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Techno-economic Analysis of Biomass Co-firing Application on Indonesia 660 MW Class Subcritical Coal-Fired Power Plant

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Abstract. Following the publication of the Ministerial of Energy and Mineral Resources of Indonesia Decree number 14.K/TL.04/MEM.L/2023 regarding the greenhouse gas (GHG) emission cap for coal-fired power plant (CFPP), PLN, the electricity company owned by Indonesia, is attempting the GHG reduction of its CFPPs at certain levels through several decarbonization programs, with biomass co-firing on its existing CFPP as the first step. The CFPP that becomes the object of this study is 660 MW class subcritical, Suralaya units 5-7, with a net capacity of 643.09 MW per unit. The biomass used is sawdust that was taken from local suppliers. The existing power plant has a carbon emission intensity of 1.03 Ton/MWh, higher than that of the carbon cap (0.911 Ton/MWh). Therefore, it should pay a carbon tax at a certain value. The biomass co-firing implementation can reduce its intensity depending on the ratio. The biomass implementation would probably require an upgrade investment. The other cost-effect factors are fuel cost and carbon tax. The degradation of CFPP performance can impact on fuel costs. Then, the biomass co-firing implementation can reduce or even prevent a power plant from paying the carbon tax. The best option regarding the financial calculation result is a 5% ratio. It potentially reduces the levelized cost of electricity (LCOE) by 0.36 IDR/kWh. However, a higher biomass ratio will probably increase the power plant LCOE. Implementing a higher biomass co-firing ratio does not always result in better financial aspects. The decision to implement shall consider the valid regulation comprehensively.

Keywords: Biomass, Co-firing, Carbon Cap, Carbon Tax, Renewable Energy.

INTRODUCTION

The Indonesian government released several laws, including a maximum greenhouse gas (GHG) cap for coal-fired power plants (Natalia et al., 2022), to speed up the proportion of renewable energy in the country's electricity system. Early in 2023, Indonesia's Minister of Energy and Mineral Resources (MEMR) issued Decree Number 14.K/TL.04/MEM.L (Ministerial of Energy and Mineral Resources Decree, n.d.). Additionally, it denotes implementing the carbon tax legislation indicated in *Undang-undang No. 7*

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of 2021 (Constitution No. 7 of 2021) (President of Indonesia, 2021). Some CFPP classifications are included in the ministerial decree's regulation, as shown in Table 1.

Table 1. CFPP categories in MEMR Decree 14.K/TL.04/MEM.L/2023

CFPP types	Installed Capacity (x)	Cap (ton CO_2e/MWh)
Non-Mine Mouth & Mine Mouth	25 MW ≤ x ≤ 100 MW	1.297
Non-Mine Mouth	100 MW ≤ x ≤ 400 MW	1.011
Non-Mine Mouth	x ≥ 400 MW	0.911
Mine Mouth	x ≥ 100 MW	1.089

Note: The value is valid for 2023 and 2024. The following regulation will be released later.

Biomass is a non-fossil fuel because it originates from organic materials such as plants and agricultural waste, which absorb carbon dioxide during their growth. Unlike fossil fuels, which release carbon that has been sequestered for millions of years, biomass fuels contribute to a shorter carbon cycle. This makes them a more sustainable and environmentally friendly option, as the carbon released during combustion is offset by the carbon absorbed during biomass growth, helping mitigate climate change impacts (B20, 2022; Osman et al., 2021). Co-firing biomass with coal in power plants can significantly reduce carbon emissions. This approach involves partially replacing coal with biomass, which is carbon neutral. By doing so, the overall carbon footprint of power generation is reduced, making coal-fired power plants more environmentally friendly. This method helps lower emissions and utilizes existing power plant infrastructure, making it a practical and cost-effective solution without adding additional Capital Expenditure (CAPEX) to the power plant (Sahu et al., 2014).

Biomass co-firing can be done by adding biomass fuel into the coal mix or inject directly into the furnace (Reza et al., 2021). The implementation was done in various locations to catch each power regulator's decarbonization target (Adhiguna, 2021). Technically, biomass co-firing faces the equipment capability barrier when the biomass specification is quite extreme, such as the moisture, calorific value, metal composition, etc. (Xu et al., 2020). The implementation could shift the operation of existing equipment, such as the fuel feeder, fan, and boiler body (Reza et al., 2021). On the other hand, biomass co-firing might reduce non-greenhouse gas (non-GHG) emissions such as NOx, SOx, and Particulate, which means the cost of emission control will be minimized. (Reza et al., 2023a)

