Jurnal Ilmiah Multidisiplin Indonesia (JIM-ID)
Vol. 5, No. 03, 2026, pp. 634-647
ISSN 2828-9463

Analysis of the Application of Co-Firing Using Sawdust–Coal on the Performance of PLTU 3 Banten Lontar

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This study analyzes the implementation of co-firing using sawdust in combination with coal at PLTU 3 Banten Lontar. The primary objective of this research is to evaluate the impact of co-firing application on power plant performance, thermal efficiency, exhaust gas emissions, and the cost of electricity production (BPP). The research method employed was an experimental approach, comparing 100% coal combustion with a fuel mixture consisting of 95% coal and 5% sawdust, conducted at PLTU Banten Lontar. The results indicate that the implementation of co-firing reveals a non-linear relationship between the 5% sawdust blending ratio and the composition of electrical energy generated. Furthermore, the application of co-firing reduced the cost of electricity production by IDR 46.45/kWh and successfully decreased CO_2, SO_2, and NO_x emissions. Specifically, CO_2 emissions were reduced by 8.82%, SO_2 emissions decreased by 17.3%, and NO_x emissions declined by 8.5%. The implications of this study suggest that co-firing can serve as a more environmentally friendly and cost-effective alternative for the power generation sector, with the potential for broader implementation in other coal-fired power plants across Indonesia.
Keywords: Co-Firing, Sawdust, Coal, Cost of Electricity Production, Emissions

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1. Introduction

In Indonesia, the demand for electrical energy continues to increase annually. According to the Electricity Supply Business Plan (RUPTL) of PT PLN (Persero) for the period 2025–2034, the average projected growth in electricity demand is 5.3% per year. In 2024, national electricity consumption reached 17.78 TWh, representing an increase of 6.17% compared to 2023. The majority of electricity generation in Indonesia is still derived from fossil energy sources such as coal and petroleum. Based on the 2024 annual report of PT PLN (Persero), coal-fired steam power plants (PLTU) dominate the national generation mix, with an installed capacity of 21,026.90 MW, accounting for 44.90% of the total installed generation capacity. Fossil fuels are non-renewable energy sources and significantly contribute to global warming (Ramanathan et al., 2009). Therefore, environmentally friendly and sustainable alternative energy sources are urgently needed to address these challenges.

The Government of Indonesia plans to gradually phase out fossil fuel-based power plants in order to achieve net zero emissions by 2060 or earlier. Pursuant to Government Regulation No. 79 of 2014 concerning the National Energy Policy, the target for the renewable energy mix is set at 23% by 2025 and 31% by 2050. In response, PLN has initiated a fuel blending strategy by combining fossil fuels with environmentally friendly energy sources such as biomass. According to the *Guidelines for National Greenhouse Gas Inventories Vol. 2* published by the Intergovernmental Panel on Climate Change in 2006, greenhouse gas (GHG) emissions resulting from biomass combustion are not accounted for under the power generation sector in national GHG inventories but are instead allocated to the forestry sector, specifically Land Use, Land-Use Change and Forestry (LULUCF) [1].

By the end of 2024, biomass co-firing had been implemented at 47 coal-fired power plant locations, with biomass utilization reaching 1.6 million tons, contributing to an estimated reduction of approximately 12.77 million tons of CO_2 emissions (Annual Report of PT PLN. The implementation of co-firing in coal-fired power plants offers several advantages, including the reduction of GHG emissions from biomass combustion [2], relatively low investment costs since it utilizes existing facilities without requiring entirely new infrastructure, the potential to minimize industrial waste, and the possibility of improving boiler combustion efficiency when operated optimally [3].

Based on these considerations, this study aims to further examine the implementation of co-firing at PLTU 3 Banten Lontar, located in Lontar and Karanganyar Villages, Kemiri District, Tangerang Regency, Banten Province. This plant was part of the first 10,000 MW accelerated development program and was inaugurated in 2011 by Susilo Bambang Yudhoyono. The coal-fired power plant has an installed capacity of 3 × 315 MW and has been entrusted to PT Indonesia Power for operation and maintenance (O&M). This research will analyze the application of co-firing using biomass in the form of sawdust, replacing the previous 100% coal combustion system at the plant.

2. Literature Review

Text classification is a fundamental task in NLP that aims to automatically categorize textual information into predefined classes using computational models [4]. Among various algorithms, the Random Forest method, introduced by Leo Breiman, has demonstrated strong performance due to its ensemble learning approach, which combines multiple decision trees to improve classification accuracy and reduce overfitting [5]. Several studies highlight that Random Forest is robust in handling high-dimensional text data and noisy datasets, making it suitable for public complaint classification systems. Research by [6] emphasizes that artificial intelligence-based systems enhance public sector efficiency by automating administrative processes, including complaint management. Furthermore, studies comparing machine learning algorithms indicate that Random Forest often outperforms traditional models such as Naïve Bayes and Support Vector Machine in classification tasks involving complex textual patterns [7].

