



Carbon Content and Economic Value of “*Lamtoro*” Biomass for the Co-Firing Control Plant on Timor Island, Indonesia

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Abstract

Timor Island has a good source of lamtoro (Leucaena leucocephala) energy forests. Although lamtoro has been used for the substitution of coal within the co-firing control plant on Timor Island, there is no empirical data on the carbon content, calorific, and economic values generated from the biomass. This study aims to investigate the potential for lamtoro woodlands to produce renewable biomass. The proximate, ultimate, and chlorine techniques have been used to analyze carbon content and calorific values. While the economic value added (EVA) tools of analysis have been used to analyze the economic value of biomass. The result of the study shows that the calorific value (HHV—higher heating value) of the coal and biomass blend with a proportion of 95%:5% is 4,342 kcal kg⁻¹, almost equivalent to the highest calorific value of coal. The commercialization of biomass created from lamtoro is financially viable, as evidenced by the company's financial performance. Analysis of the financial performance included in the biomass generation commerce showed that each kilogram of lamtoro biomass contributes IDR133.23 (18%) to the final product's value, indicating positive business prospects. Based on this result, the government should implement a policy to develop and maintain the existing forest as a source of bioenergy.

Keywords: biomass, carbon value, economic value, power plant, Timor, Indonesia

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Introduction

The 26th Conference of the Parties (COP26) in Glasgow reaffirmed global commitments under the Paris Agreement, highlighting four key areas: i) the importance of shifting to electric vehicles, ii) ending deforestation with financial assistance, iii) drafting rules for the global carbon market, and iv) mobilizing funds for developing countries. Indonesia has established the National Determined Contribution (NDC) and the long-term strategy on low carbon and climate resilience 2050, which has been ratified into Law Number 16/2016. Government policies related to energy development on Timor Island of Indonesia are contained in Regional Regulation Number 10 of 2019 concerning Guidelines for the Regional Energy General Plan (RUED) of East Nusa Tenggara (NTT) Province 2019–2050. By paying attention to the characteristic conditions of NTT Province, the NTT Provincial RUED mandates the development of New Renewable Energy as the energy source in NTT Province.

Furthermore, the NTT government has also established regional energy mix efforts through potential renewable energy (RE) sources spread across three large islands, with the Sumba Islands designated as Sumba Iconic Island, the Flores Islands as Flores Geothermal Island, and the "Timor Islands as Timor Biomass Island".

Timor Island is well-suited through multi-stakeholder cooperation (provincial government, university, state company, and community) to develop and maintain *lamtoro* (*Leucaena leucocephala*) "energy forests" to produce biomass as a coal co-mixing material for the co-firing control plant. The problems raised in this research are 1) what is the carbon value generated from the co-firing process through the energy mix between coal and biomass produced from *lamtoro* stems (*L. leucocephala*) at the power plant and 2) what is the total economic value added generated from the entire business process of producing biomass of *lamtoro* (*L.*

leucocephala) for the co-firing process with coal at the power plant in Timor Island?

The physical characteristics of the heating value of biomass are the most critical parameters for ensuring its suitability as an energy source to replace coal in the co-firing combustion process of power plants (Erol et al., 2010; Bale et al., 2016; Gravalos et al., 2016; Benu et al., 2021). One of the most crucial characteristics of fuel is its calorific value, which shows how much heat is released into the combustion chamber as a result of chemical reactions during combustion and how much energy is present in the fuel (Martins et al., 2015; Wan Ghazali et al., 2015). Studies on powdered pine tree biomass revealed lower ignition temperatures and higher combustion rates compared to anthracite coal (Liu et al., 2015).

At the same time, the total economic value added generated from the entire business process of producing biomass might be analyzed using economic value added (EVA). EVA studies focus on shareholder value, cost of capital, stock returns, and residual income models.

Methods

Location and research schedule This research was conducted at the location of the biomass production unit that has been built through cooperation between the State Electricity Company (PLN), the private sector (PT. Timor Bio Energi), the government, the university (Nusa Cendana University), and the community since 2023 in Timor Island, Kupang Regency. The data collection and analysis were conducted from July to December 2024.

Sampling and data collection A purposive sampling approach was used to gather physical and financial data. All respondents are selected deliberately from those involved in the investment, production, and marketing processes. Data points included: 1) the number of people supplying raw materials, 2) the volume of raw material sales, 3) transportation costs from the *lamtoro* forest to the biomass production site, 4) production machine operating costs, 5) the number of workers in the production unit, 6) labor costs in the production unit, 7) the selling price of raw materials, 8) transportation costs from the biomass production unit to the power plant site, 9) the volume of biomass sales, 10) the selling price of biomass to the power plant, 11) taxes, and 12) levies.

Respondents include 35 farmers who participated in the program, two landowners who participated in the program, 15 production workers, one investor, one company manager, and two traders. The purposive sampling technique was used because this study was conducted to evaluate the national project research of renewable energy funded by the LPDP Research Fund of Indonesia. At the same time, biomass samples for carbon analysis were collected from Lamtoro forests and production sites.

The selection of the blending ratio (95% coal:5% *lamtoro* biomass) was based on both policy and technical considerations. From a policy perspective, the government, through the PLN, has designated co-firing as part of the energy transition roadmap toward net zero emissions 2060. Furthermore, Bolok Power Plant established the 5% biomass blend as a realistic starting point, since technically, a 5%

biomass mixture does not require major modifications to the boiler system. At the same time, this ratio ensures that the biomass supply chain can be adequately secured for long-term and sustainable use before increasing the blending percentage to higher levels.

