JURNAL PENDIDIKAN TEKNOLOGI KEJURUAN

Vol. 5, No. 3 August 2022 P-ISSN: 2621-3273
E-ISSN: 2621-1548

Engineering and economic analysis of sawdust biomass processing as a co-firing fuel in coal-fired power plant boiler pulverized coal type

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https://doi.org/10.24036/jptk.v5i3.27723

Abstract—One type of alternative fuel that has the potential to be developed and can contribute significantly to the NRE mix is biomass. The significance of the energy mix is obtained from the use of the co-firing system at the Coal-Fired Power Plant (CFPP) by mixing coal fuel with biomass such as sawdust. Sawdust biomass as cofiring material for CFPP is very efficient because it has energy content and availability that is easy to manage. The aim of this research is to make technical and economic analysis of sawdust biomass as solid fuel for pulverized coal CFPP Co-firing type boiler. The research stages are mapping the potential of sawdust biomass to determine the availability of potential biomass around the location of the co-firing, analyze the technical side and specifications contained in sawdust biomass raw materials to determine the suitability or feasibility of pulverized coal type CFPP specifications, and analyze the economic feasibility of developing sawdust biomass processing technology to determine the cost of production of sawdust biomass so that later it will not have a technical and financial impact. The results of the economic analysis show that the sawdust biomass production business is feasible with NPV parameters > IDR 5,252,097,371, IRR=11.1% and payback period=7.7 years. Provided that if the PLTU Rembang buys biomass at a price of IDR. 862,730/Ton. Sensitivity analysis is used to determine the steps to optimize the adjustment of the ability to purchase biomass from CFPP Rembang where the reference limit for the highest reference price for biomass is IDR 782,006. Efforts that can be made to adjust the ability to purchase biomass from the CFPP Rembang include increasing the yield by 20% or reducing the price of wood by 20%.

Keyword: *NRE, Biomass, Co-firing, Feasibility, Optimize.*

I. INTRODUCTION

The use of coal as the main energy is increasing day by day, especially as fuel in power plants, cement industry, and other industries that have an impact on the environment. Indonesia's commitment was again demonstrated by ratifying the Paris Agreement in New York on April 22, 2016. One of Indonesia's commitments in the energy sector, Indonesia will start implementing a policy of using mixed energy with a minimum target of 23% coming from renewable energy by 2025. Indonesia has around 74.5 Giga Watt (GW) of installed generating capacity and generate 309 Terawatt hours (TWh) of electricity by 2021, according to the Indonesian Ministry of Energy and Mineral Resources and PLN data.

In 2021, around 87.84% of energy use will come from fossil fuel sources (37.62% coal, 16.82% gas, and 33.40% oil), 12.16% will come from new and renewable energy (4.41% Biofuel, 3.09% Hydropower, 0.05%). % Solar, 0.07% wind, 0.01% Biogas, 2.52% other NRE, not including biomass) [2]. From these data, it is stated that most of the power plants in Indonesia are still dominated by coal-fired thermal power plants, both those that use coal with high calorific value and low calorific value. In the long term, the availability of coal will dwindle, so there is a need for concrete steps to reduce the use of these fuels and replace them with alternative fuels that are environmentally friendly.

A possible approach to be able to increase the use of new renewable energy mix of biomass energy in a short time is to mix biomass with coal and burn it in power plants designed for coal fuel, a process also known as co-firing. Co-firing technology is also a strategy that has the potential to extend the life of steam power generating units that are near obsolescence and underutilized so that operations can be extended again with co-firing. Considering that there is a lot of biomass potential in Indonesia, the reason why co-firing technology is an alternative way of environmentally friendly fuel is because biomass can also be used as a counterweight and minimize dependence on fossil fuels.