Previous empirical studies have explored various approaches to complaint classification and text mining [8]. For instance, research on citizen complaint systems demonstrates that machine learning-based classification can significantly improve response time and service quality [9]. However, inconsistencies remain regarding model performance depending on preprocessing techniques and dataset characteristics[10]. Some studies argue that deep learning models provide higher accuracy, while others find that ensemble methods like Random Forest offer better interpretability and stability [11]. Additionally, prior research often focuses solely on algorithm performance without integrating the classification model into a real-time web-based system, limiting its practical implementation in government institutions [12].

Based on these gaps, the primary problem addressed in this study is how to develop an integrated web-based system capable of automatically classifying public complaints with high accuracy and efficiency [13]. The research question can be formulated as: *How effective is the Random Forest algorithm in classifying public complaints when integrated into a real-time web-based information system?* In line with this, the study proposes the following hypothesis: H_1: The application of the Random Forest algorithm has a significant effect on improving the accuracy and efficiency of public complaint classification; H_0: The application of the Random Forest algorithm does not significantly improve classification performance.

 ISSN 2828-9463

3. Methods

This study was designed using a quantitative approach that integrates field data collection and laboratory analysis to evaluate the performance and efficiency of a coal–sawdust fuel blend in a pulverized coal power plant model. Specifically, the research methodology consists of several main stages:

1. Collection of operational data. Operational data on equipment and fuel usage were obtained through interviews and document reviews provided by PT Indonesia Power UBP Banten 3 Lontar. These data include plant performance indicators, fuel parameters, and fuel characteristics used in both co-firing and 100% coal combustion processes. Data collection was conducted directly during plant operation under two fuel scenarios 95% coal and 5% sawdust, and 100% coal combustion to ensure accurate operational and fuel-related variables.
2. Measurement and laboratory analysis. Fuel parameters for sawdust and coal were tested in the laboratory to obtain proximate and ultimate analysis data. The results include moisture content, ash content, volatile matter, fixed carbon, and chemical elements such as sulfur, carbon, hydrogen, nitrogen, and oxygen. These data are essential for determining fuel characteristics that influence combustion efficiency and emission potential.
3. Observation of fuel characteristics. In addition to laboratory testing, fuel characteristic data were gathered from industrial sources in Banten related to fuel quality and properties. These characteristics serve as reference inputs for analyzing combustion system performance and efficiency.
4. Power plant operation scenarios. The plant was operated under two primary scenarios: co-firing with 95% coal and 5% sawdust, and 100% coal combustion. Operational measurements including temperature, pressure, flow rate, and energy output were recorded during each scenario.
5. Efficiency and heat rate calculations. Data obtained from direct measurements and laboratory testing were processed using established calculation formulas, including boiler efficiency, condenser heat losses, gross and net efficiency, as well as gross and net heat rates. This analysis was conducted to determine the impact of the fuel blend on overall system performance.

Overall, this methodological framework provides a basis for comparing the effectiveness of 95% coal–5% sawdust co-firing with 100% coal combustion, as well as for assessing emission reduction potential and improvements in thermal efficiency resulting from biomass integration. The approach is supported by empirical laboratory results and direct field observations, thereby ensuring the reliability and validity of the findings for analysis and decision-making in fossil- and biomass-based power generation systems.

4. Result and Discussion

Result

Power Plant Efficiency Analysis

Under 100% coal combustion, the calculation of the cost of electricity production resulted in IDR 773.94 per kWh. Based on the efficiency analysis of PLTU 3 Banten Lontar Unit #1 under two operating scenarios co-firing with 95% coal and 5% sawdust, and 100% coal combustion the results are summarized in Table 1 below.

Table 1. Results of Efficiency Analysis for 95% Coal–5% Sawdust Co-firing and 100% Coal Combustion

Parameter	Unit	Co-firing (95% coal & 5% sawdust)	100% Coal
Gross Heat Rate	kcal/kWh	2920.75	3066.25
Net Heat Rate	kcal/kWh	3111.97	3275.23
Gross Thermal Efficiency	%	29.44	28.05
Net Thermal Efficiency	%	27.64	26.26

ISSN 2828-9463

Parameter	Unit	Co-firing (95% coal & 5% sawdust)	100% Coal
Heat Loss in Condenser	MW	347.67	419.42
Boiler Efficiency	%	49.48	44.59
Gross Energy Conversion Efficiency	%	34.24	32.61
Net Energy Conversion Efficiency	%	32.13	30.53
Gross Plant Efficiency	%	144.51	136.74
Net Plant Efficiency	%	154.00	146.05
Specific Fuel Consumption (SFC)	kg/kWh	0.7377	0.7708
Cost of Electricity Production (BPP)	IDR/kWh	727.49	773.94

Table 1 presents the comparative analysis of heat rate, thermal efficiency, condenser heat losses, boiler efficiency, energy conversion efficiency, specific fuel consumption (SFC), and cost of electricity production under both operating conditions at PLTU 3 Banten Lontar Unit #1.