Coal samples were obtained from the Bolok Power Plant. Biomass samples from the production facility were collected by taking 5 kg from each of five production batches. For forest sampling, five representative plots were selected to represent the forest population. Within each plot, five *L. leucocephala* (*lamtoro*) trees were chosen based on the following criteria: healthy condition, free from pest infestation, and uniform stem diameter ranging from 5–10 cm. Each selected tree was felled, and stem sections were cut at three positions: the base, middle, and top. Each stem section was taken with a thickness of 10 cm.

The biomass samples from both the production facility and the forest were then combined, chopped into pieces of 0.5–1 cm, air-dried indoors without direct sunlight for seven days to reduce moisture content, ground into fine powder, and sieved to 60 mesh. The sieved powder was stored in airtight containers to prevent moisture absorption. Subsequently, analyses were performed on pure coal samples and coal-biomass blends (95% coal and 5% *lamtoro* powder). The analyses included proximate analysis (moisture content, volatile matter, ash content, and fixed carbon), ultimate analysis (carbon, hydrogen, nitrogen, oxygen, and sulfur), and determination of calorific value. Each analysis was conducted in triplicate (three repetitions).

Proximate analysis Moisture content was determined according to ASTM D3173. Approximately 5 g of sample was placed in a pre-dried porcelain crucible and dried in an oven at 105 ± 2 °C for 60 min. The crucible was then cooled in a desiccator to room temperature and weighed until a constant mass was obtained. Moisture content was calculated from the mass difference before and after drying. Volatile matter was determined following ASTM D3175. About 5 g of sample in a covered porcelain crucible was heated in a furnace at 900 ± 10 °C for 7 min. After heating, the crucible was cooled in a desiccator to room temperature and weighed to constant mass. The volatile matter content was calculated based on the mass loss after subtracting the moisture content.

Ash content was determined according to ASTM D3174. Approximately 5 g of sample was placed in a porcelain crucible and heated in a furnace with a programmed temperature increase: first to 250 °C and maintained for 60 min, followed by heating to 550 °C and maintained for 120 min. The residue was cooled in a desiccator and weighed until a constant mass was obtained. Ash content was calculated from the remaining residue after combustion. Fixed carbon was calculated by difference using Equation [1].

$$\text{Fixed carbon (\%)} = 100 - (\text{Moisture} + \text{Volatile matter} + \text{Ash}) \quad [1]$$

Ultimate analysis Ultimate analysis was conducted following ASTM D5373-16 using a LECO CHNS-628 elemental analyzer based on the Dumas combustion method. Powdered samples (60 mesh) were dried and weighed (approximately 2 mg for organic samples or 15 mg for mixed

samples) and sealed in tin capsules. The samples were combusted in an oxygen atmosphere at 950 °C for CHN and 1350 °C for sulfur determination. During combustion, carbon, hydrogen, nitrogen, and sulfur were converted to CO₂, H₂O, N₂, and SO₂, respectively. These gases were detected using infrared detectors (for C, H, and S) and thermal conductivity detection (for N). Instrument calibration was performed using blank tin capsules and certified reference materials. Oxygen (O) was determined indirectly by calculation as shown in Equation [2].

$$\text{Oxygen (\%)} = 100 - (\text{C} + \text{H} + \text{N} + \text{S}) \quad [2]$$

Determination of calorific value The calorific value of biomass samples was determined using a bomb calorimeter following ASTM D5865. Prior to analysis, samples were ground, sieved to 60 mesh to ensure homogeneity, and oven-dried at 105 °C for 24 h. Approximately 0.5–1.0 g of sample was placed in the combustion crucible and combusted in a high-pressure oxygen atmosphere (25–30 atm). The temperature rise during combustion was recorded and used to calculate the higher heating value (HHV), based on the calorimeter constant obtained through calibration with benzoic acid. Corrections for ignition wire and other heat contributions were applied according to the standard method. All measurements were performed in triplicate, and the results were reported as mean values with standard deviation (kcal kg⁻¹).

Economic value added EVA was calculated based on the method by Tungal (2001), following the steps outlined in Table 1. If "lamtoro" is considered a commodity, the rise in its worth during processing, shipping, or storage throughout a production process may also be regarded as economic value added based on the "Hayami Criteria". The difference between the product's value and the cost of raw materials and

other inputs, excluding labor, is known as value-added in processing (Hayami et al., 1987; Hidayat et al., 2012). The difference between the product's worth and the price of the raw ingredients alone is known as the margin. Labor, other inputs, and services to the processing sector are all included in this margin as production factors. The term "Hayami Criteria" mostly refers to the Hayami approach for value-added analysis in supply chains and the agro-industry, which comprises particular standards for categorizing the degree of added value.