Co-firing is an alternative way of environmentally friendly fuel by increasing the production of green electricity. In Indonesia, through a state-owned enterprise that has a coal-fired power plant of 18 GigaWatts (GW) with a co-firing implementation plan, the achievement of the NRE mix can focus on increasing the production capacity of the green energy co-firing target of 12,710 GWh thereby reducing CO2 emissions by 11 million tons of CO2 until 2025. To achieve the production target, a proportion of coal substitution with biomass is needed which is carried out in stages with a mixture of waste and waste/forest products up to 70% of the total coal demand depending on the specifications of the type of boiler at the Coal-Fired Power Plant (CFPP). Coal-Fired Power Plant boiler specifications consist of three types, including PC (Pulverized Coal) and CFB (Circulating Fluidized Bed) types each require mixing up to 10% to 30% of the biomass and Stoker types each use up to 70% of the biomass.

The planned biomass co-firing plan will require the creation of a large-scale biomass industry, to provide a stable supply of co-firing fuel at each Coal-Fired Power Plant site requiring 9 to 10 million tons of biomass per year [3]. Abundant sources of biomass raw materials from agricultural products can be produced through various processes to become biomass products. The results from the biomass processing process can be used directly to generate heat and electrical energy. In addition, it can also be used as gas, liquid, and solid fuel [4]. Another problem of the biomass supply chain is that the share of biomass export commodities has increased significantly with a significant increase in biomass such as palm kernel shells and wood pellets because overseas has a very attractive biomass market, while domestically, biomass is needed for power plants that substitutes coal energy with biomass energy which has a price limit of up to the equivalent of coal price, so that biomass for domestic supply is limited to the use of biomass sourced from the utilization of waste without processing.

While from a technical point of view, co-firing at a ratio of up to 50% (based on energy) is technically feasible, but currently co-firing operations are more often carried out below the 5% ratio on an ongoing basis due to limited supply [5]. Implementing a higher co-firing ratio will require additional capital investment costs which are inherently site-specific. The amount of capital investment required depends on the type of biomass, the ratio of biomass, the planned co-firing method, and the performance conditions of the particular power plant.

Additional investment which includes modification of fuel handling and storage systems is potentially required given the different nature of biomass, although modification of power generation to certain boiler types may not be necessary if the co-firing ratio is limited to a low level. Different properties of biomass such as particle size, storage requirements, chemical properties and calorific content all need to be considered when evaluating co-firing implementations. As an evaluation material, it is also necessary to analyze the sustainability of the supply of biomass raw materials with their continuous availability for the security of supply of biomass as co-firing fuel at the Coal-Fired Power Plant, it is necessary to conduct research on technical analysis and the economics of processing biomass as co-firing fuel for Coal-Fired Power Plant.

II. METHODS

This study is a technical and economic analysis in the context of developing a supply chain of biomass supply with a review of the potential of raw materials, technical requirements, economic feasibility of biomass products sold to PT PLN (Persero). This analysis is carried out specifically for certain locations around the CFPP Rembang. For the purposes of analyzing fuel requirements using sawdust biomass samples. The data on the potential for energy plantations uses data from the Perum Perhutani Forest Management Unit (KPH) as an example for the purposes of calculating the economics of sawdust biomass. In general, this analysis methodology is carried out in the form of:

- Conduct primary and secondary data collection
- Conduct literature studies by reviewing, reviewing and analyzing secondary data
- Conducting interviews and discussions
- Make direct observations
- Conducting co-firing testing to get an overview of feasibility
- Perform calculations and analysis of raw material factors, technical and economic.

The methodology for determining the location of the biomass plant is to calculate the biomass potential around the Coal-Fired Power Plant Rembang using a radius of 50 km and the furthest 100 km from the center point of the Coal-Fired Power Plant. So that the distance from the feedstock to the Coal-Fired Power

Plant is not far enough and can make the price of biomass cheaper. This will ensure the continuity of the supply of feedstock needed by the Coal-Fired Power Plant.

