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Feasibility Test for the Use of Rice Husk Biomass in Steam Power Plants (PLTU)

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Abstract. This study analyzes the feasibility of implementing biomass-based co-firing technology in coal-fired power plants as a strategy to reduce greenhouse gas emissions and support a cleaner energy transition. With the increasing environmental impact of coal-fired power plants, biomass co-firing presents a viable solution to reduce dependence on fossil fuels. This research includes an analysis of the calorific value, potential emission reductions, and evaluation of the costs associated with the application of the technology. Rice husks show the potential to produce syngas with a turbine power of 99.7 MW at a humidity of 10.47% with an emission of 118,201 kJ/hr, but the efficiency decreases at higher humidity affected by the weather. This rice husk co-firing strategy of about 5% produces 116-122 MW of turbine power with CO_2 emissions of 160,605 kJ/hr-175,480 kJ/hr, making it an effective energy transition solution and contributing to Indonesia's renewable energy targets.

Keywords: *biomass, rice husk, coal-fired power plants, co-firing, renewable energy.*

1 Introduction

Indonesia has experienced a significant increase in renewable energy capacity. Based on a report by the International Renewable Energy Agency [1,15], renewable energy capacity increased by 9.23% from 11,537 MW in 2021 to 12,603 MW in 2022. The Ministry of Energy and Mineral Resources (MEMR, 2023) also recorded an increase of 14% in 2023. This increase is in line with the government's efforts to reduce dependence on fossil fuels and increase the green energy mix. However, the main challenge in this energy transition is to find energy sources that are not only sustainable but also widely and economically accessible. The use of biomass fuel for power generation can be implemented quickly without the need to build new power plants but through the implementation of coal-fired power plant co-firing. [20,21]

One potential renewable energy alternative is biomass. Indonesia as an agrarian country has an abundant source of biomass from agricultural waste, one of which is rice husks. According to [2,23], the biomass potential in Indonesia reaches 146.7 million tons/year, with an estimated contribution of up to 24.64 GW by 2050. The use of biomass as an energy source can not only reduce dependence on fossil energy but also help in the management of agricultural waste which is often an environmental problem. Biomassa memiliki potensi energi berkelanjutan terbesar di dunia. Potensi produksi primer tahunan mencapai 4500 EJ (Exajoule), dengan potensi bioenergi sekitar 2900 EJ dan sekitar 270 EJ tersedia secara berkelanjutan [19,22]

Rice husk is a type of biomass that is available in large quantities in Indonesia. Data from the Central Statistics Agency in 2023 [3], and Katadata in 2023 show that national grain production reaches 53.98 million tons per year, which produces rice husk waste of up to 15 million tons. If this waste is not managed properly, it can lead to environmental pollution and increase greenhouse gas emissions. According to [4,5], open burning of rice husks can produce pollutants such as carbon monoxide (CO) and fine particles that are harmful to human health. Therefore, the use of rice husks as fuel for power plants can be an effective solution in reducing environmental impacts and supporting the clean energy transition.

Various studies have shown that rice husks have the potential as a viable source of electrical energy. The use of rice husks from 200 hectares of land can produce heat energy of 477,400 kcal, which is equivalent to 23.28 kWh of electricity with a combustion efficiency of 93%. Biomass energy conversion technologies, such as gasification and direct combustion, have been widely used in various countries to improve energy efficiency [7]. Downdraft gasification systems have a conversion efficiency rate of between 30-40% and produce syngas that can be converted into electricity. Some countries such as China and India have developed rice husk gasification technology as an alternative source of electricity, given their high rice production [9,10].

Indonesia, as one of the largest rice producers in the world, has great potential in developing this technology [8,11]. One of the locations that has the potential to adopt rice husk biomass as an energy source is the Pangkalan Susu Steam Power Plant (PLTU). This coal-fired power plant is one of the coal-based power plants operating in Indonesia [12]. By utilizing rice husks as a co-firing fuel or even as the main source of energy, these coal-fired power plants can reduce dependence on coal and reduce carbon emissions produced from burning fossil fuels [13,14]. Based on previous trials, the use of EFB biomass pellets has the following characteristics: the sulfur content of biomass is lower than that of coal, at 0.05-0.09%, and SO2 emissions are lower, while the volatile matter and oxygen content is higher than that of coal [16,17].