The Hayami criteria consist of specific ratio values employed in the Hayami method of value-added analysis to classify the productivity or profitability levels within agro-industry processing enterprises. These criteria are based on the value-added ratio, which is derived from factors such as output, input, prices, and labor expenses. As outlined by Hayami (1987), the categories are classified as follows: i) low value-added, indicating a value-added ratio of less than 15%; ii) moderate value-added, with a value-added ratio between 15% and 40%; and iii) high value-added, defined as a value-added ratio exceeding 40%. The calculation process generally involves assessing the value of the processed product against the costs of raw materials and other inputs, including labor and operational expenses, to establish the net added value and the corresponding ratio. This approach helps businesses and researchers assess the feasibility and profitability of transforming raw materials into more advanced products. The Hayami criterion technique (Hayami et al., 1987) produces Equation [3] for assessing the added value of biomass-producing firm (kg).

$$NT = NP - (NBB + NBP) \quad [2]$$

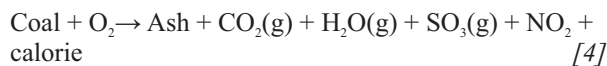
note: *NT* = value added (IDR kg⁻¹), *NP* = value of processed products (IDR kg⁻¹), *NBB* = value of raw materials (IDR kg⁻¹), and *NBP* = value of supporting materials (IDR kg⁻¹).

Table 1 Economic value-added analysis

Analysis	Formula
Calculating NOPAT	NOPAT = Operating Profit (Loss) – Taxes <i>Description: Operating profit is the company's profit from current operations, which is profit before interest. Taxes used in EVA calculations are the sacrifices incurred by the company in the creation of value.</i>
Invested capital	Invested capital = Total debt & equity - Current debt (Short-term)
Calculating WACC (weighted average cost of capital)	WACC = (D × rd × (1 - Tax)) + (E × re) <i>Description: Total debt and equity shows the portion of each dollar of own equity that is pledged as collateral for debt. Interest-free short-term loans are loans used by companies to repay or finance short-term operational needs without incurring interest expenses.</i>
Calculating capital charges	Capital charges = WACC × Invested capital Capital level (D) = (Total debt)/(Total debt & equity) × 100% Cost of debt (rd) = (Interest expense)/(Total debt) × 100% Level of capitaland equity (E) = (Total equities)/(Total debt & equity) × 100% Cost of equity (re) = (Net profit after tax)/Total equity) × 100% Tax rate = (Tax expense)/(Net income before tax) × 100%
Calculating economic value added (EVA)	EVA = NOPAT - Capital charges or EVA = NOPAT - (WACC × Invested capital) - EVA > 0 (positive): If EVA is greater than zero, then there has been an addition of economic value to the company, and the company can create company value. - EVA = 0 (break -even): If EVA is zero, then economically the company is in a break -even state because all existing profits are used to pay obligations to providers of funds (both creditors and shareholders). - EVA < 0 (negative): If EVA is less than zero, then the company has destroyed economic value. In other words, EVA represents the economic profit created by a company. It measures the value a company generates above its cost of capital. The first formula highlights that EVA is the net operating profit after tax minus the total cost of the capital employed. The second formula breaks down the capital charges by multiplying the weighted average cost of capital (WACC) by the total invested capital. Essentially, EVA shows how effectively a company is using its capital to generate profit for its investors.

Results

Physicochemical Physicochemical analyses (proximate, ultimate, and calorific value) were conducted to evaluate the potential use of coal–lamtoro biomass blends (95:5) as an alternative fuel via co-firing. The tests used to assess coal quality include proximate, ultimate, and calorific value analyses (Table 2). In general, the reactions that occur in the coal pyrolysis process are shown in Equation [4].



Economic value-added Analysis EVA is an indicator of the success of company management in increasing the added value of the company, in this case, a company engaged in the business of processing raw wood materials into a coal substitute, biomass. The assumption used is that if the company succeeds in showing effective management performance, it will then be reflected in an increase in the share price of the company. An increase in EVA indicators can occur when the company shows (Young & O'Byrne, 2001): a) increased returns on existing capital. If the value of Net Operating After Tax (NOPAT) has increased while the value of Weighted Average Cost of Capital (WACC) and capital remains invested, then EVA has increased; b) good growth will be created when NOPAT grows beyond WACC; c) if capital reduction provides more compensation by increasing the difference between NOPAT and WACC, then EVA will increase; d) in the long-term period, NOPAT is expected to be higher than WACC; and e) reduction in the cost of capital.

The EVA analysis was carried out by analyzing the cost components stated in the financial report. The cost standard used is based on the company's financial statements. The results of the calculation of the EVA analysis are presented in Table 3. EVA serves as a key indicator of management's ability to enhance company value. Strong EVA performance in a firm that processes raw wood into biomass coal substitutes reflects effective management and is typically followed by a rising share price. An EVA increase occurs when a company demonstrates the following (Young & O'Byrne, 2001): i) it generates increased returns on existing capital. This scenario happens when NOPAT rises without an increase in WACC or invested capital; ii) it achieves good growth, characterized by NOPAT growth that outpaces

WACC; iii) it efficiently reduces capital, which amplifies the difference between NOPAT and WACC; iv) it maintains long-term performance where NOPAT is expected to exceed WACC; and v) it successfully lowers its overall cost of capital (WACC). This study performed an EVA analysis based on the cost components detailed in the company's standard financial reports. The findings of this calculation are shown in Table 3.

Discussion

Proximate analysis Proximate analysis quantifies moisture, volatile matter, ash, and fixed carbon content, following the gravimetric method outlined in ASTM D7582-15 (ASTM Committee D-5 on Coal and Coke, 2010). Based on the proximate analysis data presented in Table 2, the addition of 5% *lamtoro* biomass affected the moisture content, volatile matter, ash content, and fixed carbon.

