rejection of the heat of condensation into the ambient environment when steam is transformed into water in a condenser. This energy can also be extracted to meet cogeneration thermal loads.

Process (4-1): Isentropic increase in the pressure of water supplied to the steam boiler by means of a pump. The water enters the pump as a saturated liquid and leaves as a sub-cooled liquid. The work required by this change of state, i.e. the work supplied by the pump, is generally a fraction of the work produced by the turbine (typically 5%).

The work produced by the turbine per unit mass of steam it uses, or work produced in the Rankine cycle, is symbolised by equation (1) [11, 12, 13].

$$W_{ideal} = h_2 - h_3 \tag{1}$$

Where W_{ideal} is the work produced by the Rankine cycle, i.e. the theoretical specific steam consumption, h_2 is the enthalpy of the steam feeding the turbine and h_3 is that of the steam leaving the turbine. The enthalpies h_2 and h_3 correspond to the same points 2 and 3 as in the diagram in Figure 2, which have the same entropy.

The unit work W actually produced by the steam turbine (which gives the actual specific steam consumption), takes into account the fact that the turbine does not operate according to the ideal cycle. It is calculated by equation (2) [13]:

$$W = \eta_s \cdot W_{ideal} \tag{2}$$

Where η_s is the isentropic efficiency of the turbine.

Expression (1) requires information on the enthalpy of the steam both entering and leaving the turbine.

The enthalpy h_2 and entropy s_2 of the steam entering the turbine can be determined from the pressure at point 2, P_2, and the temperature T_2 of the superheated steam, two parameters defined by the user. The enthalpy h_3 at the outlet of the extraction point can be determined as a function of the turbine outlet pressure P_3, also specified by the user, and the entropy at the extraction point s_3 (equal to s_2 on the assumption of an isentropic transformation).

In reality, the device does not behave like a theoretical model, and additional efficiency losses must be considered. The energy actually produced by the turbine for each unit mass of steam (or the effective specific steam consumption) can be established as a function of the total isentropic efficiency of the turbine-generator system, as shown by relationship (3) [13]:

$$W = \eta_{tg} \cdot W_{ideal} \tag{3}$$

In practice, efficiency is influenced by various elements along the steam path, including the diameter of the nozzle opening.

The electrical power produced by the turbine can now be obtained by multiplying the unit work produced by the mass flow rate of steam supplied to the turbine. This is represented by equation (4) [14, 15]:

$$P_{elec} = \dot{m} \cdot W \tag{4}$$

Where W is the work actually produced per unit mass of steam entering the steam turbine-generator unit.

The thermal capacity of the turbine is then symbolised by formula (5) [14]:

$$\dot{Q}_c = \dot{m}\left(h_3 - h_4\right)W \tag{5}$$

Steam quality index

The quality index of the steam leaving the turbine is obtained from the entropy of the water which may begin to appear at the turbine outlet and the entropy of the steam leaving the turbine, according to the following formula (6) which applies to the two-phase mixture [13]:

$$X_3 = \frac{s_3 - s_1}{s_v - s_1} \tag{6}$$

where x_3 indicates the quality coefficient of the steam emitted by the turbine, s_3 corresponds to the entropy of this steam, s_1 refers to the entropy of the water introduced into the steam boiler at the turbine outlet pressure, and s_v symbolises the entropy of the steam in the saturated state at this pressure. When the steam quality coefficient is below 1, this means that the steam is damp.

If the water vapour quality coefficient is below 1, this means that the vapour contains water in the form of small drops (this vapour is then referred to as humid).

In general, a steam turbine requires a minimum quality coefficient of between 0.90 and 0.95. If this coefficient is too low, it can lead to wear of the turbine blades, caused by the impact of water droplets on them, thus increasing the maintenance costs of the electricity generation system. When the pressure of the extracted steam is higher, the quality coefficient of the steam circulating in the turbine increases. If it is not possible to extract the steam at a higher pressure, it will be necessary to use several steam turbines and possibly a reheater or moisture separator. This will help to reduce maintenance costs, but will increase the initial outlay on the equipment.

