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TECHNO-ECONOMIC EVALUATION OF RICE HUSK CO-FIRING AS A SUSTAINABLE BIOMASS FUEL ALTERNATIVE

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ABSTRACT

Co-firing is a technology that blends coal with biomass at a specific ratio in steam power plants. In the Lontar area, which is surrounded by vast rice fields, there is significant potential to utilize rice husk waste as a biomass feedstock. The aim of this design is to reduce Indonesia's dependence on coal, which is considered a non-renewable energy source, while promoting the transition to renewable energy. As coal consumption continues to rise each year, this research explores the potential to reduce coal usage by co-firing it with rice husk biomass. The co-firing design implements a biomass blending ratio of 2-5% with coal. The study's results indicate that, on average, only 0.608 kg of fuel is needed to generate 1 kWh of electricity. Additionally, the Net Plant Heat Rate achieved is 2,557.5 kcal/kWh, which, when compared to non-co-firing values, demonstrates an improvement in the power plant's efficiency. From an economic perspective, the power plant in the Lontar area could save fuel costs amounting to Rp 9.24 billion over a four-month period, with the average production cost of co-firing being only Rp 346.77/kWh. Based on these technical and economic results, the co-firing design is deemed feasible and promising for further implementation in the coming years.

I. INTRODUCTION

Steam Power Plants are one of the main energy sources in Indonesia that uses coal as the main fuel. With the growing awareness of the negative impact of coal on the environment, governments and researchers are looking for more environmentally friendly alternatives. One of the technologies that can be applied is co-firing technology. This technology allows the mixing of coal with biomass, such as agricultural waste, to reduce the use of coal as a non-renewable energy source [1].

Co-firing technology has great potential in areas such as Lontar, which are surrounded by large rice fields. This area produces abundant rice husk waste, which can be used as biomass for mixing with coal. By conducting co-firing, it is hoped that the use of coal can be significantly reduced, as well as provide economic and environmental benefits [2]. In the long term, this technology is one of the strategies to support the transition to new and renewable energy.

Currently, coal consumption in Indonesia continues to increase every year, so real efforts are needed to reduce dependence on coal [3]. One of them is by developing co-firing technology that utilizes rice husk biomass, which not only reduces carbon emissions, but also has the potential to improve the efficiency of power plants. The efficiency resulting from the application of co-firing can be seen from the savings in fuel consumption as well as lower electricity production costs.

With the growing urgency of the need for clean and efficient energy, co-firing technology shows that it is technically and economically feasible to be applied more widely. This opens up opportunities to increase the role of biomass in the national energy mix, while reducing the negative environmental impact of coal burning.

Applying coal-biomass co-firing power generation is the strategy to accelerate the renewable energy share in the energy mix to reach 23% by 2025. Although biomass co-firing trials have been carried out at several Coal-Fired Power Plants (CFPP), the potential for implementing biomass co-firing on a larger scale and for the long-term propose still needs to be identified [4].

In the National Electricity General Plan, PLN plans to implement Co-firing in 52 units (Steam Power Plants) [5]. Co-firing is the substitution of coal in a certain ratio with biomass materials such as wood pellets, palm shells and sawdust. In 2024, it is estimated that the total Co-firing capacity at electric steam power plant PLN will reach 18 GW. The Co-firing plan is aimed at supporting the development of NRE in Indonesia. By implementing Co-firing, the use of NRE can be carried out quickly without the need for the construction of new generators.

II. THEORETICAL REFERENCE

Biomass energy has great potential to help reduce dependence on fossil fuels, reduce greenhouse gas emissions, and promote energy sustainability. However, the utilization of biomass energy also requires careful management to ensure that its production and use do not result in negative consequences for the environment and sustainability.