Moisture content The result of the moisture content analysis of coal was 16.21%, and the simulation of the coal mixture with biomass (95%:5%) was 20.07%. It can be seen that the biomass mixture increases the moisture content. This indicates that *lamtoro* biomass possesses a higher hygroscopic property compared to coal. The increase in moisture content is attributed to the cellular structure of *lamtoro* biomass, which tends to retain more water than coal. Moisture content will reduce the maximum combustion temperature and increase the time required for complete combustion in the furnace (Suryaningsih et al., 2017). This means that moisture content also has a direct effect on calorific value. The lower the moisture content, the higher the calorific value of coal. It is necessary to optimize the biomass production process through the drying process so that the biomass used as a renewable coal-biomass blend can increase calorific value.

Volatile matter content Volatile matter content obtained in coal is 38.01% and in the mixture (coal 95%:biomass 5%) is 35.42%. Suppose the value of volatile matter content is related to the calorific value obtained. In that case, a direct proportional relationship is obtained, namely, the higher the volatile matter content, the higher the calorific value of coal, and vice versa; the lower the volatile matter content, the lower the calorific value.

The pattern of the relationship between calorific value

Table 2 Results of proximate, ultimate, and calorific value analysis

Analysis		Unit	Base	Coal (A)	Coal 95%; Biomass 5% (B)
Proximate	Water content	%vol	adb	16.210	20.070
	Volatile matter content	%vol	adb	38.010	35.420
	Ash content	%vol	adb	13.420	14.210
	Tethered carbon	%vol	adb	32.360	30.300
Ultimate	Carbon	%vol	daf	68.820	68.660
	Hydrogen	%vol	daf	5.160	5.290
	Nitrogen	%vol	daf	1.000	1.080
	Oxygen	%vol	daf	24.550	24.420
	Sulfur	%vol	daf	0.320	0.360
Caloric value		kcal kg ⁻¹	adb	4.593	4.342

Notes: adb = Air-dried base; daf = dried ash free

Table 3 Production cost components

Cost component	Amount (IDR)
Total operating profit (loss)	1,091,244,412
Total tax (10%)	109,124,441
Total expenses/costs	39,019,000
Total interest expense	34,000,000
Total liabilities	751,244,412
Total assets	1,091,244,412
Total equity	557,929,971

Source: Results of data analysis year 2024

*USD1 = IDR16,500

1. NOPAT (Net operating after tax) = Operating profit (loss) – Taxes = IDR1,091,244,412 – IDR109,124,441 = IDR982,119,971
2. Invested capital = Total debt and equity - Short-term debt = IDR897,929,971 – IDR340,000,000 = IDR557,929,971
3. WACC (Weighted average cost of capital) = $(E \times Re) + ((D/V \times Rd) \times (1 - T))$
 E: Market value of equity; V: Total value of the company; Re: Cost of equity; D: Market value of debt; Rd: Cost of debt; T: Corporate tax rate
 $D \text{ (Total debt/Total debt \& equity} \times 100\%) = 340,000,000/897,929,971 \times 100\% = 0.3786$
 $Rd \text{ (Interest expense/Total debt} \times 100\%) = 34,000,000/897,929,971 \times 100\% = 0.0379$
 $E \text{ (Total equity/Total debt \& equity} \times 100\%) = 557,929,971/897,929,971 \times 100\% = 0.6214$
 $Re \text{ (Net profit after tax/Total equity} \times 100\%) = 591,929,971/557,929,971 \times 100\% = 1.0609$
 $Tc \text{ (Tax expense/Net profit before tax} \times 100\%) = 109,124,441/625,929,971 \times 100\% = 0.08$
 $WACC = (0.3786 \times 0.0379) (1 - 0.08) + (0.6214 \times 1.0609) = 0.67$
4. Capital charges = WACC $\times$ Invested capital = $0.67 \times 557,929,971 = 375,137,127$
5. EVA = NOPAT - Capital charges = IDR982,119,971 - IDR375,137,127 = IDR606,982,844

and volatile matter content in this study has different results from the other research (Aulia et al., 2021). Logically, volatile matter content should have a negative relationship with calorific value. It should be understood that if volatile matter contains combustible elements, namely CO, hydrogen, and methane, then an increase in volatile matter will increase combustion capacity. Therefore, the higher the volatile matter content, the higher the possibility of coal burning itself. According to Aulia et al. (2021), a high percentage of volatile matter does not necessarily reduce combustion capacity. If the composition contains combustible gas, it will increase the combustion capacity by increasing the flame length proportionally and help coal ignition more easily. However, if the composition comprises non-combustible gases, it will decrease the combustion capacity.

Ash content The ash content analysis for coal showed a result of 13.42%, and in the mixture (95%:5%), it was 14.21%. This result indicates that the biomass mix influences the increase in ash content in coal. The value of ash content when related to calorific value will usually be inversely proportional. Lower ash content contributes to a higher calorific value, while higher ash content reduces it. Ash content also shows the content of unburnable minerals such as SiO₂, Al₂O₃, Fe₂O₃, etc. Ash content is a significant factor because higher ash content in coal results in increased combustion residue, which negatively impacts performance. Thus, it can be concluded that coal of good quality can be bound by low ash content. However, the difference in ash content between pure coal and the blend (95%:5%) was only below 1%.