The use of rice husks as electrical energy shows that the energy potential produced from 200 hectares of land in Wineru Village provides heat energy of 477,400 kcal equivalent to 23.28 kWh of electricity, where the combustion efficiency of 93% of the heat energy given to the working fluid of the rice husk coal-fired power plant prototype is an average of 32,540.31 kcal. The mechanical energy produced in the turbine is 89.5 kJ/kg equivalent to 24.8 Wh of electrical energy. The output voltage of the generator is 9 Volts. The electrical energy that can be produced from 200 hectares of land is 178,078 kW. This shows that there is great potential when it can be used for rice husks as electricity [6].

This study aims to find out and analyze the potential energy source of rice husk biomass at the Pangkalan Susu PLTU. In addition, this study conducted calculations that included thermo aspects related to the potential feasibility of rice husk biomass as an energy source in the coal-fired power plant. Furthermore, this study also evaluates the economic aspect of the use of rice husk biomass to determine the feasibility of its implementation as a sustainable energy solution. With this research, it is hoped that it can contribute to the development of renewable energy in Indonesia and support government policies in increasing the green energy mix. The purpose of this study is to analyze the impact of biomass and coal co firing combustion on the distribution of temperature, pressure, and mass flow [18].

2 Methodology

This study adopts a descriptive and quantitative research methodology to thoroughly assess the potential utilization of biomass, particularly rice husks, as a sustainable alternative fuel for Steam Power Plants (PLTU). The descriptive component of this research was conducted through an extensive literature review, field observations, and the collection of secondary data related to the availability, distribution, and characteristics of rice husk biomass in the target area. These qualitative explorations provided contextual understanding and supported the formulation of technical and economic models.

The quantitative component involves the application of engineering principles and process simulation techniques to evaluate the technical and economic viability of biomass co-firing. This includes performing mass and energy balances, simulating combustion and gasification processes, analyzing thermodynamic performance indicators, and calculating economic metrics to determine feasibility.

The scope of the study encompasses several key elements:

1. Identification and quantification of potential energy output from rice husk
2. Evaluation of appropriate biomass conversion technologies
3. Execution of a comprehensive thermoeconomic feasibility analysis that integrates both engineering and financial considerations.

The analysis focuses on two main perspectives:

a. Thermal Aspects: This includes the assessment of system performance through calculations of thermal efficiency, exergy efficiency, and identification of energy losses. Exergetic analysis was performed to better understand irreversibilities within the energy conversion process and to determine the thermodynamic effectiveness of integrating rice husks into existing coal-fired systems.
b. Economic Aspects: The economic evaluation covers cost analysis of the proposed biomass integration, including estimation of capital and operational expenditures, determination of unit cost of electricity, and financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period to assess the profitability and investment attractiveness of the co-firing scheme.

To ensure accuracy and reliability of the technical analysis, process simulations and thermodynamic modeling were carried out using Aspen Plus version 14, a professional-grade software widely used in energy systems engineering. Aspen Plus was utilized to model the combustion and energy conversion processes, allowing for detailed insight into system behavior under various biomass blending scenarios. The use of this software facilitates a high degree of model precision and supports reproducibility of the study by other researchers or practitioners.