There are types of solid biomass, including agricultural waste: Agricultural waste such as straw, rice husks, corn husks, and corn cobs are examples of solid biomass produced from agricultural processes. This waste can be used as fuel in the combustion process to generate heat or electricity. In addition, there are also types of wood chips, sawdust, wood fibers, and small pieces of wood are other examples of solid biomass that is often used in industry as fuel or raw materials. In addition, Plant Fibers: Plant fibers such as straw, bamboo, or coconut fiber can also be used as solid biomass for a variety of applications, including the manufacture of building materials and combustion as fuel.

Co-firing coal-fired power plants is a term that refers to the use of biomass fuels along with conventional fuels, such as coal, in the combustion operations of Steam Power Plants. This process aims to reduce dependence on fossil fuels, reduce greenhouse gas emissions, and improve sustainability and energy efficiency.

In coal-fired power plants, biomass fuels such as rice husks, sawdust, straw, agricultural waste, or other biomass are mixed and burned together with conventional fuels in the coal-fired power plant's incinerator. Co-firing technology has become quite popular technology in an effort to reduce the environmental impact of power plants and achieve energy sustainability goals.

Rice husk waste is a considerable waste generated in the agricultural industry, which is 20% of rice. The rice husk produced by Indonesia can reach around 15 million tons per year [6]. Rice husk is a waste product of rice milling that is separate from the grain of rice, where the rice husk has a hard layer, namely kariopsis which consists of two leaf shapes, namely crown husk and petal husk. Rice husks can be found in rural areas, as a by-product of rice milling which has a lot of potential. Rice husks are not flammable outdoors unless air is blown into them. Rice husks are highly resistant to moisture and decay by fungi, which makes it difficult for rice husks to decompose naturally. If the rice husk goes through the combustion process, it will produce rice husk ash. The density of rice husk tends to be low, namely 70-110 kg/m³, at the time of shaking, it is 145 kg/m³ or 180 kg/m³ in the form of briquettes or pellets. Therefore, rice husks require a large volume for storage and transportation, so long-distance transportation becomes uneconomical. The ash content obtained when rice husks are burned is 17-26%, much higher than other fuels (wood 0.2-2%, coal 12.2%). The caloric value of rice husks is high with an average of 3410 kcal/kg and can be used as one of the sources of renewable energy.

There are several studies that discuss the use of rice husks as co-firing. Ríos-Badrá et al., The research is focused on the properties and physical and chemical characteristics of husk pellets as well as efforts to improve the quality of husk pellets by using a mixture of husk with other materials such as the addition of husk charcoal, used cooking oil and others [7].

The energetic potential of the briquette with a standard mesh size of babassu coconut and rice. Mulch layer bagasse of the babassu mesocarp combined with rice straw powder was used. Both particle size and ash content were evaluated. The results show that there is a viability in the use of the briquette of 50% babassu and 50% rice straw. From this work can be raised questions about how other waste can be availed, generating new research on biomass [8].

Susanto, et.al., In his study, the results of the comparison of mixing sub-bituminous coal biopellets and rice husks in portable boilers with variations of 100%:0%, 95%:5%, 85%:15% showed that the highest data was found in sub-bituminous coal fuel. without a mixture of rice husk biopellets that produce a load of 17 watts with voltage parameters of 265 V, current of 1.17 A, temperature of 456HAIC and turbine rotation of 718 RPM. Sub-bituminous coal fuel with the mixing of rice husk biopellets with a ratio of 95%:5% with a load of 17 watts produces a voltage of 257 V, a current of 0.83 A, where the temperature produced in the ratio is 452HAIC and the turbine rotation is 664 RPM [9].

Meanwhile, Muniroh, et.al., discussed the Business Model Canvas and Business Strategy of BUMD Rice Husk PT Gerbang NTB Emas as a Co-Firing Material for Renewable Electrical Energy. The results of the study provide an overview of the nine elementts of BMC and the formulation of the rice husk business strategy of PT Gerbang NTB Emas. In addition, there is a need for a strategy to overcome the Business Model Canvas on customer segment, channel and customer relationship elements to support the success of PT Gerbang NTB Emas' rice husk business [10].