The rule states that if the intensity of GHG emissions exceeds the cap, every CFPP in its category must pay a carbon tax. However, it should be considered if the CFPP should pay the tax or make efforts to reduce the GHG intensity to a specific value given the carbon tax price of IDR 30 per kg CO_2. Based on experience, biomass co-firing is one of the simplest methods to perform decarbonization. As a fuel that is thought to be carbon-neutral, biomass is projected to lower the GHG of the existing CFPP so that, in some cases, it can avoid CFPP paying a carbon tax. However, biomass co-firing implementation needs an additional investment cost to modify, upgrade, or add new equipment to the existing CFPP (Peters et al., 2020). Therefore, techno-economic analysis should be done to analyze the cost-benefit that resulted from biomass co-firing implementation. The estimation would combine the various parameters, including the CFPP design, lifetime, location, operational, and regulation aspects. This could result in reduce or increase the levelized cost of electricity (LCOE) of the existing CFPP.

METHODOLOGY

The study is conducted through a three-step process, executed sequentially: commencing with data collection, followed by technical simulation, and concluding with financial calculation. Each phase is meticulously designed to ensure the comprehensive and accurate analysis required for robust results.

Data Collection

As stated in the introduction, the foundation of this study is the Suralaya 5-7 Coal-Fired Power Plant (CFPP). The specifications of this plant were gathered from various sources within PLN and supplemented with secondary information. A summary of the general data about Suralaya 5-7 is presented in Table 2.

Suralaya 5-7 is designed to burn low-rank and low-sulfur coal. Recently, its net heat rate is about 2,495 kCal/kWh. The data from Table 2 will be used in the technical simulation to model the existing power plant. Then, for financial calculation purposes, the data package used is shown in Table 3.

Table 2. CFPP fuel characteristics

Parameter	Value	Unit
Net Output Power	643.09	MW
Net Heat Rate	2,495.00	kCal/kWh
Coal Composition		
Total Moisture	33.39	%As received
Carbon	45.80	%As received
Hydrogen	2.86	%As received
Oxygen	12.33	%As received
Nitrogen	0.55	%As received
Sulfur	0.07	%As received
Ash	5.00	%As received
Coal Calorific Value (by Dulong Equation) (Drbal et al., 1996)	4157.00	kCal/kg (HHV)

Technical Simulation

The study would begin with technical simulation to model Suralaya 5-7 CFPP using Steam Pro 30.0 software. This is the foundation of the existing operation condition using 100% coal based on the newest actual information. After that, enter the co-firing parameter into the model using

Table 3. Financial input data

Parameter	Value	Unit	Note
Exchange Rate	4,945	IDR/USD	Exchange rate
Suralaya 5-7 lifetime	40	Years	PLN Regulations no. 0299.P/DIR/2016
Suralaya 5-7 Commercial Operation Date	1994	Year	
Carbon Intensity Cap	0.911	Ton CO_2/MWh	MEMR Decree no 14.K/TL.04/MEM.L/2023
Carbon Tax	30.00	IDR/kg CO_2	Constitution No. 7 year 2021
Inflation	4.14	%	Indonesia Inflation data in last ten years
Suralaya 5-7 Coal Price	54.87	USD/Ton	On site, based on estimation (Ministerial of Energy and Mineral Resources, 2022)
Fuel Annual Escalation	1.00	%	Palu-3 CFPP Feasibility Study
O&M Annual Escalation	1.00	%	Palu-3 CFPP Feasibility Study
Capacity Factor	85.00	%	Assumption