Mapping the potential of biomass by looking for sources to fulfill the supply of sustainable biomass supply up to a radius of 100 km from the power plant. So that the distance from the feedstock to the Coal-Fired Power Plant is not far enough and can make the price of biomass cheaper. This will ensure the continuity of the supply of feedstock needed by the Coal-Fired Power Plant. For the results of energy plantation forest products that can be used as fuel for Coal-Fired Power Plant boilers. In this study, a geospatial analysis of the potential distribution of energy plantation forest belonging to Perum Perhutani has been carried out. Perum Perhutani as one of the forest companies that manages state forest areas in Java Island has prepared for planting energy plantation forests. This analysis is carried out by using the process of overlaying some data from the RBI (Rupa Bumi Indonesia) map obtained through the Indonesian Bakosurtanal Agency, where currently the data can be downloaded for free through the Geoportal Indonesia website. As shown in figure 1. there are several Forest Management Units (KPH) Perum Perhutani that can support the supply of biomass to CFPP Rembang, namely KPH Mantingan, KPH Blora, KPH Pati and KPH Cepu.

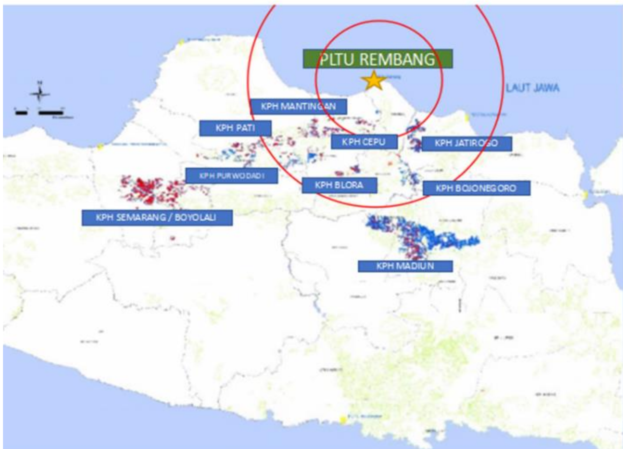

Figure 1. Potential HTE belonging to the Central Java Cluster Perhutani

From the results of the overlay process, there is an effective planting area (area that is really planted, biomass crops), and potential estimates logs planted by 88 tons/ha of wet wood. From the results of mapping the potential of biomass, there is a total area of 8,141 hectares of energy plantation forest with a total area of potency planted wood logs of 716,408 Tons/Year. The potential of Energy Plantation Forests that can be used for CFPP fuel is shown in Table 1.

Table 1. Perum Perhutani KPH HTE Potential

KPH	Area (Ha)	Potential Yield (Ton/Years)
Mantingan	2,478	218,064
Blora	2,225	195,800
Cepu	1,298	114,224
Pati	2,140	188,320
Total	**8,141**	**716,408**

Selection of the right tree as a source of biomass for energy needs to be carried out to get maximum results in producing energy. The calorific value is an important indicator in determining the type of wood for energy. The calorific value of a fuel shows the amount of energy released by a fuel in complete combustion. According to Montes et al. (2011) the calorific value depends on the chemical composition, moisture content, density, and ash content contained in the wood. Haygreen and Bowyer in the book Soettjipto (2007) explain that the calorific value also varies between species due to the varying proportions of carbon, oxygen, and hydrogen present. Determination of species in the development of industrial plantations for energy, among others:

- Identification of local/local species that have good and even growth cover a wide area
- Identification of non-local species that are suitable for growth with selected site location
- The species has high growth (m^3/year)
- The species has a high calorific value

Several types of plants have the potential to be developed as potential energy plants, namely acacia auri, mangium, kaliandra, gamal, eucalyptus pelita, lamtoro and turi.