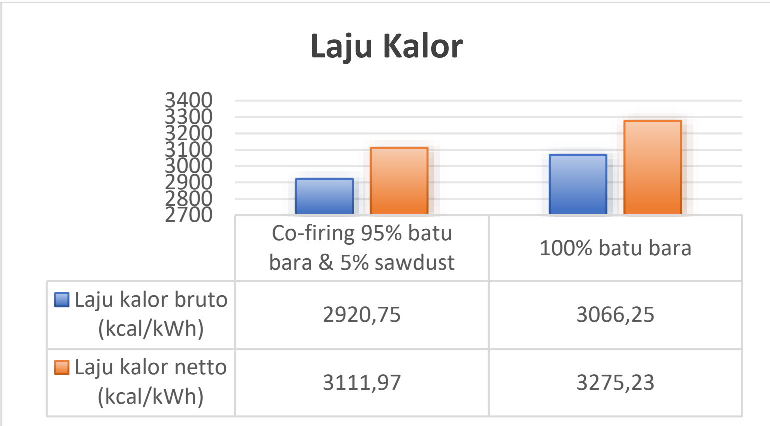


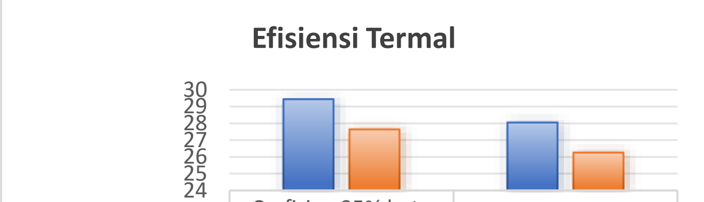
Figure 1. Comparison of Heat Rates under 95% Coal–5% Sawdust Co-firing and 100% Coal Combustion

Figure 1 illustrates the comparison of heat rates between the two operating scenarios. Under co-firing conditions, the gross heat rate ($HR_{(B)}$) was 2920.75 kcal/kWh and the net heat rate ($HR_{(N)}$) was 3111.97 kcal/kWh. In contrast, under 100% coal combustion, the gross heat rate reached 3066.25 kcal/kWh and the net heat rate was 3275.23 kcal/kWh.

The gross heat rate under co-firing was lower by 145.5 kcal/kWh compared to 100% coal combustion. This reduction indicates an improvement in the system's thermal efficiency, as less thermal energy is required per unit of electricity generated. This enhancement can be attributed to the characteristics of sawdust, which contains a higher volatile matter content, thereby improving ignition quality and flame stability within the combustion chamber. Moreover, biomass has lower ash and sulfur content, which can reduce fouling and slagging in the boiler, ultimately enhancing heat transfer rates.

Similarly, the net heat rate decreased significantly under co-firing conditions, being 163.26 kcal/kWh lower than under 100% coal combustion. This decline suggests that efficiency improvements occurred not only in the combustion process but also across the overall power generation system after accounting for internal power consumption. With relatively stable auxiliary power usage, the reduction in net heat rate reflects enhanced boiler and turbine performance resulting from more optimal combustion conditions.

Based on the analysis of gross and net heat rate data, it can be concluded that co-firing with a fuel mixture of 95% coal and 5% sawdust improves power generation efficiency compared to 100% coal combustion. The reduction in gross heat rate by 145.5 kcal/kWh and net heat rate by 163.26 kcal/kWh indicates that the power plant requires less thermal energy to produce electricity under co-firing conditions. This efficiency improvement is supported by the characteristics of sawdust, which enhance combustion quality and reduce the potential for fouling and slagging in the boiler. The implementation of sawdust co-firing therefore represents an effective and practical alternative for reducing coal consumption and creating opportunities for emission reduction, without requiring major modifications to the existing power generation system.



	Co-firing 95% batu bara & 5% sawdust	100% batu bara
Efisiensi termal bruto (%)	29,44	28,05
Efisiensi termal netto (%)	27,64	26,26

Figure 2. Comparison of Thermal Efficiency under 95% Coal–5% Sawdust Co-firing and 100% Coal Combustion

Figure 2 illustrates the comparison of thermal efficiency between the two operating scenarios. Under co-firing conditions (95% coal and 5% sawdust), the gross thermal efficiency (η_thB) reached 29.44%, while the net thermal efficiency (η_thN) reached 27.64%. In contrast, under 100% coal combustion, the gross thermal efficiency was 28.05% and the net thermal efficiency was 26.26%.

Gross thermal efficiency under co-firing increased by 4.96% compared to the 100% coal combustion scenario. This improvement indicates that the combustion process became more effective in converting the total available thermal energy into electrical energy. Several factors contributed to this enhancement: the high volatile matter content of sawdust accelerates combustion reactions; ignition and flame propagation become more stable; and the reduced potential for fouling and slagging improves heat transfer effectiveness.

Net thermal efficiency also experienced a significant increase of 5.26%. This rise demonstrates that the benefits of co-firing extend beyond the combustion process itself and positively affect net electricity output after accounting for internal plant consumption, such as pumps and fans. This finding indicates that co-firing contributes to improved operational stability and combustion quality, thereby enhancing overall system performance.

Based on the analysis of both gross and net thermal efficiency under the two operational scenarios, several conclusions can be drawn. The implementation of sawdust co-firing significantly improves the thermal efficiency of the power plant in both gross and net parameters, with efficiency gains ranging from 4.96% to 5.26%. This demonstrates that co-firing positively influences combustion effectiveness and overall generation system performance. The reactive characteristics and low ash content of sawdust support improved combustion quality and reduced heat losses. The application of co-firing at a 5% blending ratio can be implemented without major system modifications, making it an effective, economical, and environmentally friendly energy transition solution. Furthermore, the implementation of biomass co-firing using sawdust has the potential to reduce coal consumption and contribute to carbon emission reduction.