The production of ash in biomass-fired power plants presents some issues, including how to handle and use it. Ash-storing facilities will face difficulties as a result of the ongoing increase in ash amount, which will also raise management, transfer, and disposal expenses. The nutrients and structure of the soil may also be impacted by direct discharge to land locations. According to Munawar et al. (2021): "Production of the ash in biomass-fired power plants

raises multiple problems, exclusive handling of ash and its utilization. The continuous rise in ash quantity will challenge ash-storing facilities while increasing management, transferring, and disposal costs. Direct disposal to the land sites may also affect the soil nutrients and its structure".

Fixed carbon The result of the analysis of fixed carbon content obtained in coal is 32.36%, and in the simulation of the mixture (95%:5%), it is 30.30%. It can be seen that the biomass mix affects the reduction of the level of fixed carbon in coal. If the value of fixed carbon is linked to the calorific value, then both will have a directly proportional relationship. Fixed carbon content directly determines coal's calorific value, as it represents the primary combustible material that generates heat during combustion. This component constitutes the carbon remaining after moisture and volatile matter are driven off. Consequently, removing these elements increases the fixed carbon percentage, which in turn raises the calorific value.

Furthermore, the fixed carbon value serves as a key reference for estimating the coal combustion ratio. However, it should be noted that different pyrolysis-level treatments will certainly produce different levels of tethered carbon. The analysis conducted by Setyawan et al. (2024) showed that pyrolysis at a temperature of 600 °C can ideally produce biochar with the least moisture, minimal fiery remains, low unstable matter content, and, most importantly, high settled carbon and calorific values.

Ultimate analysis The analysis refers to the ASTM D5373-16 standard (ASTM Committee D-5 on Coal and Coke, 2010). Based on the ultimate analysis presented in Table 2, the results provide an overview of the chemical composition, namely carbon, hydrogen, nitrogen, sulfur, and oxygen. The analysis indicates that the carbon content in coal is about 68.82%, and the simulated coal-biomass blend (95%:5%) is about 68.66%. It can be seen that biomass contributes to the reduction of carbon content in coal, although not very significantly. The relationship between carbon content and

calorific value is directly proportional or positive.

Furthermore, the analysis indicates that the hydrogen content in coal is about 5.16%, and the simulated coal-biomass blend (95%:5%) is about 5.29%. These results show that the biomass contributes to the increase in hydrogen content. Furthermore, when related to calorific value, high hydrogen content in coal affects the calorific value of coal because the moisture content increases, the quality of coal decreases, and the calorific value decreases. The moisture content in coal is influenced by the tendency of hydrogen to be bound by oxygen into H_2O . For coal that contains moisture content during combustion, the water will evaporate, reducing the calorific value of the coal.

The analysis indicates a slight increase in hydrogen content from 5.16% in pure coal to 5.29% in the 95:5 coal-biomass blend, suggesting a minor contribution from the biomass. However, this elevated hydrogen content can adversely affect the coal's calorific value. Hydrogen tends to bond with oxygen, forming moisture (H_2O). During combustion, the evaporation of this inherent water consumes energy, thereby reducing the practical calorific value and overall coal quality. Similarly, the analysis of nitrogen, oxygen, and sulfur content in pure coal used for combustion revealed that the respective contents are 1%, 24.55%, and 0.32%. The nitrogen, oxygen, and sulfur content for the energy mix is 1.08%, 24.42%, and 0.36%, respectively. It can be seen that the biomass mix contributes to the increase in nitrogen content in coal. High nitrogen content in coal will increase the flame temperature of coal, thus increasing the calorific value of coal on combustion. However, the nitrogen will turn into nitrogen oxides, which will pollute the air. It can also be observed that the biomass mix does not contribute significantly to the change in oxygen content in coal. The oxygen in coal will bind with hydrogen to form water molecules, which causes a decrease in heating value.

The energy mix between coal and biomass derived from *lamtoro* stems (*L. leucocephala*) contributes to the increase in sulfur content in coal. Sulfur in coal consists of organic sulfur and inorganic sulfur. Organic sulfur is usually present in coal along with coal formation and comes from coal-forming plants. Analysis of the nitrogen, oxygen, and sulfur content revealed varying results. The biomass mix increased the nitrogen content in the coal to 1.08%, although not significantly. This higher nitrogen content can raise the flame temperature, thereby increasing the coal's calorific value during combustion. However, the nitrogen can transform into nitrogen oxides, which pollute the air. In contrast, the biomass mix did not significantly alter the oxygen content, which remained at about 24.55% for pure coal and 24.42% for the mix. Oxygen in coal can bind with hydrogen to form water molecules, an action that lowers the heating value. Regarding sulfur, the energy mix with *lamtoro* stems (*L. leucocephala*) caused a slight increase to 0.36%, but this was also not significant. It is important to note that sulfur in coal consists of organic sulfur, which forms during the coalification process and originates from the coal-forming plants themselves.