2). Hirn Rankine Cycle

The Hirn Rankine cycle is an adaptation of the Rankine cycle that incorporates pressure losses and system inefficiencies. It is used to simulate the actual operation of steam turbines. This cycle comprises the same phases as the Rankine cycle, but takes into account the following elements [16]:

(a) Modelling pressure losses in heat exchangers

(b) Losses due to turbine inefficiency

(c) Heat loss in pipes

Back-pressure cycle

To generate both mechanical power and a significant amount of heat, it is preferable to allow all the steam from the generator to expand in a prime mover, so that when it leaves, it is in a suitable state for subsequent use for heating. The condenser is therefore replaced by a heat exchanger, which recovers the thermal energy generally lost to the cold source. Since this heat exchanger operates at a higher pressure than the conventional condenser, it is referred to as a back-pressure cycle. The process diagram is shown in Figure 3, while the associated thermodynamic cycle is illustrated in Figure 4. In this scenario, it is essential that the state at the turbine outlet corresponds to that at point (1) in Figure 4. As the turbine exhaust pressure is greater than atmospheric pressure, it is indicated that it is operating at back pressure.

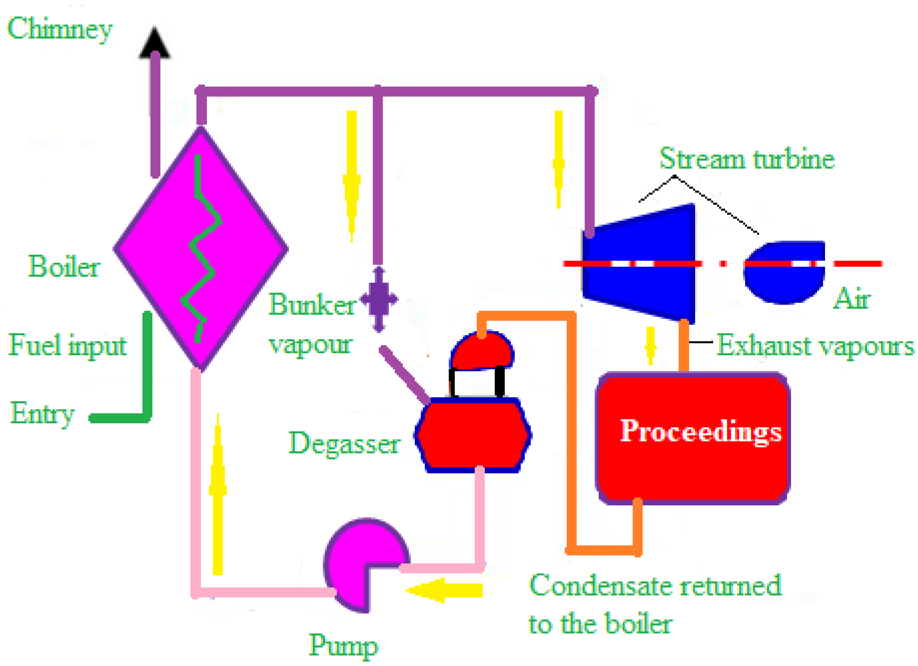

Figure 3. Schematic diagram of the installation.

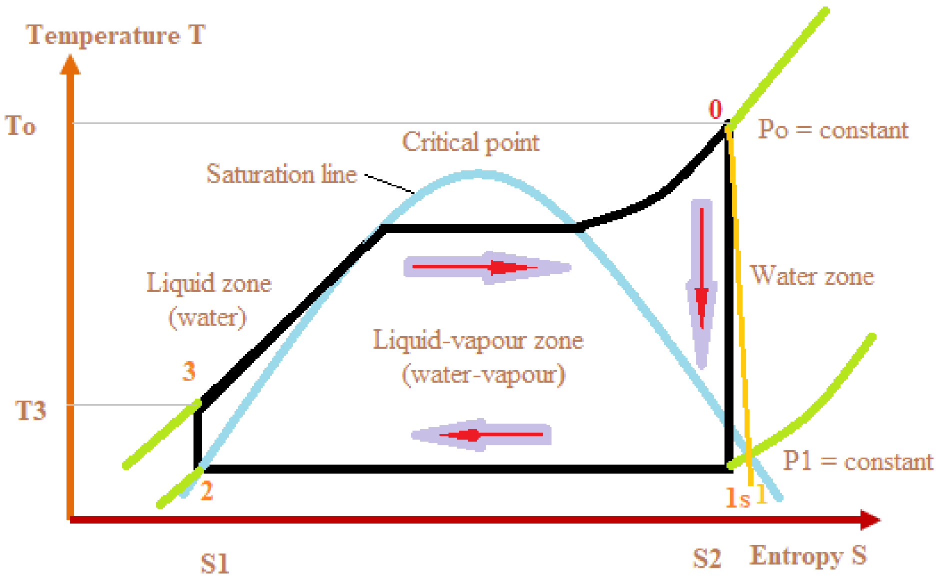

Figure 4. Thermodynamic diagram of the process.