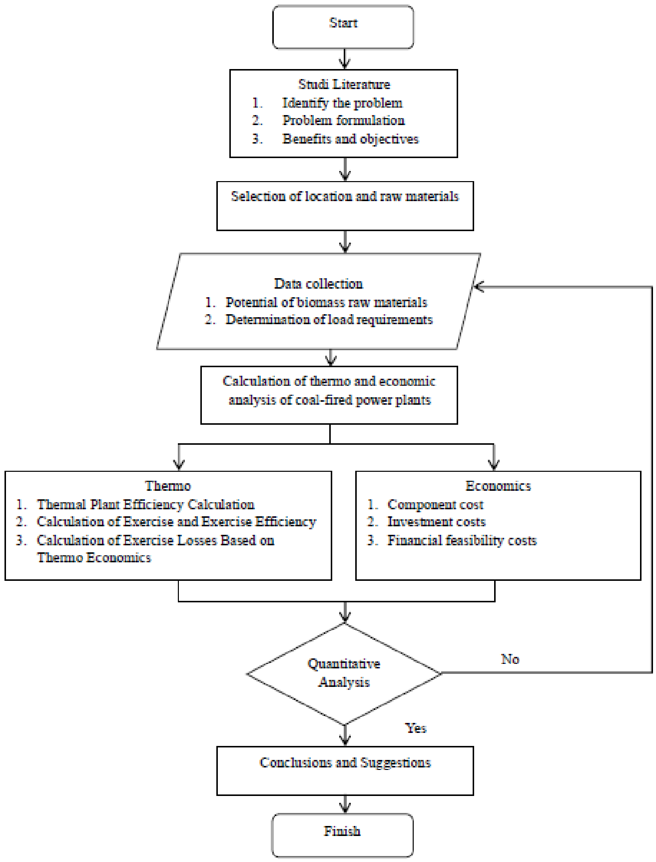

Figure1. Research Procedure

The research was conducted in Pangkalan Susu District, Langkat Regency, North Sumatra Province, which is an area with significant biomass energy potential from rice husk waste.In this area, rice husks have not been utilized optimally, thus providing considerable opportunities for the development and research of biomass-based coal-fired power plants.

2.1 Data

This study simulates the performance of the Pangkalan Susu coal-fired power plant with Coal Firing (LRC) and rice husks as alternative fuels. Coal has a higher moisture content (36.47%) than rice husk (10.47%), which affects combustion efficiency. Rice husks have a higher ash content (14.78% - 16.5%) than coal (4.52% - 7.11%), which can lead to the formation of scale in the boiler. But kandungan volatile matter sekam padi lebih tinggi (60,95% - 68,08%), so that it is more flammable. The calorific value of rice husks (3514 - 3925 kCal/kg) is lower than that of coal (3932 - 6190 kCal/kg), so more amounts are needed to produce the same energy. In addition, the higher oxygen content of rice husks decreases combustion efficiency and increases exhaust emissions. The results of this analysis are used to model combustion performance, assess energy efficiency, and estimate ash emissions and handling, in order to assess the feasibility of rice husks as an alternative fuel for coal-fired power plants.

Table 1. Results of Fuel Characteristics Analysis *Performance Test*

PARAMETER	UNIT	COAL FIRING (LRC)			RICE HUSK		
		AR	ADB	DB	AR	ADB	DB
Proxymate Analysis							
Moisture Content	%Wt	36,47	14,05	0	10,47	10,18	0
Volatile Matter	%Wt	31,25	42,28	49,2	60,95	61,15	68,08
Fixed Carbon	%Wt	27,75	37,55	43,69	13,8	13,85	15,41
Ash Content	%Wt	4,52	6,11	7,11	14,78	14,82	16,5
Gross Calorie Value	kCal/kg	3932	5320	6190	3514	3526	3925
Gross Calorie Value	kj/kg	16451,488	22258,88	25898,96	14702,576	14752,784	16422,2
TOTAL	%Wt	100	100	100	100	100	100
Ultimate Analysis							
Carbon	%Wt	41,48	56,12	65,29	36,96	37,09	41,29
Hydrogen	%Wt	3,1	4,19	4,88	5,7	5,72	6,37
Nitrogen	%Wt	0,62	0,83	0,97	0,48	0,49	0,54
Oxygen	%Wt	13,64	18,45	21,47	31,36	31,46	35,03
Sulfur	%Wt	0,18	0,24	0,28	0,24	0,24	0,27
TOTAL	%Wt	100	100	100	100	100	100

2.2 Process Simulation

Simulations using Apen Hysys software were carried out to analyze the impact of *Co-firing implementation* on combustion efficiency and boiler or turbine performance at the coal-fired power plant. This simulation considers several aspects, including:

1. Comparison of coal with rice husk biomass of 100% each state
2. Co-firing between coal and rice husks with a composition of 5% with a weather cycle of 1 year.

From the simulation results, it was found that an increase in the biomass ratio can cause changes in combustion efficiency as well as a decrease in electrical power produced due to the difference in heat value between coal and rice husks. The results of the model validation show that the simulation is close to the real conditions at the coal-fired power plant, providing a realistic picture of the boiler's performance in the *co-firing* scenario. Thus, this simulation approach can be a reference in planning for optimizing the use of biomass in other coal-fired power plants.