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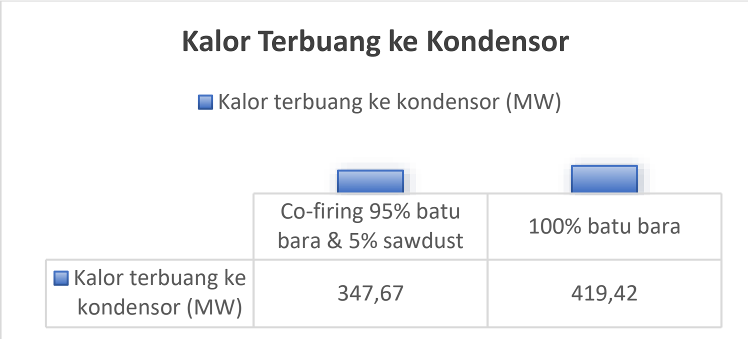

Figure 3. Comparison of Heat Rejected to the Condenser under 95% Coal–5% Sawdust Co-firing and 100% Coal Combustion

Figure 3 presents a comparison of the heat rejected to the condenser under the two operating scenarios. Under co-firing conditions (95% coal and 5% sawdust), the heat rejected to the condenser (Q_out), converted into electrical power equivalent, was 347.67 MW. In contrast, under 100% coal combustion, the heat rejected to the condenser reached 419.42 MW.

Based on these data, co-firing resulted in a lower amount of heat rejected to the condenser, representing a reduction of 71.75 MW compared to 100% coal combustion. This difference indicates a change in the thermodynamic performance of the plant's Rankine cycle. Several technical aspects explain this phenomenon. First, both gross and net thermal efficiencies were higher under co-firing conditions. Improved efficiency means that a greater portion of thermal energy is converted into turbine work, thereby reducing the residual thermal energy in the exhaust steam and ultimately decreasing the heat load discharged to the condenser.

Under co-firing operation, combustion becomes more stable and the temperature distribution within the furnace more uniform. This condition contributes to more optimal steam pressure and temperature at turbine inlet, more efficient expansion within the turbine, and lower exhaust steam enthalpy, which in turn reduces the heat rejected in the condenser. Additionally, the sawdust component contains lower ash and sulfur content than coal, resulting in reduced deposits on heat transfer surfaces. Consequently, boiler effectiveness improves, and the generated steam possesses better thermodynamic quality. These improvements enhance turbine expansion efficiency and further reduce energy losses to the condenser. Although sawdust constitutes only 5% of the co-firing mixture, coal combustion characteristics remain dominant, while the inclusion of sawdust provides notable technical benefits without disrupting system stability.

From the analysis of condenser heat rejection under the two operational scenarios, several conclusions can be drawn. The implementation of sawdust co-firing reduced condenser heat rejection to 347.67 MW, compared to 419.42 MW under 100% coal combustion. The reduction of 71.75 MW indicates that more thermal energy was effectively converted into turbine work under co-firing conditions. This decrease in rejected heat is consistent with the observed improvement in thermal efficiency, reflecting enhanced thermodynamic performance of the Rankine cycle. The application of 5% sawdust co-firing offers technical advantages, including more stable combustion, reduced fouling and slagging, improved steam quality, and lower thermal energy losses to the cooling system. Therefore, sawdust co-firing represents an effective strategy to enhance coal-fired power plant performance while reducing condenser energy losses, without requiring major modifications to the existing power generation system.

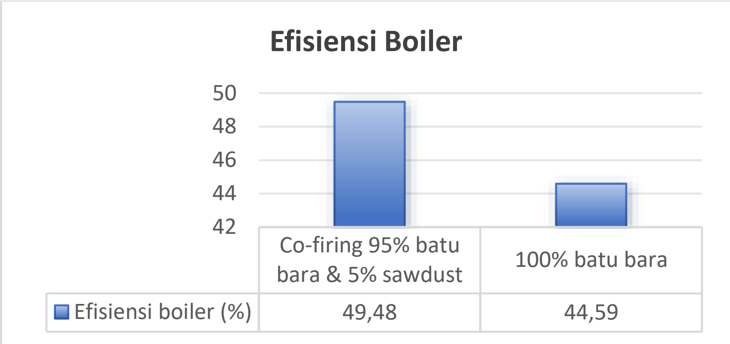

Figure 4. Comparison of Boiler Efficiency in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 4 presents a comparative graph of boiler efficiency between the implementation of 95% coal and 5% sawdust co-firing and 100% coal combustion. The boiler efficiency (ηB) under the co-firing scheme reached 49.48%, whereas the boiler efficiency under 100% coal combustion was recorded at 44.59%.

Based on these data, it is evident that the co-firing condition produced a higher boiler efficiency, showing an improvement of 10.97% compared to 100% coal combustion. This improvement can be attributed to the distinct characteristics of the sawdust–coal fuel mixture. Although the calorific value of sawdust is lower than that of coal, sawdust offers advantages in terms of cleaner combustion and improved thermal efficiency, as it ignites more readily at lower temperatures. Furthermore, sawdust contains lower ash and sulfur content, which reduces slagging and fouling that may obstruct heat transfer within the boiler, thereby enhancing efficiency.