Heat balance in the turbine

The steam turbine efficiency is expressed by formula (7) [17, 18]. The power of the steam turbine and that of the pump are calculated using relations (8) and (9) respectively [14, 15, 18].

$$\eta_{TV} = \frac{h_0 - h_1}{h_0 - h_{1s}} \quad (7)$$

$$\dot{W}_{TV} = \dot{m}_v \left(h_0 - h_1\right) \quad (8)$$

$$\dot{Q}_{1-2} = \dot{m}_v \left(h_1 - h_2\right) \quad (9)$$

$$\dot{Q}_{3-0} = \dot{m}_v \left(h_0 - h_3\right) \quad (10)$$

$$\dot{W}_p = \dot{m}_v \left(h_3 - h_2\right) \quad (11)$$

Heat balance in the boiler

To ensure that a boiler is working properly, it is necessary to carry out a heat balance and identify any faults in its components, as shown in Figure 5 below.

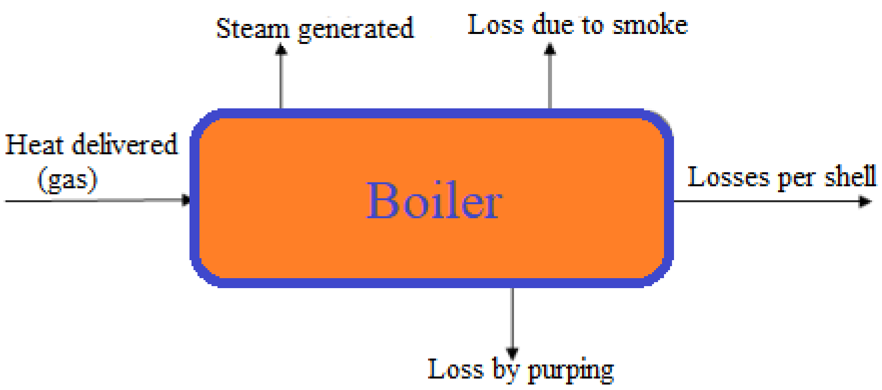

Figure 5. *Boiler energy balance.*

Indirect method for calculating boiler efficiency

Heat losses can be assessed according to the ASME (American Society of Mechanical Engineers) test code. This strict code covers all types of fuel, but in Algeria boilers mainly use natural gas or fuel oil, making some of the losses mentioned in the code irrelevant. A simplified method for calculating the efficiency of a boiler is described by equation (12) [15, 18, 19, 20]:

$$efficiency = \frac{input - loss}{ouput} \times 100 \quad (12)$$

The exergy efficiency of the Rankine-Hirn cycle can fluctuate according to various parameters of the cycle, such as:

1) The temperature and pressure of the steam at the turbine inlet
2) Condenser temperature and pressure
3) Type of working fluid (water, ammonia, etc.)
4) Pump and turbine efficiency

It is calculated by relationship (13) [21, 22]:

$$\eta_{ex} = \frac{W_{TV} - W_p}{\dot{Q}_{3-0}} \quad (13)$$

2.2.2. Environmental Analysis

Emissions from the biomass power plant are calculated using equation (14) [23].

$$EmCO_2 = \frac{m \cdot \%C \cdot F}{\eta_{TV}} \quad (14)$$

Where m is the mass of biomass burnt per year (t/yr),%C is generally between 0.45 and 55 tC/t biomass, F is the CO_2 emission factor per tonne of carbon burnt (generally it is 3.6 7 t CO_2/t C).