In this study, the physical properties and optimization of briquettes made from rice husk and sawdust were carried out. The bio-waste material of homogeneous particle sizes of 0.5mm and two binders of 90:10 percentage compositions which were sun-dried, prepared and compressed for the production of the briquettes. Energy valuation of the briquettes was carried out using a bomb Calorimeter. he results indicated that composite briquettes of mahogany sawdust and rice husk produced using starch gave the maximum energy value of 5.69kcal/g whereas those made with clay gave the least calorific value of 3.35kcal/g. This indicates that briquette from a composite of Mahogany sawdust/rice husk is, as a result, more appropriate for starting and retaining the fire for cooking and other domestic heating [11].

III. METHODOLOGY

In this article, the methods used in this study are qualitative and quantitative descriptive based on literature review. The literature review information on the analysis of the use of rice husk waste used comes from journals/scientific articles/books related to the same topic. The discussion of the study began by examining the origin of rice husk waste and its waste characteristics. Then continued with a study on the processing and utilization of rice husk waste based on the data that had been obtained in the previous study. Collection of data on boiler equipment operating parameters and other supporting data (data for NPHR and SFC calculations). Data collection was carried out before Co-firing and during the Co-firing process. Finally, the data that has been obtained from the joint literature review will be drawn into a conclusion of the analysis of the utilization of rice husk waste so that an informative data unit is obtained.

To determine the effect of biomass co-firing on production costs, a comparison of SFC and production costs was carried out when using coal and during co-firing. For the calculation of Specific Fuel Consumption (kg/kWh) is obtained using the equation.

$$SFC = \frac{\text{Total Fuel}}{\text{Awakened kWh}} \quad (1)$$

NPHR (Net Plant Heat Rate) is an indicator of the reliability and efficiency of a thermal plant, especially coal-fired power plants. The smaller the NPHR value, the more efficient the coal-fired power plant is declared and vice versa. For the calculation of NPHR can use the equation:

$$NPHR = \frac{\text{Fuel Consumption} \times \text{Calorie Value}}{\text{Gen.output} - \text{Aux. power}} \quad (2)$$

To calculate the use of production costs so that they can be used as a comparative parameter for non-cofiring and co-firing, the equation.

$$\text{Production cost} = \text{Fuel Prices} \times \text{SFC} \quad (3)$$

Next, the NPHR and SFC calculations are carried out using the data that has been taken, after the calculation is completed, the data comparison process is carried out. Data comparison is to compare data before Co-firing and after Co-firing which results in the form of deviation values in each co-firing process. The data that is compared are the operating parameters of boiler equipment during commissioning with the current (full coal and co-firing) The results of SFC and NPHR calculations are compared between full coal and Co-firing.

IV. RESULTS AND DISCUSSIONS

There is one steam power plant in the Lontar area, which uses rice husk biomass as a method of mixing coal fuel or so-called co-firing in order to carry out the government's program in 2021 as new and renewable energy (NRE) which is targeted in 2024 of 18 GW by using a biomass portion of 2%-5% biomass mixed with coal. This co-firing is carried out in the context of Renewable energy efforts which is a general plan for national electricity with co-firing is expected to help the target that is the purpose of this plan. The co-firing is carried out using a direct co-firing scheme where biomass is mixed directly with coal before the combustion process or put into a coal feeder. The implementation of Co-firing is carried out from the data obtained is that for a period of 4 months from January-April 2024, PLTU Lontar has 3 Power Generation Units where from the data obtained every month the implementation of co-firing is carried out alternately, this happens because of the availability of rice husk biomass fuel and the rules for the implementation of co-firing are carried out only up to 5% of the total biomass used.

Specific Fuel Consumption (SFC)

The SFC calculation is carried out to be able to find out the SFC value of how many Kg is needed to produce one kWh in a coal-fired power plant. Specific Fuel Consumption non-cofiring and cofiring for the period of January-April 2024, the dataused is one month of production where the total of 4 months of production is made per hour with the total data divided by 30 days and 24 hours, from the data obtained to be assumed the use of co-firing for 1 full month, for that the SFC calculation uses equation (1) which uses hourly parameters, Here's the equation (1).