In addition, the co-firing combustion process tends to be more balanced and optimized. The inclusion of sawdust promotes more homogeneous combustion due to its rapid ignition properties. This enhances the combustion rate and maximizes energy utilization within the boiler.

Conversely, coal is relatively more difficult to combust optimally. While coal has a high calorific value, it requires higher temperatures and more precise control to achieve optimal efficiency. If the combustion temperature is insufficient, incomplete combustion may occur, leading to unutilized emissions and reduced efficiency. In 100% coal combustion, not all fuel energy is effectively converted; a portion is lost as flue gas or unused heat, particularly when combustion is imperfect. Moreover, coal combustion requires additional energy input to reach the required temperature for complete combustion, increasing energy consumption without proportionally increasing output. Coal also burns more slowly than sawdust, resulting in less homogeneous and less efficient combustion.

Based on the analysis, it can be concluded that the implementation of sawdust co-firing yields higher boiler efficiency (49.48%) compared to 100% coal combustion (44.59%). This indicates that even a small proportion of sawdust (5%) can enhance boiler performance. Therefore, the use of mixed fuels such as biomass-based sawdust co-firing demonstrates significant potential to improve efficiency while reducing dependence on fossil fuels.

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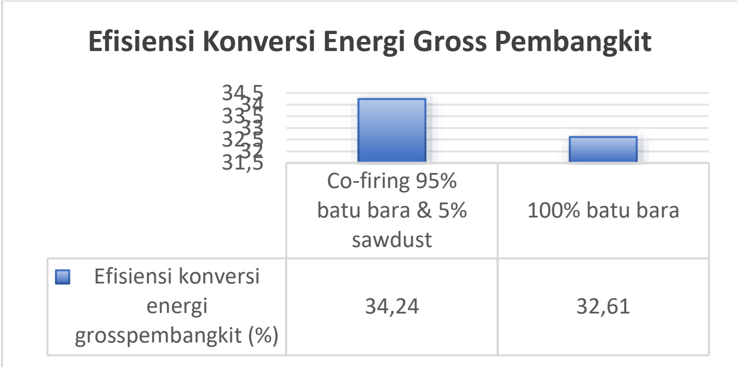

Figure 5. Comparison of Gross Energy Conversion Efficiency in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 5 illustrates the comparison of gross energy conversion efficiency between 95% coal and 5% sawdust co-firing and 100% coal combustion. The gross energy conversion efficiency (η_{KEG}) under the co-firing scheme was recorded at 34.24%, whereas under 100% coal combustion it reached 32.61%.

The implementation of co-firing demonstrates an increase in gross energy conversion efficiency compared to 100% coal combustion. The higher efficiency observed in the coal–sawdust mixture may be attributed to the lighter combustion characteristics of sawdust and its ability to produce more stable heat, contributing to a more efficient combustion process. Additionally, the presence of sawdust as an alternative fuel that is relatively more economical and environmentally friendly supports improved overall power plant performance.

In contrast, although coal possesses a high calorific value, the recorded gross energy conversion efficiency under 100% coal combustion was lower at 32.61%. This may be influenced by operational factors, including the high dependence on non-renewable coal and the inherent limitations in achieving optimal combustion efficiency with a single fuel source.

Based on the analysis, it can be concluded that the application of sawdust co-firing enhances the gross energy conversion efficiency of the power plant compared to 100% coal combustion. The blending of sawdust with coal reduces reliance on coal and improves overall plant efficiency. Although 100% coal combustion remains widely used in many power plants, the incorporation of sawdust through co-firing provides advantages in terms of carbon emission reduction and decreased coal consumption, aligning with broader efforts to promote energy sustainability.

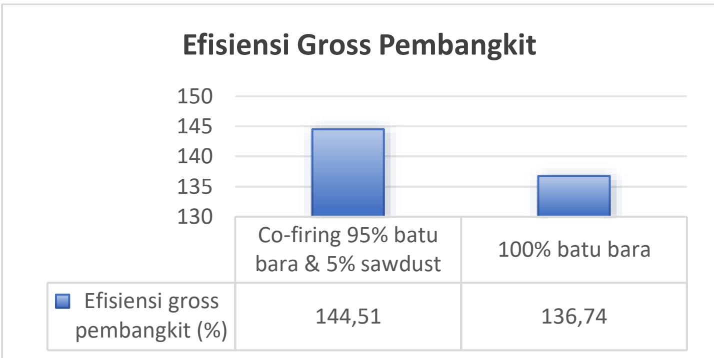

Figure 6. Comparison of Gross Plant Efficiency in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 6 presents a comparative graph of gross plant efficiency between the implementation of 95% coal and 5% sawdust co-firing and 100% coal combustion. The gross plant efficiency (η_{Gross}) under the co-firing scheme was recorded at 144.51%, whereas under 100% coal combustion it was 136.74%.

In the implementation of sawdust co-firing, the resulting gross plant efficiency of 144.51% indicates relatively strong performance, as boiler efficiency remains high despite partial fuel substitution with sawdust. The adoption of co-firing aims to reduce dependence on coal and lower carbon emissions, given that sawdust, as a biomass fuel, is more environmentally friendly than coal. The high efficiency value suggests that the coal–sawdust mixture can operate effectively without significantly compromising boiler performance.