Table 1. *Characteristics of the power plant [24].*

(0): Turbine input and reading of steam characteristics from thermodynamic data:	
P_0 = 5, 4 MPa T_0 = 480 ℃	V_0 = 0, 0611323 m^3/kg h_0 = 3381,902 kJ/kg S_0 = 6, 87382 kJ/kg.k
1): Turbine output and reading of steam characteristics from thermodynamic data	
P_1 = 0, 27 MPa T_1 = 140 ℃	V_1 = 0, 68763 m3 /kg h_1 = 2742,043 kJ/kg S_1 = 7, 0799 kJ/kg.k
(1s) Isentropic output and reading of steam characteristics from thermodynamic data	
V_{1S} = 0, 649753 m3 /kg h_{1S} = 2658, 696 kJ/kg	

X_{1s} = 0, 972

(2): saturated liquid and reading of vapour characteristics from thermodynamic data

T_2 = 105 ℃	V_2 = 0, 001047 m3 /kg
P_2 = 0, 27 MPa	h_2 = 440, 239 J/kg
	S_2 = 1, 3628 kJ/kg.k

(3): pump outlet

P_3 = 5,4 MPa	h_3 = 445, 608 kJ/kg
$S_3 = S_2$ = 1, 3628 kJ /kg.k	V_3 = 0, 001045 m3/kg

The boundary conditions for this model are as follows:

$$2800 \le h0 \le 3400 \ \text{KJ/Kg} \quad (15)$$

$$2700 \le h1 \le 2900 \ \text{KJ/Kg} \quad (16)$$

$$1000 \le hs \le 2500 \ \text{KJ/Kg} \quad (17)$$

$$450 \le h3 \le 500 \ \text{KJ/Kg} \quad (18)$$

$$0 \le mCO2 \le 2000 \ \text{Kg} \quad (19)$$

3. Results and Discussion

Criteria are used in this analysis to measure system performance, with electrical power and Biomass energy and exergy yields as the main output indicators. In order to analyse the impacts of biomass plant enthalpies, various factors have been considered and are presented in Table 1. The general assessment and optimisation was carried out using agricultural residues (dried banana peels) as the fuel source. In this analysis, the simulation results, in particular the effects of enthalpies on the performance of the Biomass power plant, are analysed and the optimal values are presented. The numerical code is written in MATLAB for numerical programming.

System performance

Figure 6 shows the effects of isentropic enthalpy on the energy yield of the biomass plant. Thus the increase in isentropic enthalpy from 1000 to 2500 KJ.Kg^{-1} implies a slow rate of growth in the exergy efficiency of the biomass plant from 27% to 53%, then increasing significantly to around 73%. This could be attributed to improvements in heat flow management and optimisations in the biomass-to-energy conversion process.

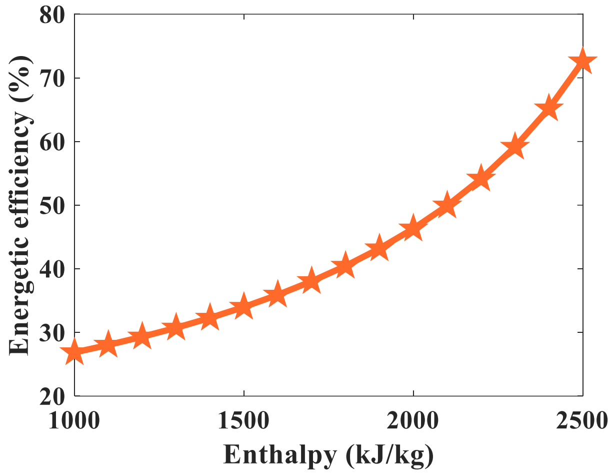

Figure 6. *Effect of isentropic enthalpy hs_1 on energy efficiency.*

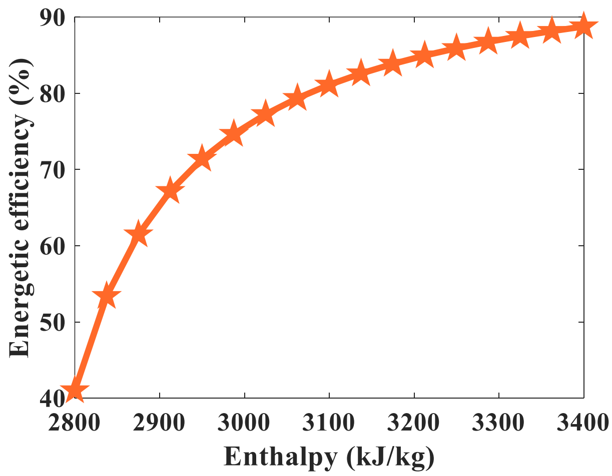

Figure 7. *Effect of enthalpy at the turbine inlet on the energy efficiency of the machine.*