Table 1: Data non-cofiring.

Moon	Total Fuel (Kg)	Awakened (kWh)
January	171,709.82	272,926.45
February	168,303.32	259,742.30
March	162,693.43	269,789.23
April	161,649.71	253,684.62

Source: Authors, (2024).

Using the data in the table, the Specific Fuel Consumption (SFC) value can be calculated using equation 1. Results of the calculation of Specific Fuel Consumption in January.

$$SFC = \frac{171{,}709.82}{272{,}926.45} = 0.629\ Kg/kWh$$

In the same way, the results of the calculation of the non-cofiring full consumption species for the period of January – April were obtained as shown in Table 1.

Table 2: Non-cofiring SFC calculation results.

Bulan	SFC (Kg/kWh)
January	0.629
February	0.647
March	0.603
April	0.637

Source: Authors, (2024).

The non-co-firing SFC value in Table 2 is influenced by the quality of coal fuel and the load conditions that must be accommodated by the coal-fired power plant, the lower the SFC value, the more efficient the fuel used. It can be seen that the SFC value from January to April has fluctuated although not significantly at only 0.6 kg/kWh, but this value has a great influence on the calculation of the production cost of a coal-fired power plant.

Furthermore, when using the husks in the data in Table 3 used Specific Fuel Consumption co-firing

Table 3: Data co-firing.

Moon	Total Fuel (Kg)	Awakened (kWh)
January	171,709.82	285,260.53
February	168,303.32	263,059.08
March	162,693.43	284,690.17
April	161,649.71	258,941.45

Source: Authors, (2024).

Using the data in Table 3, the value of Specific Fuel Consumption (SFC) co-firing can be calculated using equation 1. Co-firing coal with a percentage of 2%, 4%, and 5% biomass mixed with the direct co-firing method, the direct co-firing method is by mixing coal directly with rice husk biomass that has been sorted before the fuel enters the coal feeder. The results of the calculation of the Specific Fuel Consumption co-firing in January.

$$SFC = \frac{171{,}709.82}{285{,}260.53} = 0.601\ Kg/kWh$$

By using the same method, the results of the calculation of the Species full consumtion co-firing period for the period of January – April were obtained as shown in Table 4.

Table 4: SFC co-firing calculation results

Moon	SFC (Kg/kWh)
January	0.601
February	0.630
March	0.571
April	0.624

Source: Authors, (2024).

The data obtained by using 4% co-firing in January was 0.601 Kg/kWh, 5% co-firing in February was 0.639 Kg/kWh, 5% in March was 0.571 Kg/kWh, and 2% co-firing in April was 0.624 Kg/kWh can be compared with non-cofiring data, the less fuel used (Kg) is used to produce per kWh.

Net Plant Heat Rate (NPHR)

Net Plant Heat Rate is an indicator of the reliability and efficiency of a thermal plant, especially in coal-fired power plants. The result of the NPHR value is in the form of kcal/kWh assuming the use of co-firing for 1 month where how many calories are needed to produce one kWh, the smaller the NPHR value, the more efficient the coal-fired power plant is stated to be more efficient and vice versa (Table 5).

Tabel 5: Net Plant Heat Rate data with full coal.

Bulan	Bahan bakar (Kg)	Nilai Kalori (kcal)	Gen. output (MW)	Aux. Power (MW)
January	171,709.82	4594.00	267.47	13.33
February	168,303.32	4680.41	282.89	13.15
March	162,693.43	4665.53	288.62	13.50
April	161,649.71	4543.22	292.19	13.37

Source: Authors, (2024).

The calculation of NPHR looks at the burning hours with the parameters of coal consumption (Kg), the value of calories produced during combustion time (kcal/kg), generator output and aux power or self-use. The calculation uses equation 2. NPHR in January 2024.

$$NPHR = \frac{171709.82 \times 4590.00}{267.47 - 13.33} = 3{,}101.2 \text{ kcal/kWh}$$

With the same calculation, the NPHR value presented in table 6 is obtained.