Calorific value analysis Based on the analysis results in Table 2, the HHV of coal is $4,593 \text{ kcal kg}^{-1}$, and the simulated mixture (95%:5%) is $4,342 \text{ kcal kg}^{-1}$. The calorific content of

the simulated mixture is relatively high when compared to the results of other studies on several coal substitute materials, such as rice husk, teak sawdust, and ironwood sawdust, and obtained the HHV of $3,380 \text{ kcal kg}^{-1}$ (adb), $4,460 \text{ kcal kg}^{-1}$ (adb), and $4,465 \text{ kcal kg}^{-1}$ (adb), respectively (Istomo & Tristiasti, 2017; Gumirat & Satriawan, 2021; Sasongko et al., 2023; Supriyati et al., 2023; Wahyudi & Tanggasari, 2023).

Furthermore, this calorific value must be converted into Btu lb^{-1} units according to ASTM standards so that $8,267.4 \text{ Btu lb}^{-1}$ and $7,815.6 \text{ Btu lb}^{-1}$ are obtained, respectively. This calorific value shows the heat generated, absorbed, and released. Each unit of fuel contains the number of calories utilized for combustion. The results show that both pure coal and the results of the mix simulation are included in the low-rank coal type A lignite group because it has a calorific value between $6,300 \text{ Btu lb}^{-1}$ and $8,300 \text{ Btu lb}^{-1}$ (Advancing Standards Transforming Markets, 2019). This type of low-rank coal has a low market selling price, so if it is connected to the combustion operational process at the power plant center, a cheaper cost component will also be produced.

The analysis determined that pure coal has the HHV at $4,593 \text{ kcal kg}^{-1}$ ($8,267.4 \text{ Btu lb}^{-1}$). Meanwhile, the 95% coal and 5% biomass simulation also yielded a high calorific value of $4,342 \text{ kcal kg}^{-1}$ ($7,815.6 \text{ Btu lb}^{-1}$), which surpasses alternatives like rice husk. These calorific values place both materials in the low-rank coal category, specifically type A lignite. A key advantage of this coal rank is its lower market price. Therefore, adopting the coal-biomass blend for power plant operations has the potential to reduce fuel costs without compromising the heat quality required for combustion. Overall, the addition of 5% *lamtoro* biomass to coal increased the moisture and ash contents, which directly contributed to the reduction of fixed carbon and total carbon. The decrease in fixed carbon and carbon content resulted in a lower calorific value. The reduction in calorific value was also influenced by the increase in hydrogen content, as higher hydrogen levels in the sample tend to bond with oxygen to form water molecules. Despite the decline in calorific value, this blending ratio remains a potential option for reducing dependence on pure coal as a fuel source.

Economic value added The analysis shows that the value of EVA achieved by the Biomass Production Company (PT. Timor Bio Energy) in the Kupang Regency is greater than 0 ($EVA > 0$), namely IDR606,982,844, indicating excellent performance and exceeding the industry average. Increased production efficiency, product innovation, and expansion of export markets are the main factors driving this growth. Although the value of EVA shows that the performance of the biomass company has a good economic value-added performance, the calculation of this EVA indicator is usually directly related to the Debt-Equity-Ratio (DER) performance indicator of the company and is not significantly associated with other performance indicators such as Return on Asset (ROA) and Total Asset Turnover Ratio (TATO) (Agustina et al., 2020).

Companies need strong support through conservation programs that engage both the community and the private sector in preserving forests, improving basic infrastructure such as road access to reduce transportation costs, and implementing necessary policies like tax holidays. In

addition, as a business entity, the company needs to continue to be aware of challenges such as fluctuations in coal prices that have an impact on raw material prices and operational costs as a consequence of increasingly open global competition. The company also needs to continue to innovate in collaboration with universities and various other research institutions and seek market penetration to maintain the momentum of EVA and make a good contribution to shareholders, society, and the environment (Bajus, 2023).

Economic value added/unit of measurement (kg) The analysis derives the added value per kilogram by accounting for all supporting material costs during the business process of the company in 2024, including: production, transportation, electricity, labor, and maintenance. It defines the raw material value as the purchase price per kg of "*lamtoro*" biomass and the processed product value as its subsequent selling price per kg. The added value of *lamtoro* biomass can be calculated based on the Equation [5].

$$NT = NP - (NBB + NBP) \quad [5]$$

note: NP = IDR740 kg⁻¹ (value added); NBB = IDR300 kg⁻¹ (value of processed products); NBP = IDR 306.77 kg⁻¹ (value of raw materials); NT = IDR740 kg⁻¹ - (IDR300 kg⁻¹ + IDR306.77 kg⁻¹); and NT = IDR133.23 kg⁻¹ (value added).

EVA analysis of the biomass production company using the Hayami method (Hayami et al., 1987) shows that each kilogram of *lamtoro* biomass produced contributes IDR 133.23 (18%) to the final value of processed products. The results of this study indicate a moderate positive business prospect for developing the biomass industry in Timor. The government needs to provide further support in terms of policies that support business development in this sector. The results of the economic value-added analysis of IDR133.23 kg⁻¹ of biomass are lower than the findings of other research (Pahlevi et al., 2024) on the added value of briquette products made from the biomass waste of wetland resources, which showed the added value of IDR4170 kg⁻¹ or 33% of the value of processed products. The higher added value of briquettes made from biomass waste is due to the higher price of briquettes (IDR9000 kg⁻¹) compared to the cost of biomass (IDR900 kg⁻¹) in the market. The higher briquette price is determined by the fact that briquettes are produced using better processing technology and can produce higher heat during combustion.