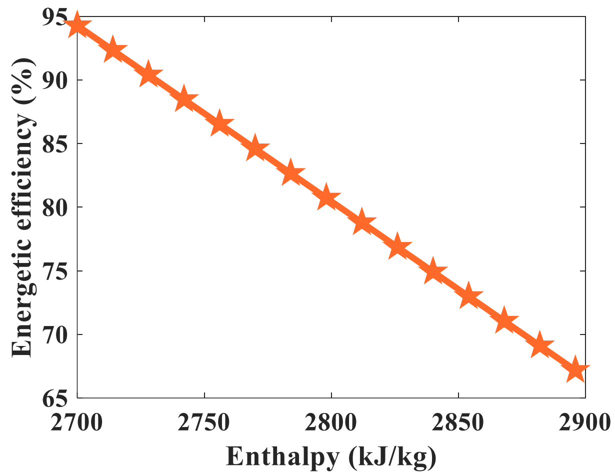

Figure 8. *Effect of enthalpy at the turbine outlet on the power plant's energy efficiency.*

The effects of enthalpy at the turbine inlet on the energy efficiency of the biomass plant are shown in Figure 7. It can be seen that varying the enthalpy at the turbine inlet from 2800 to 3400 kJ.Kg^{-1} leads to a significant increase in energy efficiency from 40 to 77%, then increases at a slow rate to an optimum value for the energy efficiency of the biomass plant at around 88%. This improvement in efficiency can be attributed to better management of thermal exergy and optimised combustion processes. Achieving maximum efficiency suggests that the biomass plant is capable of exploiting the resource very efficiently under certain conditions, such as the quality of the biomass, which must have a moisture content of less than 20% in order to improve combustion and reduce losses.

Figure 8 shows that the increase in enthalpy at the turbine outlet from 2700 to 2900 kJ.Kg^{-1} has a negative impact on the energy efficiency of the biomass power plant, dropping from 94.7% to around 68%. This means that much of the energy that could be used to produce work is lost, affecting the overall efficiency of the plant. This could indicate a problem with the turbine design or operating conditions, such as poorly adjusted fluid flow or sub-optimal pressure conditions.

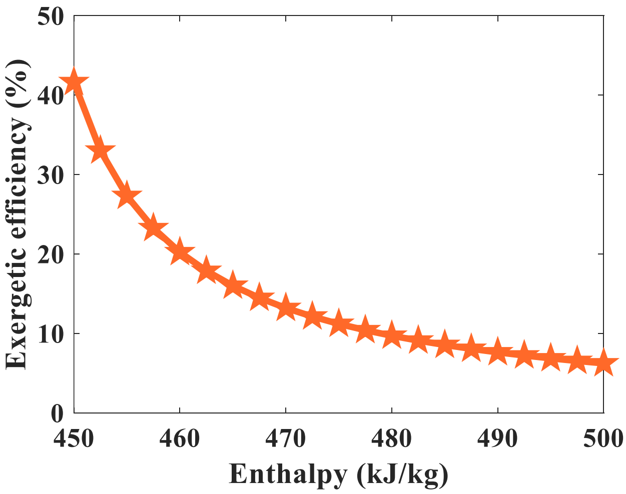

Figure 9*. Effect of the pump h_3 output enthalpy on exergetic efficiency.*

Figure 9 shows the impact of the pump's output enthalpy on the exergy efficiency of the biomass plant. It can be observed that the increase in output enthalpy in the Biomass power plant pump from 450 to 500 kJ.Kg^{-1}, leads to a decrease in the exergy efficiency of the machine from 41 to 18% at a rapid rate, then decreases insignificantly to around 8%. This can be attributed to friction losses, inefficiencies in energy transfer or non-optimum operation of the pump.