Table 6: results of non-cofiring NPHR calculation.

Moon	NPHR kcal/kWh
January	3101.23
February	2945.33
March	2758.98
April	2633,99

Source: Authors, (2024).

The results of the NPHR calculation with fuel parameters (Kg), calorie value (kcal), generator output (MW) and self-use or aux power (MW) produce a kcal/kWh value in Table 6 shows that in January it is 3101.23 kcal/kWh which means that 3101.23 kcal is needed to produce 1 kWh, the MW calculation is changed to kW and subtracted by self-use, in February the NPHR value is obtained of 2945.33 kcal/kWh by using fuel lower than In January, in March 2024 the NPHR value was 2758.98 kcal/kWh with the use of fuel lower than in February, and in April it was produced from the calculation of the NPHR value of 2633.99 kcal/kWh which means that the NPHR value decreases every month, this value is also influenced by the fuel used and the amount of fuel recorded.

Meanwhile, the NPHR value with co-firing is obtained from the data presented in Table 7.

Table 7: net plant heat rate data with co-firing

Moon	Bahan bakar (Kg)	Nilai Kalori (kcal)	Gen. output (MW)	Aux. Power (MW)
January	171,709.82	4213.98	267.47	13.33
February	168,303.32	4212.55	282.89	13.15
March	162,693.43	4132.23	288.62	13.50
April	161,649.71	4126.43	292.19	13.37

Source: Authors, (2024).

The data obtained is data that is recapped for 1 month for fuel consumption into /30 days and divided by 24 hours with the data obtained. The calculation of NPHR at the percentage of 1-5% mixing biomass with coal is calculated using the following equation 2:

NPHR in January 2024

$$NPHR = \frac{171{,}709.82 \times 4213.98}{267.47 - 13.33} = 2847.17 \text{ kcal/kWh}$$

The value obtained from the calculation will be compared with non-co-firing data, with the statement that the smaller the NPHR value, the more efficient a coal-fired power plant will be to produce 1 kWh. The following results of the NPHR calculation are shown in Table 8.

Table 8: Net Plant Heat Rate co-firing results

Moon	NPHR (kcal/kWh)
January	2847.17
February	2628.28
March	2443.61
April	2392.34

Source: Authors, (2024).

Obtained from table 8 of 2847.17kcal/kWh for the month of January so per 1 kWh requires 2847.17 kcal needed to generate per kWh, in February the NPHR data of 2628.61 kcal/kWh this value is smaller than the value in January, in March the value obtained is also lower than the previous month with a value of 2443.61 kcal/kWh as well as in April where the NPHR value is lower than the month previously it was 2392.24, the NPHR value obtained from the calculation will be compared with non-cofiring data, with the statement that the smaller the NPHR value, the more efficient a coal-fired power plant will be to produce 1 kWh.

Cofiring and Non Co-firing

After obtaining the results of the SFC and NPHR calculations by comparing co-firing and non-co-firing assuming the use of 1 month of co-firing, this comparison was made in order to see the difference between SFC co-firing and non-co-firing as well as NPHR co-firing and non-co-firing, seeing how the comparison of the two parameters is shown in Table 9 and Table 10.

Table 9: *SFC* Co-firing and Non Co-firing.

Nilai SFC	January (Kg/kWh)	February (Kg/kWh)	March (Kg/kWh)	April (Kg/kWh)
Non Co-firing	0.629	0.647	0.603	0.637
Co-firing	0.601	0.639	0.571	0.0624

Source: Authors, (2024).

The results of the value in Table 9 can be said that SFC Co-firing is lower than the value of non-co-firing SFC, which means that the value of SFC Co-firing is better because it only requires a low value to produce 1 kWh.

Table 10: *NPHR* Co-firing and Non Co-firing.