By comparison, the gross plant efficiency under 100% coal combustion was 136.74%, which is lower than that achieved through co-firing. Full coal combustion typically generates higher emissions and reflects complete reliance on limited, non-renewable natural resources. Although the efficiency is lower, 100% coal combustion may offer relatively stable operation due to the consistency of a single fuel source.

Based on the analysis, it can be concluded that the implementation of sawdust co-firing yields higher gross plant efficiency (144.51%) compared to 100% coal combustion (136.74%). This finding indicates that co-firing is not only more efficient in terms of energy utilization but also contributes to mitigating environmental impacts. The application of co-firing provides a more environmentally sustainable alternative in power generation, with significant potential for emission reduction and the utilization of renewable resources.

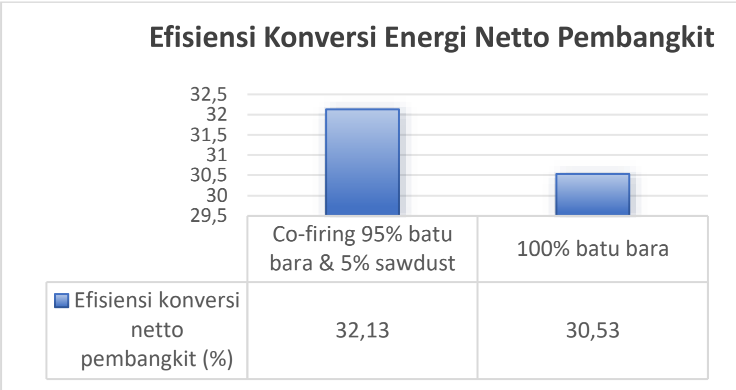

Figure 7. Comparison of Net Energy Conversion Efficiency in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 7 illustrates the comparison of net energy conversion efficiency between 95% coal and 5% sawdust co-firing and 100% coal combustion. The net energy conversion efficiency (η_KEN) under the co-firing scheme was recorded at 32.13%, while under 100% coal combustion it was 30.53%.

Sawdust exhibits different fuel characteristics compared to coal, including variations in moisture content and ash content. Nevertheless, the combination of coal and sawdust can enhance the combustion process by reducing the formation of smoke and harmful flue gases. The combustion quality of the coal–sawdust mixture may be more efficient due to the interaction between the two fuels, which can improve overall combustion performance.

The implementation of sawdust co-firing demonstrates a positive effect on energy conversion efficiency, despite the lower calorific value of sawdust compared to coal. The addition of sawdust can enhance the combustion process, particularly by improving combustion stability and reducing the required combustion time. The higher efficiency observed in co-firing may also be associated with emission reductions resulting from the use of renewable biomass fuel, thereby improving overall plant performance.

Based on the comparative analysis of net energy conversion efficiency between the 95% coal and 5% sawdust co-firing method and 100% coal combustion, it can be concluded that the implementation of sawdust co-firing achieves higher energy conversion efficiency (32.13%) compared to 100% coal combustion (30.53%). Although the difference in efficiency is relatively modest, the use of sawdust as a

ISSN 2828-9463

blended fuel offers additional benefits, including emission reduction and more sustainable utilization of renewable resources.

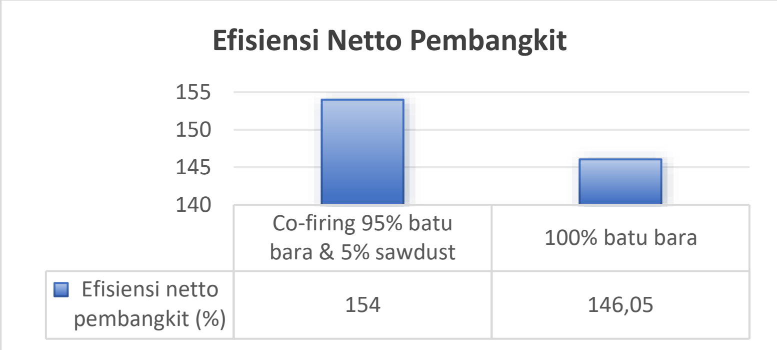

Figure 8. Comparison of Net Plant Efficiency in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 8 presents a comparative graph of net plant efficiency between the implementation of 95% coal and 5% sawdust co-firing and 100% coal combustion. The net plant efficiency (η_Netto) under the co-firing scheme was recorded at 154%, whereas under 100% coal combustion it was 146.05%.

There is a considerable difference in net plant efficiency between the two operating methods. The implementation of co-firing with a sawdust mixture achieved a higher efficiency of 154%, compared to 146.05% under 100% coal combustion. This improvement can be attributed to the fact that sawdust, as a biomass fuel, is more environmentally friendly than coal. The inclusion of sawdust reduces the combustion burden on coal, thereby enhancing overall efficiency in the power generation process. In addition, the combustion process involving a sawdust mixture may be more stable and efficient under certain plant operating conditions.

In contrast, 100% coal combustion often results in lower efficiency, particularly due to higher emissions, less complete combustion, and full reliance on fossil fuels with high energy density. Pure coal combustion may lead to greater energy losses, thereby negatively affecting overall efficiency.