At the same time, the ultimate analysis shows high hydrogen content because the coal-biomass blend in the combustion process affects the calorific value of coal. The moisture content increases (20.07%), the coal quality decreases, and the calorific value decreases. Indeed, the moisture content of the briquettes produced from heterogeneous sawdust admixture only ranges from 8% to 15% (Akpenpuun et al., 2020). The biomass production business for coal substitution in the co-firing power plant unit on the island of Timor (Bolok Power Plant) is due to the type of installed power plant engine, which only makes it possible for the co-firing process with biomass substitution materials.

An EVA analysis using the Hayami method reveals that each kilogram of *lamtoro* biomass contributes IDR 133.23 (18%) to the final product's value (Hayami et al., 1987), indicating positive business prospects for biomass

development in Timor. However, this added value is lower than the IDR4,170 kg⁻¹ (33%) reported for briquettes made from wetland biomass waste (Pahlevi et al., 2024). The higher value of briquettes stems from their superior market price, which is a result of advanced processing technology that enhances their quality and calorific value. The feasibility of using "*lamtoro*" biomass is influenced by its properties; the blend shows a moisture content of 20.07%, which can lower combustion quality and calorific value. In contrast, briquettes from heterogeneous sawdust maintain a lower moisture content of only 8.15% (Akpenpuun et al., 2020). Ultimately, the potential for this biomass production business at the Bolok Power Plant on Timor Island is determined by the specific type of installed engine, which is designed to allow co-firing with biomass substitution materials.

Limitations This study did not include analyses of biomass estimation, carbon reserves, or greenhouse gas emission factors, which are necessary to evaluate the potential of biomass for coal substitution in power plants and its contribution to reducing greenhouse gas emissions. Furthermore, optimization of different blending ratios has not yet been carried out to determine maximum thermal efficiency, the impact on boiler performance, and the standardization of biomass quality from producers. These limitations arise from the policy directive for the Bolok Power Plant, which specifies a 95% coal, 5% biomass blending ratio.

Conclusion

The HHV of the coal-biomass blend closely matches that of coal. Although replacing coal with biomass raises moisture and ash content, this blend ratio remains a practical option for reducing reliance on pure coal as a fuel source. Economic analysis shows that *lamtoro* (*L. leucocephala* (Lam.) de Wit) biomass is a profitable coal substitute for Timor Island power plants. Every kilogram of biomass appreciably boosts total product value, reflecting efficient output and robust market demand. Based on the results of technical and economic analysis from this study, the government can utilize the potential of the existing *lamtoro* forests as a source of biomass production to be used as a substitute for coal. This policy can clearly make a significant contribution to efforts to reduce emission levels. At the same time, the government also needs to adopt policies for the conservation of *lamtoro* forests, including environmentally friendly methods and systems for harvesting the trees.

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References

- Advancing Standards Transforming Markets. (2019). *Standard test method for gross calorific value of coal and coke* (ASTM D5865/D5865M-19). https://doi.org/10.1520/D5865_D5865M-19
- Agustina, N., Sadalia, I., & Silalahi, A. S. (2020).