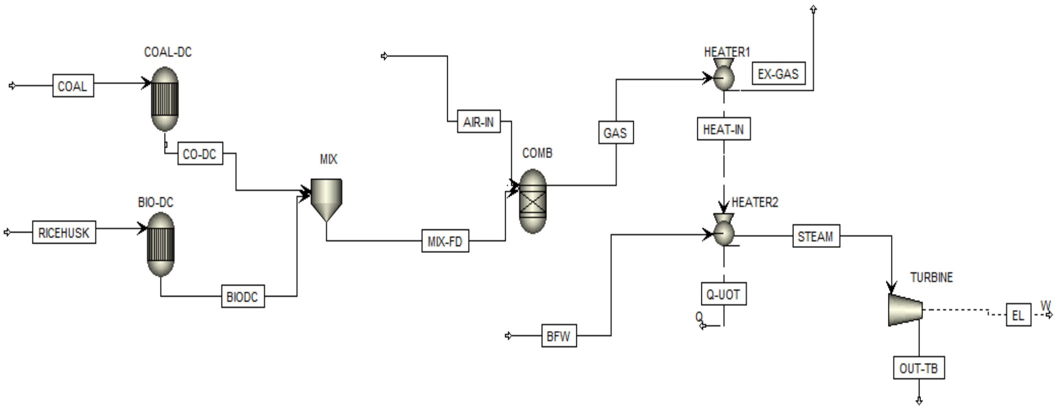

Figure2. Combustion modeling scheme with Aspen Plus

3 Result and Discussions

3.1 Comparison of coal with rice husk biomass.

In understanding the potential and performance of rice husk gasification as a renewable energy source, a series of simulations were carried out that described operational conditions at various temperature, pressure, and fuel composition parameters. This simulation resulted in the gasification of rice husks that produced syngas with a CO2 content of 118,201. Under these conditions, the turbine output power generated reaches 99.7 MW, which shows a fairly good performance for steam power generation applications. In addition, the CO2 emissions resulting from this process are lower compared to burning coal, indicating that the use of rice husks as biomass fuel has the potential to reduce environmental impact, particularly in terms of greenhouse gas reductions. These parameters are then used as a baseline or reference point for efficiency without any additional intervention or modification in the gasification process.

Meanwhile, the coal used is Low Rank Coal (LRC) as a fuel compared to rice husks. The simulation results showed that coal produced syngas of higher quality, characterized by a CO content of 178,495 kJ/h and a calorific value of 516,101 kJ/s, which is higher than rice husks. The output power of the turbines is also larger, reaching 122.5 MW, which indicates the better thermal efficiency of coal compared to rice husk biomass. However, this improved performance comes with greater environmental consequences, this reflects that although coal has advantages in terms of energy efficiency and power output, its use has a negative impact on the environment due to higher greenhouse gas emissions. Therefore, fuel selection must consider the balance between energy efficiency and environmental impact, especially in the context of global efforts to reduce carbon emissions and switch to cleaner and more sustainable energy sources.

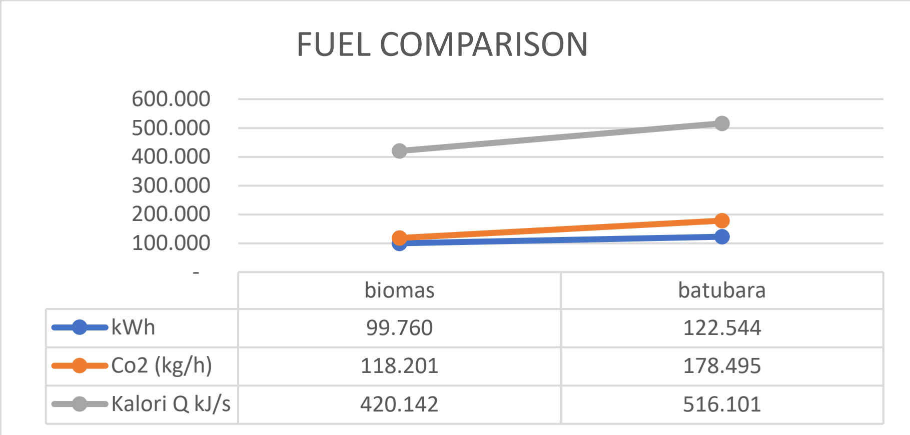

Figure 3. Comparison chart of coal with rice husk

3.2 Co-firing between coal and rice husks with a composition of 5% with the weather cycle.

Indonesia, especially in North Sumatra, which is located around the equator, has a tropical climate that is different from countries in temperate regions which have four seasons (spring, summer, autumn, and winter). In general, it is known that there are two main seasons, namely **the rainy season** and **the dry season**. However, in daily conversation, people also often mention the existence of **the pancaroba season**, which is the transition period between the dry season and the rainy season.