The impact of the enthalpy at the turbine inlet on the power plant's electrical output can be seen in Figure 10, where it can be seen that increasing the enthalpy at the turbine inlet from 2800 kJ.Kg^{-1} to 3400 kJ.Kg^{-1} leads to a significant increase in the Biomass power plant's electrical output from 3 to 27 MW. That's an increase of 88%. This could be attributed to optimisations in the combustion and conversion process, enabling the turbine to operate under more favourable conditions.

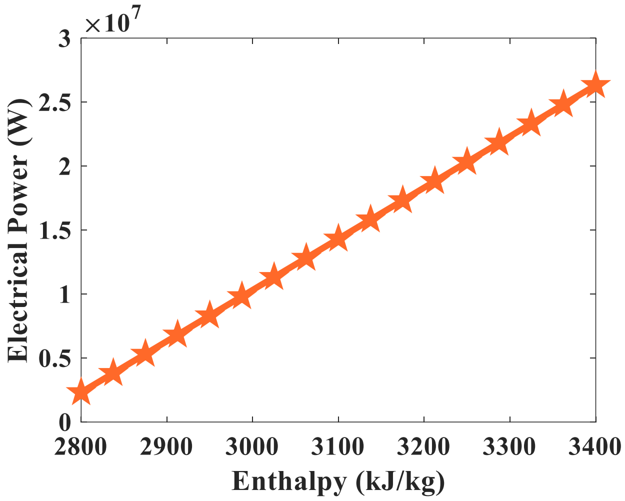

Figure 10*. Effect of enthalpy at the turbine inlet on the electrical power produced.*

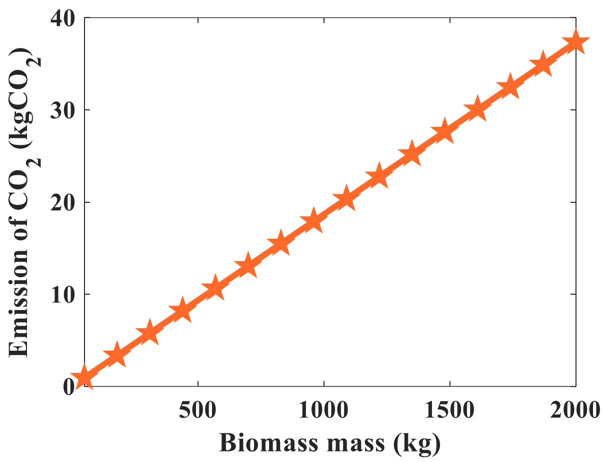

Figure 11*. Effect of biomass mass on CO_2 emissions.*

The effects of biomass on CO_2 emissions are shown in Figure 11. It can be seen that increasing the mass of biomass from 50 to 2000 Kg leads to a significant increase in CO_2 emissions into the atmosphere from 2 to 38 Kg CO_2. This may be due to the fact that biomass combustion generates CO_2, and a greater mass of biomass burnt leads to proportionally higher emissions.

The trade-offs between CO_2 emissions and energy efficiency in a biomass power plant comes down to analyzing the tensions between environmental and technical performance: biomass power plants offer a renewable alternative, but their high energy efficiency can increase CO_2 emissions if combustion is poorly controlled. Optimizing efficiency while limiting emissions requires advanced technologies and sustainable management, illustrating the trade-off between technical performance and environmental impact.

4. Validation

In this section, the comparison of the results of this study with those from the literature is established.

In 2022, Ref [25] studied the thermodynamic, economic and environmental aspects of an integrated system for cooling, heating and electricity production powered by biomass and natural gas. The Eco-Indictor 99 method is used to quantify the environmental impact. The results indicate that the efficiency of the system's exhaust is 39.45% however in this study it is 41%, which is a relative error of 3%.

Comparison of this study with that of Ref [26]. The energy efficiency obtained by Ref [26] is 35.54% using coal as fuel. In contrast, the efficiency obtained in this study is 40%. The model presented in this study therefore outperforms that of Ref [26] using dry banana peels.