Based on the comparative analysis, the implementation of sawdust co-firing demonstrates superior net plant efficiency compared to 100% coal combustion. Furthermore, the use of sawdust provides additional advantages in terms of sustainability and environmental impact reduction. Thus, the co-firing method not only enhances plant efficiency but also represents a more environmentally sustainable alternative to conventional coal combustion.

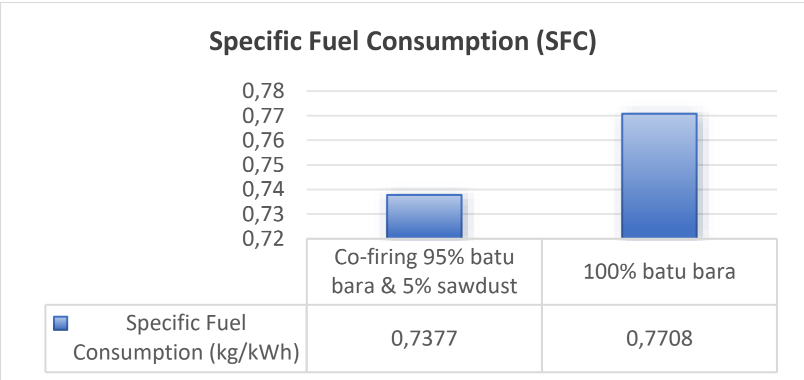

Figure 9. Comparison of Specific Fuel Consumption (SFC) in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 9 illustrates the comparison of Specific Fuel Consumption (SFC) between 95% coal and 5% sawdust co-firing and 100% coal combustion. The SFC value under co-firing was recorded at 0.7377 kg/kWh, whereas under 100% coal combustion it was 0.7708 kg/kWh.

Under the 95% coal and 5% sawdust co-firing scenario, the SFC of 0.7377 kg/kWh is lower than that of 100% coal combustion, which recorded 0.7708 kg/kWh. This indicates that the addition of sawdust as a supplementary fuel reduces the amount of fuel required to generate one kWh of electrical energy.

The reduction in SFC signifies that the combustion process becomes more efficient when a blended fuel is used, resulting in fuel savings. The decreased coal consumption in co-firing suggests that less energy is wasted to produce the same energy output. Moreover, the use of sawdust contributes to potential carbon emission reductions, as biomass generally has lower emission intensity compared to coal.

From the analysis conducted, it can be concluded that the implementation of sawdust co-firing results in lower Specific Fuel Consumption (SFC) compared to 100% coal combustion. This finding demonstrates that co-firing enhances combustion efficiency and reduces coal consumption for the same energy output. The advantages of co-firing extend beyond fuel efficiency to include potential carbon emission reduction and the utilization of more environmentally sustainable alternative fuels such as sawdust. Therefore, coal–sawdust co-firing represents a more efficient and sustainable alternative in power generation processes.

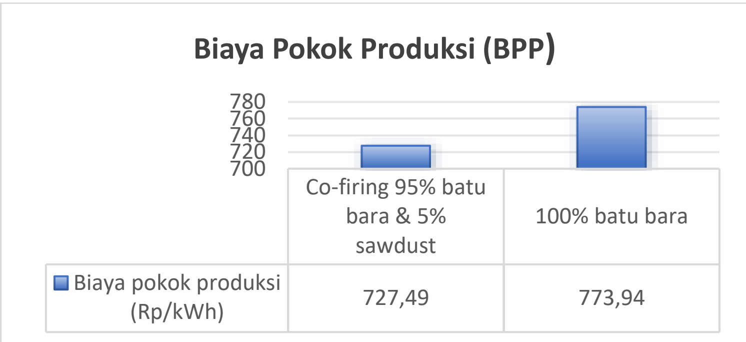

Figure 10. Comparison of Cost of Production (BPP) in the Implementation of 95% Coal & 5% Sawdust Co-Firing and 100% Coal Combustion

Figure 10 presents a comparative graph of the cost of production (BPP) between the implementation of 95% coal and 5% sawdust co-firing and 100% coal combustion. The BPP under the co-firing scheme was recorded at IDR 727.49/kWh, whereas under 100% coal combustion it reached IDR 773.94/kWh.

The cost of production for the 95% coal and 5% sawdust co-firing configuration is lower than that of 100% coal combustion, with a difference of approximately IDR 46.45/kWh. This indicates that incorporating sawdust in a small proportion can reduce production costs compared to full coal utilization. The implementation of co-firing with sawdust demonstrates potential cost savings, although the margin of difference is relatively moderate. Sawdust, as an alternative fuel, may be less expensive or more readily available than coal, thereby contributing to the reduction in production costs.

In addition to cost savings, the use of sawdust may contribute to carbon emission reductions, which are essential for environmental sustainability. If this cost differential can be maintained or further enhanced through technological improvements or a higher proportion of sawdust in the fuel mix, co-firing could become a more economically advantageous and environmentally sustainable option.

Based on the analysis, it can be concluded that the implementation of sawdust co-firing is economically more beneficial than 100% coal combustion. The difference in production cost of IDR 46.45/kWh reflects significant cost-saving potential. Furthermore, the integration of sawdust in co-firing offers sustainability advantages, particularly in terms of carbon emission reduction. Therefore, co-firing technology represents a more efficient and environmentally friendly alternative, with strong potential for broader implementation if further optimization is achieved.