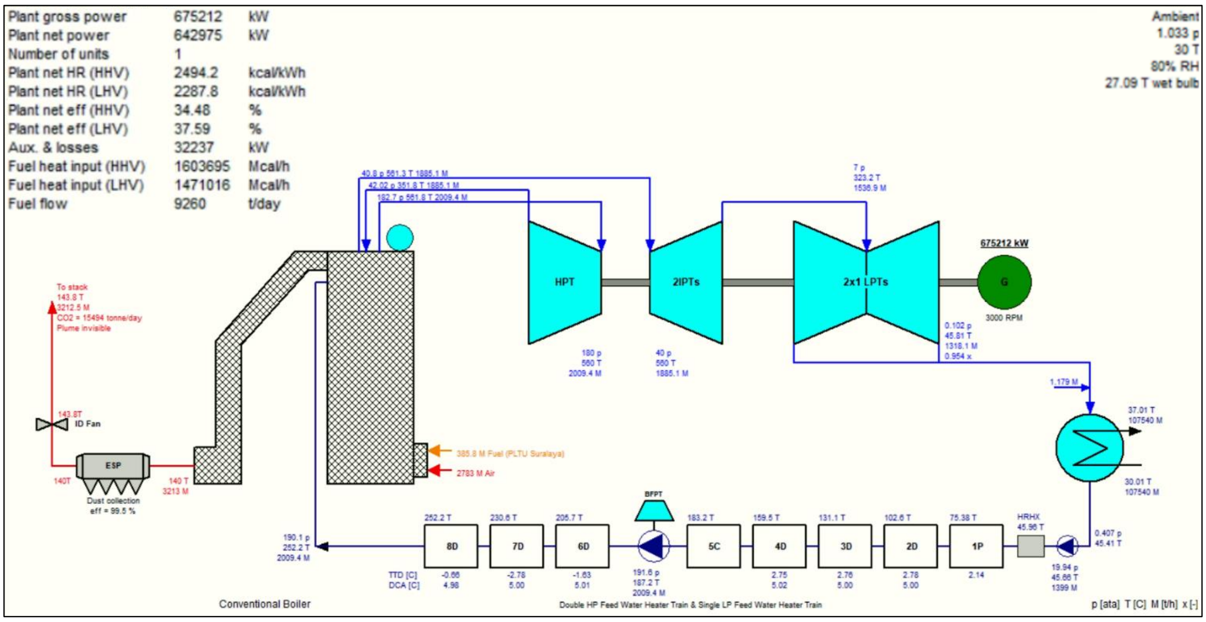

Fig.1: Existing CFPP model result

Steam Master 30.0 software. With the same CFPP design, the combustion parameter would shift depending on the variable entered. That is also called as off-design simulation. This aims to estimate the effect of biomass co-firing on the power plant performance and equipment modification needs.

The study is based on a technical model of the Suralaya CFPP units 5-7, created using Thermoflow Steam Pro software version 30. This model serves as the foundational model for the study, using 100% coal as the fuel. The characteristics of the coal used in the base model are detailed in Figure 1.

Furthermore, the co-firing parameters, which include biomass characteristics constituting 5% of the total fuel, are inputted into the base model. The same method is repeated for different 15% and 30% fuel ratios. This procedure, known as off-design simulation, aims to evaluate the differences between various parameters on the performance of the base model power plant and the equipment loads, identifying any necessary modifications.

Financial Calculation

This step entails calculating the impact of co-firing based on technical simulations to estimate the cost differential from the existing Levelized Cost of Energy (LCOE) (Septian and Muhammad Reza, 2024). The calculation incorporates relevant Indonesian and PLN regulations regarding the implementation of CFPP and biomass co-firing. The investment cost for equipment modification will be estimated using Steam Pro 30.0 software, which not only aids in technical simulations but also provides equipment pricing estimates.

RESULTS AND DISCUSSION

Power Plant Model

The CFPP model was simulated based on actual technical operation data. The model simulation result can be seen in Figure 1.

The steam turbine configuration is subcritical single-reheat with a main steam pressure of 180 bar. On the boiler side, the design was based on site operation data, including excess air, flue gas temperature, boiler efficiency, and site conditions. While the model may not entirely represent the actual operational aspects due to its numerical simulation approach, which does not capture the detailed actual processes, it provides a general representation of the energy conversion design of the existing power plant.

Off-design Simulation

The next step is to estimate the power plant's performance when applying biomass co-firing. As explained in the introduction, the implementation will use sawdust as the common type of biomass used in power plants (Variny et al., 2021). The sawdust specification was taken by a local sawdust analysis that can be seen in Table 4.

Table 4. Sawdust specification

Parameter	Value	Unit
Sawdust Composition		
Total Moisture	41.47	%As received
Carbon	28.06	%As received
Hydrogen	3.17	%As received
Oxygen	24.80	%As received
Nitrogen	0.15	%As received
Sulfur	0.07	%As received
Ash	2.01	%As received
Sawdust Calorific Value (by Dulong Equation)	2292.80	kCal/kg (HHV)

The sawdust used is untreated and sourced from a local supplier, resulting in high moisture content and a relatively low calorific value. Co-firing with sawdust can worsen performance in several ways. The lower calorific value and higher moisture content of sawdust can lead to inconsistent burning, reducing combustion efficiency and potentially causing incomplete combustion, resulting in higher emissions of unburned hydrocarbons.

The model created with Steam Pro software was subsequently transferred to Steam Master to conduct off-design simulations. In this scenario, biomass is assumed to be mixed with coal in the coal stockpile, and this blend is fed into the boiler together via the coal feeding system (Leuschke and Babcock, 2018; Reza et al., 2024). Key parameters to be monitored include the net plant heat rate, coal feeding flow rate, and carbon emissions. The outcomes of these simulations are detailed in Table 5.