Nilai NPHR	January (kcal/kWh)	February (kcal/kWh)	March (kcal/kWh)	April (kcal/kWh)
Non Co-firing	3101.23	2945.33	2758.98	2633.99
Co-firing	2847.17	2628.28	2443.61	2392.34

Source: Authors, (2024).

The results of the NPHR comparison in Table10, that with a lower co-firing value which means more efficient because it only requires a small amount of kcal needed to produce 1 kWh where the lower the NPHR value the better, the co-firing value and the non-co-firing value are compared with each other to see how much kcal it takes to produce 1 kWh.

Production Cost

The total cost incurred for coal and the calculation of production costs using equation 3. With the production cost of a sample of the January production as follows:

Production cost = Rp.1052,33 ×0,629 = 661.91 Rp/kWh

For the production cost with non-co-firing SFC requires Rp.661.91 per kWh, the results of the calculation are shown in Table 11 as follows.

Table 11: Coal Production Costs.

Moon	SFC (Kg/kWh)	Coal Fuel Prices (Rp)	Production Cost (Rp/kWh)
January	0.629	1052.33	661.91
February	0.6470	1052.33	680,85
March	0.603	1052.33	634,55
April	0.637	1052.33	670,33

Source: Authors, (2024).

Meanwhile, the cost of co-firing production which is the total cost incurred for coal and the calculation of production costs uses equation 3. The calculation for January is as follows:

Production cost = Rp.570.58 ×0,601 = 342.91 Rp/kWh

For the production cost with non-co-firing SFC requires Rp.342.91 per kWh, the results of the calculation are shown in table 12 as follows.

Table 12: Biomass Production Costs

Moon	SFC (Kg/kWh)	Coal Fuel Prices (Rp)	Production Cost (Rp/kWh)
January	0.601	570.58	342,91
February	0.639	570.58	364,60
March	0.571	570.58	325,80
April	0.624	570.58	356,04

Source: Authors, (2024).

Based on the results in Table 12, the calculation of SFC co-firing with a biomass price of Rp 570.58 per kg shows that the average cost required for producing 1 kWh is Rp 350.00. Without co-firing, the production cost in January amounted to Rp 135,948,091,753.98, while with co-firing, it was reduced to Rp 70,429,454,371.98. This indicates a cost reduction of nearly 50% when compared to using coal alone. In February, it is estimated that the monthly production cost was Rp 128,954,719,359.00, whereas the co-firing production cost was only Rp 69,056,166,084.00. Similarly, in March, the production cost without co-firing was Rp 130,068,104,586.00 compared to Rp 66,781,480,536.00 with co-firing. In April, the production cost without co-firing reached Rp 124,974,879,968.52, while the co-firing production cost was Rp 66,379,329,977.76. From these assumptions, it is concluded that using co-firing for one month can significantly reduce production costs.

V. CONCLUSIONS

Co-firing technology, which mixes coal with biomass such as rice husks, has the potential to reduce coal use in coal-fired power plants (PLTU) in Indonesia. In the Lontar area, which has a lot of rice husk waste, this co-firing design aims to support renewable energy and reduce dependence on coal.

The use of a mixture of 2-5% biomass showed an increase in PLTU efficiency, with significant fuel cost savings of IDR 9.24 billion in 4 months, and an average production cost of IDR 346.77/kWh. Therefore, from an economic and technical perspective, co-firing is worth continuing in the future.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Samsurizal, Revi Falka Azlinando and Arif Nur Afandi.
Investigation: Revi Falka Azlinando and Samsurizal.
Discussion of results: Samsurizal, Revi Falka Azlinando and Arif Nur Afandi.
Methodology: Samsurizal, Revi Falka Azlinando and Arif Nur Afandi.
Writing – Original Draft: Samsurizal, Revi Falka Azlinando and Arif Nur Afandi.
Writing – Review and Editing: Samsurizal, Revi Falka Azlinando and Arif Nur Afandi.
Supervision: Samsurizal and Arif Nur Afandi.
Approval of the final text: Samsurizal and Arif Nur Afandi.

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