Discussion

The implementation of co-firing with a fuel mixture of 95% coal and 5% sawdust, compared to 100% coal combustion at PLTU 3 Banten Lontar, aims to evaluate power plant performance, thermal efficiency, fuel calorific value, flue gas emissions, and the cost of electricity production (BPP) resulting from the co-firing application. The data utilized in this study consist of field observation data and combustion performance data obtained from PT Indonesia Power at PLTU 3 Banten Lontar.

Auxiliary power consumption (self-consumption) under co-firing conditions was recorded at 16.31 MW, slightly higher by 0.96% compared to 16.15 MW under 100% coal combustion. This increase is influenced by the characteristics of sawdust, which has a lower calorific value and lower density than coal, resulting in increased fuel flow rates and higher power consumption during the combustion process [14].

Gross thermal efficiency under co-firing reached 29.44%, while 100% coal combustion achieved 28.05%. Similarly, net thermal efficiency under co-firing was 27.64%, higher than the 26.26% recorded under full coal combustion. This improvement indicates that the co-firing application enhances energy conversion efficiency within the power plant, as reflected by the reduction in gross and net heat rates, signifying more efficient electricity generation from the available thermal energy [15].

Under co-firing conditions, CO_2 emissions were measured at 11.58%, lower than the 12.70% produced under 100% coal combustion. This reduction is attributed to the lower carbon content of sawdust compared to coal, although coal combustion remains the dominant source of CO_2 emissions. SO_2 emissions decreased to 172.63 mg/m³ under co-firing, compared to 208.65 mg/m³ under full coal combustion, due to the lower sulfur content in sawdust. Likewise, NO_x emissions declined from 236.03 mg/m³ under 100% coal combustion to 215.86 mg/m³ under co-firing. These findings demonstrate that incorporating sawdust into the coal mixture can effectively reduce air pollutants associated with combustion. Overall, the co-firing application significantly reduces CO_2, SO_2, and NO_x emissions gases that are harmful to human health and the environment and complies with the emission standards stipulated in Regulation of the Minister of Environment and Forestry No. 15 of 2019.

From an economic perspective, the cost of electricity production (BPP) under co-firing was lower, amounting to IDR 727.49 per kWh, compared to IDR 773.94 per kWh under 100% coal combustion, resulting in a difference of approximately IDR 46.45 per kWh.

The implementation of biomass co-firing at a commercial-scale coal-fired power plant in Indonesia presents substantial potential to support a cleaner energy transition and contribute to achieving the national target of a 23% renewable energy mix by 2025. Nevertheless, several challenges remain, including technical adjustments to boiler operations and combustion systems to accommodate the distinct characteristics of biomass compared to coal, biomass supply chain management and quality control, and the need for modifications to combustion control systems to maintain optimal efficiency [16].

5. Conclusion

This study aims to analyze the impact of implementing co-firing with a fuel mixture of 95% coal and 5% sawdust on the performance of Unit #1 at PLTU 3 Banten Lontar. The research findings indicate that:

1. The implementation of co-firing with a 5% sawdust blending ratio relative to total coal consumption during unit operation demonstrates a non-linear relationship between the 5% sawdust blending ratio and the resulting electrical energy output composition.

2. The application of co-firing using sawdust results in a lower cost of electricity production, amounting to IDR 727.49 per kWh, compared to IDR 773.94 per kWh under 100% coal combustion.
3. The implementation of co-firing successfully reduced CO_2 emissions from 12.70% under 100% coal combustion to 11.58% under co-firing conditions. Similarly, SO_2 emissions decreased from 208.65 mg/m³ to 172.63 mg/m³, and NO_x emissions declined from 236.03 mg/m³ to 215.86 mg/m³. Therefore, the adoption of co-firing represents a more environmentally friendly alternative and complies with the emission standards stipulated in Regulation of the Minister of Environment and Forestry No. 15/2019.

Despite demonstrating the technical, economic, and environmental benefits of co-firing implementation, this study has several limitations that should be acknowledged. First, the analysis is limited to a single blending ratio (5% sawdust), which does not fully capture the optimal composition range that may yield maximum efficiency and emission reduction. Second, the study focuses on short-term operational performance without evaluating long-term impacts such as boiler degradation, slagging, fouling behavior, and maintenance costs. Third, the variability in sawdust quality, including moisture content, particle size, and calorific value, was not deeply examined, even though these factors can significantly influence combustion stability and overall system performance.

Based on these limitations, future research is recommended to explore a wider range of biomass blending ratios to identify optimal co-firing conditions under different operational loads. Long-term performance assessments are also necessary to evaluate the durability of equipment and the economic feasibility over extended periods. In addition, further studies should incorporate a more detailed characterization of biomass properties and their influence on combustion efficiency and emission profiles. Expanding the scope to include other types of biomass and conducting comparative analyses across different power plant units or locations would also provide broader generalizability. Finally, integration with advanced monitoring systems and optimization models is recommended to enhance real-time control and improve the overall effectiveness of co-firing implementation in coal-fired power plants.

6. References

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