- Relationship of economic value added (EVA) and financial performance of PT. LC Industry Indonesia period 2013–2017. *International Journal of Research and Review*, 7(1), 480–485.
- Akpenpuun, T. D., Salau, R. A., Adebayo, A. O., Adebayo, O. M., Salawu, J., & Durotoye, M. (2020). Physical and combustible properties of briquettes produced from a combination of groundnut shell, rice husk, sawdust and wastepaper using starch as a binder. *Journal of Applied Sciences and Environmental Management*, 24(1), 171–177. <https://doi.org/10.4314/jasem.v24i1.25>
- ASTM Committee D-5 on Coal and Coke. (2010). Standard test methods for proximate analysis of coal and coke by macro thermogravimetric analysis. ASTM International. <https://doi.org/10.1520/D7582>
- Aulia, A., Farid, F., & Zahar, W. (2021). Korelasi parameter analisis proksimat dan analisis ultimat terhadap nilai kalori batubara. *Jurnal Pertambangan dan Lingkungan*, 2(1), 21–30. <https://doi.org/10.31764/jpl.v2i1.4715>
- Bajus, R. (2023). The impact of the application of the economic value-added method in the food company. *Potravinarstvo Slovak Journal of Food Sciences*, 17, 972–985. <https://doi.org/10.5219/1910>
- Bale, J., Valot, E., Monin, M., Polit, O., Bathias, C., & Soemardi, T. (2016). Experimental analysis of thermal and damage evolutions of DCFC under static and fatigue loading. *Revue des Composites et des Matériaux Avances*, 26(2), 165–184. <https://doi.org/10.3166/RCMA.26.165-184>
- Benu, F. L., Amheka, J., King, P., Liufeto, F., & Wulakada, H. (2021). Assimilative capacity of mangrove conversion to salt pond industry: A case study of Bipolo Village, District of Kupang, Indonesia. *Review of International Geographical Education Online*, 11(12), 886–895. <https://doi.org/10.48047/rigeo.11.12.83>
- Erol, M., Haykiri-Acma, H., & Küçükbayrak, S. (2010). Calorific value estimation of biomass from their proximate analyses data. *Renewable Energy*, 35(1), 170–173. <https://doi.org/10.1016/j.renene.2009.05.008>
- Gravalos, I., Xyradakis, P., Kateris, D., Gialamas, T., Bartzialis, D., & Giannoulis, K. (2016). An experimental determination of gross calorific value of different agroforestry species and bio-based industry residues. *Natural Resources*, 7(1), 57–68. <https://doi.org/10.4236/nr.2016.71006>
- Gumirat, M. I. I., & Satriawan, D. (2021). Analisis kalor biobriket sekam padi pada variasi perekat dan variasi tekanan. In *Seminar Nasional Terapan Riset Inovatif (SENTRINOV) ke-7* (pp. 598–604). Politeknik Negeri Jember.
- Hayami, Y., Kawagoe, T., Morooka, Y., & Siregar, M. (1987). *Agricultural marketing and processing in Upland Java. A perspective from a sunda village*. Bogor: CGPRT Centre.
- Hidayat, S., Marimin, Suryani, A., Sukardi, & Yani, M. (2012). Modifikasi metode Hayami untuk perhitungan nilai tambah pada rantai pasok agroindustri kelapa sawit. *Jurnal Teknologi Industri Pertanian*, 22(1), 22–32.
- Istomo, F. P., & Tristiasti, A. (2017). Penetapan nilai kalori dalam batubara dengan kalorimeter Parr 6200. *Jurnal Sains Natural*, 7(2), 83–90. <https://doi.org/10.31938/jsn.v7i2.257>
- Liu, G. Q., Liu, Q. C., Wang, X. Q., Meng, F., Ren, S., & Ji, Z. P. (2015). Combustion characteristics and kinetics of anthracite blending with pine sawdust. *Journal of Iron and Steel Research International*, 22(9), 812–817. [https://doi.org/10.1016/S1006-706X\(15\)30075-3](https://doi.org/10.1016/S1006-706X(15)30075-3)
- Martins, G. I., Secco, D., Rosa, H. A., Bariccatti, R. A., Dolci, B. D., Melegari de Souza, S. N., Santos, R. F., Benetoli da Silva, T. R., & Gurgacz, F. (2015). Physical and chemical properties of fish oil biodiesel produced in Brazil. *Renewable and Sustainable Energy Reviews*, 42, 154–157. <https://doi.org/10.1016/j.rser.2014.10.024>
- Munawar, M. A., Khoja, A. H., Naqvi, S. R., Mehran, M. T., Hassan, M., Liaquat, R., & Dawood, U. F. (2021). Challenges and opportunities in biomass ash management and its utilization in novel applications. *Renewable and Sustainable Energy Reviews*, 150, Article 111451. <https://doi.org/10.1016/j.rser.2021.111451>
- Pahlevi, Z. S., Pratama, R., Karivan, Y. K., & Paramita, F. B. A. C. (2024). Pemanfaatan bonggol jagung menjadi briket arang di Desa Kesimantengah Kecamatan Pacet Kabupaten Mojokerto. *Prosiding Patriot Mengabdi*, 3(1), 1113–1120.
- Sasongko, N. A., Putra, N. G., & Wardani, M. L. D. (2023). Review of types of biomass as a fuel- combustion feedstock and their characteristics. *Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering*, 6(2), 170–184. <https://doi.org/10.21776/ub.afssaae.2023.006.02.8>
- Setyawan, H. Y., Sunyoto, N. M. S., Sugiarto, Y., Dewanti, B. S. D., Widayanti, V. T., Hakim, L., Kurniawan, S., Nugroho, G. A., Ulandari, D., Choirun, A., Hanindipto, F. A., Sundari, S. A., Pamungkas, I. A., Pratama, A. P. A., & Wan, Z. (2024). Characterisation of biochar from various carbon sources. *BIO Web of Conferences*, 90, Article 06003. <https://doi.org/10.1051/bioconf/20249006003>
- Supriyati, W., Silalahi, E. R., Nuwa, & Alpian. (2023). Karakteristik briket arang dengan komposisi serbuk

- kayu sungkai (*Peronema canescens*) dan kayu ulin (*Eusideroxylon zwageri*). *Jurnal Hutan Tropika*, 18(1), 99–108. <https://doi.org/10.36873/jht.v18i1.9398>
- Suryaningsih, S., Nurhilal, O., Yuliah, Y., & Mulyana, C. (2017). Combustion quality analysis of briquettes from variety of agricultural waste as source of alternative fuels. *IOP Conference Series: Earth and Environmental Science*, 65, Article 012012. <https://doi.org/10.1088/1755-1315/65/1/012012>
- Tunggal, A. W. (2001). *Memahami konsep economic value added (EVA) dan value-based management (VBM)*. Harvarindo.
- Wahyudi, W., & Tanggasari, D. (2023). Uji karakteristik briket serbuk gergaji kayu jati dengan pencampuran ampas tebu berdasarkan jumlah variasi perekat (tepung beras ketan). *Sultra Journal of Mechanical Engineering*, 2(1), 17–28. <https://doi.org/10.54297/sjme.v2i1.426>
- Wan Ghazali, W. N. M., Mamat, R., Masjuki, H. H., & Najafi, G. (2015). Effects of biodiesel from different feedstocks on engine performance and emissions: A review. *Renewable and Sustainable Energy Reviews*, 51, 585–602. <https://doi.org/10.1016/j.rser.2015.06.031>
- Young, S. D., & O'Byrne, S. (2001). *EVA and value-based management: A practical guide to implementation*. McGraw-Hill.