Table 2. Potential energy plants to be developed in Indonesia

No	Plant	Caloric Value (kcal/kg)*	Cycle plant (years)	Crop Yield (m3/ha)
1	Acacia Auri	4,500	5	120-160
2	Mangium	4,700- 5,110	5	163
3	Kaliandra	4,200 – 4.800	4	35-65
4	Gamal	3,600 – 4,200	3	25-30
5	E. Pelita	4,200	5	150-240
6	Lamtoro	4,400	5	20-60
7	Turi	4,000	5	20-25

Based on the United States Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program (2004) to calculate biomass requirements based on calorific value can be formulated as follows:

$$H_b = M_b \times \frac{HV_b}{\frac{M_b}{100} \times HV_b + \left(1 - \frac{M_b}{100}\right) \times HV_c} \quad (1)$$

Descriptions:

H_b = % Biomass, heat basis
M_b = % Biomass, mass basis
HV_b = Heating Value of Biomass (kcal/kg)
HV_c = Heating Value of Coal (kcal/kg)

To calculate the biomass needed in a day, it can be formulated as follows:

$$DBF_{Max} = DCF_{Max} \times \frac{HV_c}{HV_b} \times \frac{H_b}{100} \quad (2)$$

Descriptions:

DBF_{Max} = daily biomass feed rate at maximum rated load (ton/day)
DCF_{Max} = daily coal feed rate at maximum rated load (ton/day)

Biomass co-firing consists of burning biomass along with fossil fuels in coal-and gas–fi red power plants (ETSAP E01, E02). This brief deals with biomass co-firing in coal power plants, which is by far more widespread and extensively proven than biomass co-firing in gas-fired plants. Co-firing can play an important role in increasing the share of biomass and renewable sources in the global energy mix and reducing greenhouse gas (GHG) emissions (ETSAP 05; IEA 2010). Only a relatively low investment is needed to adapt or retrofit existing conventional coal power plants for biomass co-fi ring, or to build new power plants specifically designed for co-firing. Co-firing Technologies – Co-firing includes three major technologies:

- Direct co-firing is the simplest, cheapest, and most common option. Biomass can either be milled jointly with the coal (i.e., typically less than 5% in terms of energy content) or pre-milled and then fed separately into the same boiler. Common or separate burners can be used, with the second option enabling more flexibility with regard to biomass type and quantity.
- Indirect co-firing is a less common process in which a gasifier converts the solid biomass into a fuel gas that is then burned with coal in the same boiler. Though more expensive because of the additional technical equipment (i.e. the gasifi er), this option allows for a greater variety and higher percentages of biomass to be used. Gas cleaning and fi ltering is needed to remove gas impurities before burning, and the ashes of the two fuels remain separate.
- Parallel co-firing requires a separate biomass boiler that supplies steam to the same steam cycle. This method allows for high biomass percentages and is frequently used in pulp and paper industrial facilities to make use of by-products from paper production, such as bark and waste wood.

II. RESULTS

The plan to fulfill biomass for CFPP Rembang uses two types of plants that have been planted by Perum Perhutani. The types of plants that have been planted are kaliandra and gamal plants. It was found that wood chip kaliandra had a moisture content of 21.1% with a calorific value of 3,642 kcal/kg. While wood chip gamal has a moisture content of 26.8% with a calorific value of 3,471 kcal/kg. If the biomass is in the form sawdust, then kaliandra has a moisture content of 8.48% and a calorific value of 4,218 kcal/kg. While the average gamal in the form of sawdust has a moisture content of 8.25% and a calorific value of 4,185 kcal/kg. It can be concluded that the kaliandra and gamal biomass in the form of sawdust are feasible to be used as a substitute for Coal-Fired Power Plant fuel because the coal used generally has a heating value of around 4,200 kcal/kg.