5. Conclusion

In the present study, a material, energy and exergo-environmental balance model taking into account the effects of enthalpies was developed to study the performance of a biomass power plant. The biomass power plant uses dried banana peels as fuel. The main optimal parameters of the biomass power plant to achieve higher energy efficiency, power output and energy yield were determined. The main results are presented below:

1) Increasing the enthalpy at the turbine inlet increases the energy efficiency of the biomass power plant to its maximum value of 88% for an optimum enthalpy value of 3400 $kJ.Kg^{-1}$.
2) The increase in enthalpy at the pump outlet reduces the exergy efficiency of the machine.
3) The increase in the mass of dry banana peelings increases the amount of CO_2 emissions released by the biomass power plant.
4) The increase in enthalpy at the turbine inlet increases the machine's electrical power.

Abbreviations

ηtg	Overall Isentropic Efficiency of the Turbine-generator Set,%
h	Enthalpy, $KJ.Kg^{-1}$
$\dot{m}$	Steam Mass Flow Rate to the Turbine
%C	Carbon Content of Biomass
F	CO_2 Emission Factor per Tonne of Carbon Burned, t CO2/t C
m	Mass of Biomass Burnt per Year, $t.Year^{-1}$
Pelec	Electrical Power Produced by the Steam Turbine-generator Unit, W
s	Entropy, $J.K^{-1}$
η_{ex}	Exergetic Efficiency,%

Author Contributions

Ghislain Junior Bangoup Ntegmi: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Francois Lanzetta: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft

Bernard Bali Tamegue: Writing – original draft, Validation, Visualization

Wandji William Nyamsi: Writing – original draft, Validation, Visualization

Mahamat Hassane Babikir: Validation, Visualization

René Tchinda: Supervision

Funding

This study did not receive funding from any person or institution.

Data Availability Statement

The data used are included in article trough the supplementary material referenced in article.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] IEA, 2012. Biomass Combustion and Co-firing. http://www.ieabcc.nl/

[2] Koppejan, J., & Van Loo, S. (2012). *The handbook of biomass combustion and co-firing*. Routledge. https://doi.org/10.4324/9781849773041

[3] BEC. (2011). Effect of moisture content in biomass material. Biomass Energy Centre http://www.biomassenergycentre.org

[4] Quaak, P., Knoef, H., & Stassen, H. E. (1999). Energy from biomass: a review of combustion and gasification technologies.

[5] Kanda, H., & Li, P. (2011). Simple extraction method of green crude from natural blue-green microalgae by dimethyl ether. *Fuel*, *90*(3), 1264-1266. https://doi.org/10.1016/j.fuel.2010.10.057

[6] Amos, W. A. (1999). *Report on biomass drying technology* (No. NREL/TP-570-25885). National Renewable Energy Lab.(NREL), Golden, CO (United States). https://doi.org/10.2172/9548

[7] Anderson, J. O., & Toffolo, A. (2013). Improving energy efficiency of sawmill industrial sites by integration with pellet and CHP plants. *Applied energy*, *111*, 791-800. https://doi.org/10.1016/j.apenergy.2013.05.066

[8] Danon, G., Furtula, M., & Mandić, M. (2012). Possibilities of implementation of CHP (combined heat and power) in the wood industry in Serbia. *Energy*, *48*(1), 169-176. https://doi.org/10.1016/j.energy.2012.02.073

[9] Peterseim, J. H., Tadros, A., Hellwig, U., & White, S. (2014). Increasing the efficiency of parabolic trough plants using thermal oil through external superheating with biomass. *Energy Conversion and Management*, *77*, 784-793. https://doi.org/10.1016/j.enconman.2013.10.022

[10] Angrisani, G., Bizon, K., Chirone, R., Continillo, G., Fusco, G., Lombardi, S.,... & Urciuolo, M. (2013). Development of a new concept solar-biomass cogeneration system. *Energy Conversion and Management*, *75*, 552-560. https://doi.org/10.1016/j.enconman.2013.06.042

[11] Sabonnadière, J. C. (2006). *Nouvelles technologies de l'énergie*. Hermès.