Table 5. Off-design simulation result

Parameter	Unit	0%	5%	15%	30%
Net Plant Output	MW	643.09			
Net Plant Heat Rate	kCal/kWh	2494.20	2501.30	2525.80	2570.70
CO_2 emission intensity	Ton/MWh	1.034	0.960	0.873	0.740
Fuel Con-sumption	Ton/h	385.87	395.84	418.97	459.84

The simulation showed that maintaining the same net plant output decreases plant efficiency when implementing biomass co-firing. This decline in efficiency is primarily due to the more challenging specifications of biomass combustion. Biomass typically has higher moisture content, lower calorific value, and lower density than coal, leading to less effective boiler combustion. Despite these drawbacks, biomass co-firing can significantly reduce carbon emissions, supporting decarbonization efforts and potentially exempting power plants from carbon taxes. The impact of biomass co-firing on several operational parameters is illustrated in Figure 2.

Biomass co-firing implementation can reduce the carbon emission intensity of Suralaya 5-7 by 7.2% with a 5% co-firing ratio, 15.5% with a 15% co-firing ratio, and 18.4% with a 30% co-firing ratio. However, attention

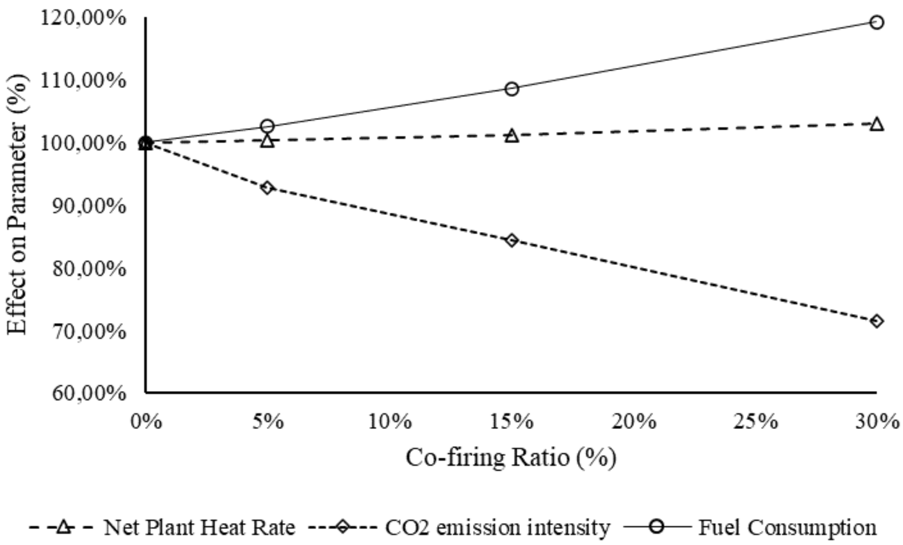

Fig. 2: Biomass co-firing effect on considered parameters

must be given to the coal-feeding system, as the fuel flow rate into the boiler will increase. This increase is necessary because the boiler requires more heat and a higher fuel flow rate to maintain the net plant output when co-firing with biomass.

There is a likelihood of upgrading the existing equipment, particularly the fuel feeding system, when implementing biomass co-firing. A boiler is designed to consume a specific fuel type, and any change in fuel specifications may necessitate modifications. Therefore, the investment required for these upgrades should be factored into the financial calculations to ensure a comprehensive analysis of the costs associated with biomass co-firing implementation.

Financial Calculation

As mentioned before, a modification that should be performed when applying biomass co-firing is a fuel-feeding system upgrade. Therefore, cost estimation for upgrading must be entered as a program CAPEX. The value was taken from cost estimator simulation using Thermoflow PEACE. The CAPEX is not taken from new equipment but the price gap between fuel feeding systems at a specific capacity for each case. The upgrading cost of the fuel feeding system is shown in Table 6.

Table 6. Upgrading cost

Co-firing Ratio (%)	Upgrading Cost (USD)
5%	957,000
15%	3,032,000
30%	6,624,000

Suralaya 5-7 was commercial on date (COD) in 1994 and built by OECD manufacturers. Its operational lifetime is 40 years, based on PLN Directors Regulations no. 0299.P/DIR/2016. That means the design operation will be ended in 2034. Assuming that the co-firing program will be actualized in 2024, there are 11 years left until the end of operation. The weighted average cost of capital (WACC) is 9.28% based on the actual PLN's work plan and company budget (Reza et al., 2023b).

The financial model is calculated based on the operational cost gap between the existing and co-firing conditions. Some pricing parameters that differentiate the operational cost between both. It can be seen in Table 7.