Table 2. Rainfall Table in North Sumatra 2023

Parameter	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	164	128	228	196	175	256	303	536	598	271	190	326
Rainy Day	25	17	19	14	18	12	19	28	21	25	23	22
Information	Rain	Hot	Panca	Hot	Panca	Hot	Panca	Rain	Rain	Rain	Rain	Rain

This simulation is designed to evaluate the effect of increasing rice husk moisture every month which is influenced by the season. In the pancaroba season we increase it to 15% while in the rainy season it is increased to 20% to represent the actual conditions of the change in seasons and less than optimal fuel storage. This increase in humidity caused a decrease in heat to (514,000-518,000) kJ/s. The results showed that the gasification efficiency decreased tp was not too significant and had no impact on turbine power, while CO_2 emissions increased to 174,000-175.00. The selection of these parameters aims to identify operational challenges that arise due to moisture variations.

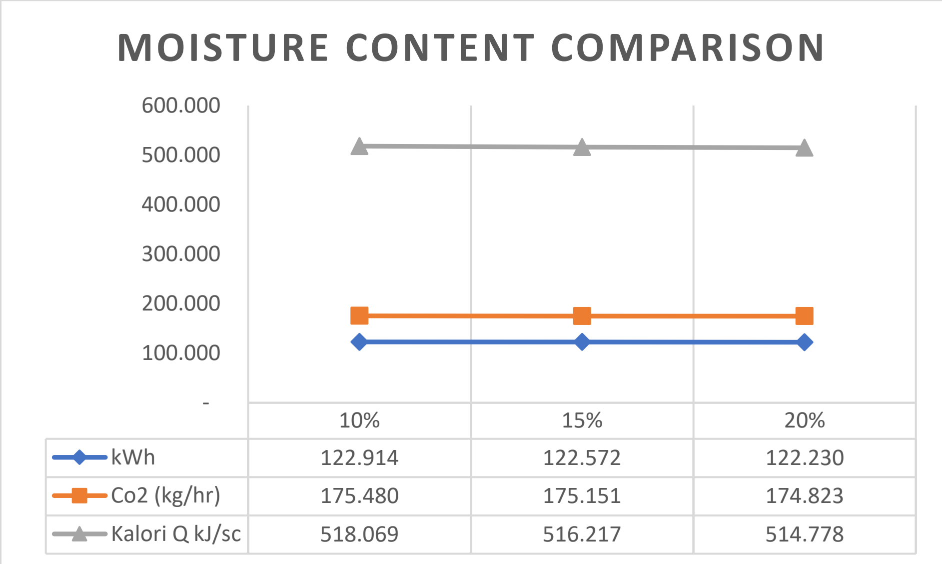

Figure 4. Comparison chart of coal with rice husks

Table 3. SFC value of Pangkalan Susu PLTU simulation results

Item	**Cofiring composition**					
	0%	5%	7,5%	10%	20%	30%
Coal (kg/hr)	95.690	90.906	88.513	86.121	76.552	66.983
Rice husk (kg/hr)	0	4.785	7.177	9.569	19.138	28.707
Total Fuel (kg/hr)	95.690	95.690	95.690	95.690	95.690	95.690
kWh Production (kWh)	130.967	129.139	128.668	127.894	125.536	123.027
SFC (kg/kWh)	0,731	0,741	0,744	0,748	0,762	0,778

The impact of biomass use on fuel costs (component C) is influenced by the value of specific fuel consumption and the price of fuel used in the cofiring process and the price of the fuel used in the cofiring process of coal and rice husk biomass rice husk biomass. It can be seen that the total amount of fuel remains constant at 95,690 kg/h across all variations, although the proportion of coal decreases as the rice husk biomass increases. The electricity production (kWh) tends to decrease from 130.967 kWh at 0% cofiring to 123.027 kWh at 30% cofiring. In addition,

the Specific Fuel Consumption (SFC) value, which reflects fuel efficiency, increases from 0.731 kg/kWh to 0.778 kg/kWh, indicating that as the proportion of rice husk increases, the generation efficiency tends to decrease.
By using the realized price of coal and rice husk biomass in accordance with the 2020 PLN price, the price for coal was obtained at Rp. 765.61/kg while for rice husk biomass it was Rp. 581.59 /kg. The BPP component C which can be seen in Table 4.