[12] Demraoui, F. Z., Amhamdi, L. A. T. I. F. A., & Harrouz, A. (2023). *Analyse et efficacité des projets d'énergies renouvelables: photovoltaïque et éolienne avec RET Screen* (Doctoral dissertation, UNIVERSITE AHMED DRAIA-ADRAR). https://dspace.univ-adrar.edu.dz/jspui/handle/123456789/8058

[13] Park, B. S., Usman, M., Imran, M., & Pesyridis, A. (2018). Review of Organic Rankine Cycle experimental data trends. *Energy conversion and management*, *173*, 679-691. https://doi.org/10.1016/j.enconman.2018.07.097

[14] Kaur, H., Gupta, S., & Dhingra, A. (2022). Analysis of hybrid solar biomass power plant for generation of electric power. *Materials Today: Proceedings*, *48*, 1134-1140. https://doi.org/10.1016/j.matpr.2021.08.080

[15] Bangoup Ntegmi, G. J., Tchinda, R., Simo, E., Babikir, M. H., Kamta Legue, D. R., Chopkap Noume, H., & Kenfack, A. Z. (2024). Energy and exergo-environmental performance analysis of a Stirling micro-fridge with imperfect regenerator. *International Journal of Ambient Energy*, *45*(1), 2351089. https://doi.org/10.1080/01430750.2024.2351089

[16] Coppola, M. (2024). *Study on the use of a parabolic dish collector to drive a small-scale organic Rankine cycle* (Doctoral dissertation, Politecnico di Torino). https://webthesis.biblio.polito.it/30584/

[17] Li, T., Wang, J., Chen, H., Li, W., Pan, P., Wu, L., & Chen, H. (2023). Performance analysis of an integrated biomass-to-energy system based on gasification and pyrolysis. *Energy Conversion and Management*, *287*, 117085. https://doi.org/10.1016/j.enconman.2023.117085

[18] Ntegmi, G. J. B., Chara-Dackou, V. S., Babikir, M. H., Awakem, D., Chopkap, H. N., Simo, E., & Tchinda, R. (2024). Energy and exergo-environmental analysis of a refrigerator-Stirling/Photovoltaic system for cold production. *Results in Engineering*, 102443. https://doi.org/10.1016/j.rineng.2024.102443

[19] Chakrabarti, A. (2018). *Energy Engineering and management*. PHI Learning Pvt. Ltd.. ISBN-978-93-87472-90-7.

[20] Sattasathuchana, S., Parnthong, J., Youngian, S., Faungnawakij, K., Rangsunvigit, P., Kitiyanan, B., & Khemthong, P. (2023). Energy efficiency of bio-coal derived from hydrothermal carbonized biomass: Assessment as sustainable solid fuel for municipal biopower plant. *Applied Thermal Engineering*, *221*, 119789. https://doi.org/10.1016/j.applthermaleng.2022.119789

[21] Yang, S., Wang, G., Liu, Z., Deng, C., & Xie, N. (2024). Energy, exergy and exergo-economic analysis of a novel SOFC based CHP system integrated with organic Rankine cycle and biomass co-gasification. *International Journal of Hydrogen Energy*, *53*, 1155-1169. https://doi.org/10.1016/j.ijhydene.2023.12.150

[22] Ntegmi, G. J. B., Babikir, M. H., Chara-Dakou, V. S., Chopkap, H. N., Mounkang, O., Kenfack, A. Z., & Tchinda, R. (2025). Thermo-economic and environmental analysis of a Dish-Stirling/Stirling thermal solar refrigerator for cold production. *Renewable and Sustainable Energy Reviews*, *216*, 115701. https://doi.org/10.1016/j.rser.2025.115701

[23] YACOUBI Sofiane, (2014). Dimensionnement d'une centrale de cogénération à base des turbines à vapeur. Ecole Nationale Polytechnique.

[24] Nikam, K. C., Kumar, R., & Jilte, R. (2021). Exergy and exergo-environmental analysis of a 660 MW supercritical coal-fired power plant. *Journal of Thermal Analysis and Calorimetry*, *145*(3), 1005-1018. https://link.springer.com/article/10.1007/s10973-020-10268-y

[25] Exergetic, exergo-economic, and exergo-environmental analyses of a trigeneration system driven by biomass and natural gas. *Journal of Thermal Analysis and Calorimetry*, *147*(6), 4303-4323. https://link.springer.com/article/10.1007/s10973-021-10813-3

[26] Hai, T., Ali, M. A., Alizadeh, A. A., Almojil, S. F., Almohana, A. I., & Alali, A. F. (2023). Reduction in environmental CO_2 by utilization of optimized energy scheme for power and fresh water generations based on different uses of biomass energy. *Chemosphere*, *319*, 137847. https://doi.org/10.1016/j.chemosphere.2023.137847