Each parameter has an effect on the electricity price. Investment and fuel costs increase the LCOE because it is an additional cost that should be spent by the power plant when implementing biomass co-firing. On the other hand, the carbon tax factor is included in the cost reduction side for LCOE. In the biomass co-firing implementation, the carbon emission intensity is technically decreased, which can reduce or even prevent a power plant from paying the carbon tax.

Based on the calculation, the trend of biomass co-firing influence on LCOE is shown in Figure 3.

The impact of biomass co-firing on the Levelized Cost of Energy (LCOE) exhibits a varied response depending on the co-firing ratio. At a 5% co-firing ratio, the LCOE can be reduced by 0.36 IDR/kWh. However, increasing the biomass ratio further tends to raise the LCOE. This increase occurs because higher biomass ratios beyond a certain point do not provide additional benefits for carbon tax avoidance. The power plant can avoid carbon taxes by reducing its emission intensity from 1.03 Ton/MWh to 0.911 Ton/MWh. Achieving this for Suralaya 5-7 requires implementing approximately a 7.6% biomass co-firing ratio. Beyond this level, further increases in the biomass ratio do not offer any financial advantage.

Table 7. Cost gap factor

Parameters	Explanation
Investment	The needs to upgrade the existing equipment make an additional cost for electricity price. In this study, the upgrade shall be done is in the fuel feeding system.
Fuel Cost	The change in the power plant performance makes the fuel cost slightly higher. Even though the release of the newest biomass price regulation by PLN said that biomass price can same as existing coal (with calorific value proportionate), the worse performance will escalate fuel cost (Hariana et al., 2023)
Carbon Tax	The existing power plant's carbon emission was indicated to break the carbon cap limit which means they should pay the carbon tax. Biomass co-firing implementation will technically reduce carbon emission intensity which can reduce or even avoid a power plant to pay the carbon tax

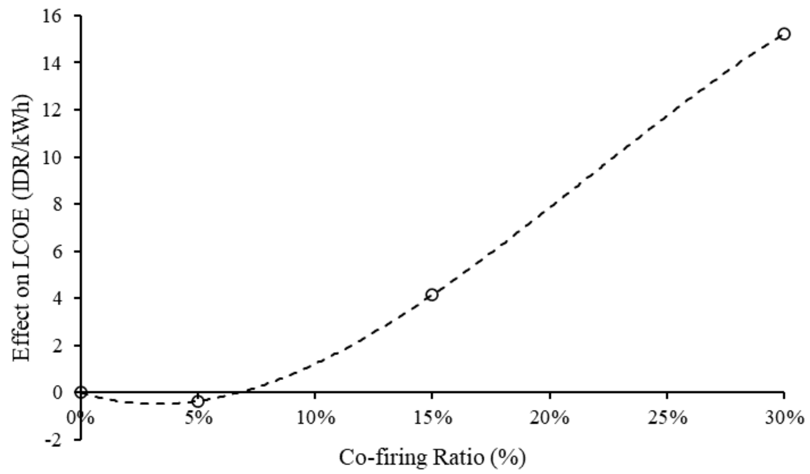

Fig.3: Biomass co-firing effect on LCOE

Table 8. Cost gap factor

Parameter	Unit	5%	15%	30%
Net Present Value (NPV)	million IDR	25,239.01	- 198,918.41	- 760,915.64
Internal Rate of Return (IRR)	%	16.08%	-	-
Payback Period	Years	4	No	No
Effect on LCOE	IDR/kWh	-0.36	4.15	15.24

Other financial parameters, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period, were also calculated in this study (Hedianto and Daryanto, 2019). The results of these calculations are presented in Table 8.

The only variable that leads to a good financial result is the 5% biomass co-firing ratio. First, the NPV shows that the power plant will have a positive net cash flow by the end of its operation. Second, the IRR is higher than the WACC, indicating that the return on capital is better than planned. Third, the payback period is not too close to the end of the power plant's operation.

CONCLUSIONS

Implementing a higher biomass co-firing ratio may not always yield favorable financial results. Decisions on this matter must thoroughly evaluate the regulatory landscape. In Indonesia, recent regulations, including those from PLN, have introduced frameworks addressing carbon taxes and biomass co-firing applications. These developments underscore the need for flexible strategies that adapt to updates or changes in policies.

In this study, the optimal path for Suralaya 5-7 is a biomass co-firing ratio of approximately 5%. While increasing the ratio beyond 7.6% could amplify environmental benefits, it poses the risk of significant financial losses for the power plant. Striking the right balance is crucial to ensure sustainability without compromising economic stability.

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