Table 4. Calculation of production cost of component C

Item	**Cofiring composition**					
	0%	5%	7,5%	10%	20%	30%
kWh Production (kWh)	130.967	129.139	128.668	127.894	125.536	123.027
SFC (kg/kWh)	0,731	0,741	0,744	0,748	0,762	0,778
Coal Prices (Rp/kg)	765,61					
Rice Husk Price (RP/kg)	581,59					
BPP (Rp/kWh)	559,39	560,49	559,12	559,06	555,53	552,55

The price of coal was recorded at Rp765.61 per kg, while rice husk was cheaper at Rp581.59 per kg. Although efficiency decreased slightly, the partial replacement of coal with rice husk had a positive impact on the Cost of Production (BPP), which decreased from Rp559.39/kWh at 0% cofiring to Rp552.55/kWh at 30% cofiring or about 1.2%. This shows that the use of rice husk as an alternative fuel can be an economical strategy in energy diversification efforts.

Table 5. Calculation of Investment Cost of Equipment Addition

No	**Item**	**Unit**	**Value**
1	Rotary Dryer	Ton/Jam	20
	On-Site Needs	Pcs	1
	Price	Rp 825.000.000,00	Rp 825.000.000,00
2	Construction Storage	Unit (m)	20 X 25
	Storage Construction Needs	Pcs	1
	Price	3-10 Jt/m	Rp 2.750.000.000,00
	Total		**Rp 3.575.000.000,00**

Because humidity affects the decrease in heat and power generated in the transitional season and the rainy season. So in optimizing cofiring between the two seasons, several additional facilities are needed such as a rice husk biomass storage warehouse and a rotary dryer to treat rice husk biomass before it is used as fuel in the Pangkalan Susu PLTU. By using several assumptions and calculations of the financial feasibility study of the addition of materials and storage for the Pangkalan Susu PLTU.

Table 6. Financial viability assessment

No	Parameter	Nilai
1	Investment Cost (Rp)	3.575.000.000,00
2	Fuel Costs (kg/kWh)	552,55
3	Selling Price (Rp/KWh)	1444,7
4	CF (%)	64,36
5	IRR Project (%)	25
6	NPV Project (Rp)	2.305.358.326,77
7	B/C Ration Project (Laughs)	2,04
8	Payback Period (Year)	3,6

The project required an initial investment cost of Rp3.575 billion with a fuel efficiency of 552.55 kg/kWh. The electricity generated was sold at Rp1,444.7 per kWh, while the plant utilization rate (CF) reached 64.36%. The financial feasibility analysis showed very positive results, with an IRR of 25% indicating a high rate of return, and an NPV of IDR2.305 billion indicating the added value of the project. The B/C ratio of 2.04 times indicates that every Rp1 invested will generate Rp2.04 worth of benefits, while the payback period of 3.6 years reflects a relatively short payback period. Overall, the project is considered highly feasible and profitable based on all financial parameters analyzed.

4 Conclusion

The study analyzes the feasibility of implementing biomass-based co-firing technology as a strategy to reduce greenhouse gas emissions and support a cleaner energy transition. With the increasing environmental impact of coal-fired power plants, biomass co-firing presents a viable solution to reduce dependence on fossil fuels. The study includes an analysis of caloric value, and the potential emission reductions associated with the application of the technology. Rice husks show the potential to produce syngas with a turbine power of 99.7 MW at a humidity of 10.47% with an emission of 118,201 kJ/h, but its efficiency decreases at higher humidity affected by the weather and at the time of storage errors but for such a decrease is not very significant. The rice husk co-firing strategy of around 5% produces 122 MW of turbine power with a decrease in humidity of around 200-400 kWh while CO_2 emissions are 175 tons/hour, making rice husk biomass suitable for use as an effective energy transition solution and contributing to Indonesia's renewable energy targets. The conclusion emphasizes the importance of adopting co-firing technology as a strategic step in mitigating sustainable energy development. This research provides valuable insights for energy policymakers and stakeholders in Indonesia and beyond, who are advocating for a transition to more sustainable energy practices. The basic production cost (BPP) shows a downward trend with co-firing. When using coal alone, the BPP reaches Rp 559.39/kWh, while when using 30% rice husks, this figure drops to Rp 552.55/kWh, representing a saving of around 1.2%.From a financial perspective, the rice husk biomass co-firing project is deemed viable based on several economic indicators. The investment costs required for additional facilities such as a rotary dryer and rice husk storage warehouse amount to Rp 3.575 billion. The Net Present Value (NPV) of this project reaches Rp 2.305 billion, with an Internal Rate of Return (IRR) of 25%, indicating a high return on investment. The Benefit-Cost Ratio (BCR) of 2.04 times indicates that every Rp 1 invested generates a benefit of Rp 2.04. The payback period is relatively short, at 3.6 years.

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