Table 3. Biomass test results

Plant Biomass	Treatment	Total Moisture	Fixed Carbon	Sulfur (adb) Total	Gross Calorific Value (ar)
		% ar	% adb	kcal/kg	kcal/kg
Kaliandra	Chip	21.13	16.60	0.11	3,642
	Sawdust	8.48	17.72	0.11	4,218
Gamal	Chip	26.83	17.98	0.12	3,471
	Sawdust	8.25	18.37	0.12	4,185

Biomass plants that are ready to be harvested are then cut down and processed so that they can be put into the boiler used. The process of processing plant biomass into sawdust is not too complicated, but not simple either. It's not too complicated, because actually the manufacturing process requires a simple machine, namely a woodchipper machine and a hammer mill. Not simple, because even though the use of the engine is simple, it is necessary to pay attention to the moisture content, particle size, and calorific value to match the fuel specifications in the boiler design. For Pulverized Coal (PC) boilers, higher specifications require smaller particle sizes, low moisture content and high heating values. Circulating Fluidized Bed (CFB) and Stoker boilers require lower supply specifications.

The natural dried drying process is a drying process from solar radiation energy, while the dryer is a drying process using a heating device with a certain fuel. The yield with natural dried, starting with the processing of wood logs into sawdust ready to enter the boiler, is 28.57% or from 88 tons/ha of wood logs it will be 25.15 tons/ha sawdust.

Table 4. Potential Sawdust for CFPP Rembang

KPH	Potential Yield (Ton/Year)	Potential Sawdust (Ton/Years)	Potential Sawdust (Ton/Day)
Mantingan	218,064	62,301	244
Blora	195,800	55,940	219
Cepu	114,224	32,634	128
Pati	188,320	53,803	211
Total	**716,408**	**204,647**	**801**

CFPP Rembang has a generating capacity of 2x315 MW, with coal needs of ± 6,718 tons per day with CF 70% so coal need is 1,716,449 Ton/year. The type of boiler owned by CFPP Rembang, itself is a pulverized coal boiler. The coal used in the CFPP Rembang power plant is 4,200 kcal/kg. If calculated from the biomass potential, the percentage of cofiring for CFPP Rembang can be implemented at 12% of biomass.

CFPP Rembang has conducted co-firing trials using 5% sawdust biomass. Biomass in the form of sawdust is obtained from several wood craftsmen and collectors around the CFPP Rembang.

Table 5. Sawdust specification data used during the trial

Parameter Proximate	Unit (Ar)	Value
Total Moisture	%	59.28
Ash Content	%	1.82
Volatile Matter	%	21.81
Fixed carbon	%	17.1
Total sulfur	%	0.03
Gross calorific value	kcal/kg	1,867
HGI	-	<32

The results of these trials indicate that the operating parameters of the CFPP (load, total coal biomass flow, main steam temperature, and main team flow) during the trial run were relatively normal. FEGT is also still within safe limits and the average tends to decrease from 1,125 °C to 1,079 °C. The emission test results also showed a decrease in the level of SO2 and NOx in the exhaust gas emissions from combustion in the boiler. From the results of this trial, it can be concluded that the 5% co-firing carried out at the CFPP Rembang is still safe and within normal limits.

Table 6. Daily biomass sawdust feed rate at maximum rated load

Biomass Plant	Treatment	Gross CV (ar)	Mass basis (Mb)	Heat basis (Hb)	DBF Max
		kcal/kg	%	%	Ton/day
Kaliandra	Chip	3,642	5	4.36	338.15
	Sawdust	4,218	5	5.02	335.83
Gamal	Chip	3,471	5	4.17	338.84
	Sawdust	4,185	5	4.98	335.96

The design of a biomass supplying plant for CFPP needs is considered by considering the needs of the CFPP and also the supply capability of the HTE managed from the supplier. With biomass (gamal and kaliandra) which has a calorific value of 4,100 kcal/kg for capacity 327 ton/day of sawdust are needed to supply the CFPP Rembang. The requirements of the biomass plant are shown in the table below:

Table 7. Investment capital biomass sawdust plant

Investment capital		Biomass Plant		
		Unit	Specification	Total (IDR)
1	Mobile Chipper	17	Cap.5 TPH. Power 30 kW	1,224,000,000
2	Hammer Mill	5	Cap. 5 TPH. Power 172 kW	2,004,450,000
3	Wheel Loader	1	Bomac BWL-22RZ	450,000,000
4	Steer Loader	1	Bomac TX-3505	400,000,000
5	Belt Conveyor			370,012,500
6	Roller Conveyor			35,000,000
7	Construction Storage		Area: 9,595 m^2	21,589,006,903
8	Manufacture Construction		Area: 724 m^2	2,172,300,000
9	Drying Construction		Area: 21,062 m^2	4,212,489,152
10	Weighbridge			300,000,000
11	Other Equipment			3,120,224,605
	Total Investment capital			35,877,483,160

The estimated economic price is sought by determining the price above the HPP which can make the investment generate IRR = Cost of Capital + 2% so that NPV > 0. The cost of capital used is the reference capital cost used by PT PLN, which is 9.1%. While 2% is the expected profit premium from the project to be executed. Another assumption used regarding the cost of capital is the use of bank loans of 70% and 30% of own capital with the assumption of interest costs of 10%. The required capital cost is IDR 35,877,483,160 for the processing of sawdust biomass, the need for 5% of the CFPP Rembang.

Table 8. Economic cost of biomass sawdust

No	Economic cost	Value
1	Net Present Value	IDR 5,252,097,371
2	IRR	11.1 %
3	Payback Period	7.7 Year

In determining the economic price of biomass, it is necessary to first calculate the cost of production (HPP) of biomass which consists of the price of wood, processing costs and transportation costs. Timber prices consist of stand costs such as seed costs, plant costs, maintenance costs, non-technical costs, management costs as well as PSDH and harvesting costs. Processing costs consist of labor costs, energy/electricity costs, transportation costs for KPH-biomass processing center and equipment depreciation costs. Transportation costs are the costs required for the delivery of HTE biomass products to CFPP Rembang which are influenced by distance and cost/km. The cost components to be estimated are the price of wood, processing costs, transportation costs to form the cost of production (HPP) of biomass.

Table 9. Cost of production biomass sawdust

No.	Price Components	Price (IDR/Ton)
1	Price of wood	432,506
2	Processing costs	272,188
3	Transportation costs	52,913
A	Total (1+2+3) HPP Biomass	757,607
B	Investment Cost	105,123
(A+B)	Economic price of biomass	862,730

Sensitivity analysis is carried out to identify factors that have a major influence on changes in economic prices. Sensitivity analysis is used to determine the steps to optimize the adjustment of the ability to purchase biomass from CFPP Rembang where the reference limit for the highest reference price for biomass is IDR 782,006. The highest benchmark price is based on the rules in force at the CFPP Rembang where for the purchase of biomass, the coal price refers to the equivalent calorific value.

There are six factors that were analyzed for sensitivity in determining the economic price of biomass at CFPP Rembang, namely wood price, harvest productivity, yield, wood productivity, supply quantity, distance and CAPEX with a sensitivity level tested of +/- 20%.

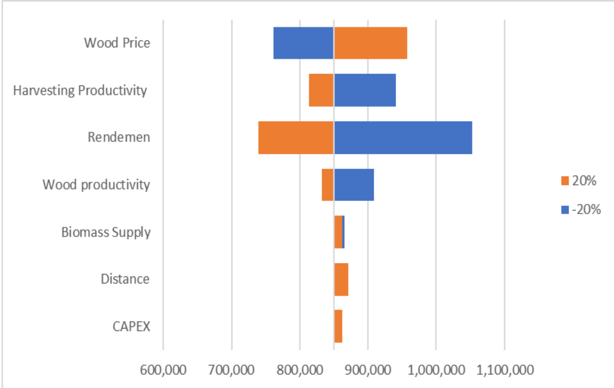

Figure 2. Biomass Economic Price Sensitivity Analysis

The yield of the biomass processing process is the factor that has the highest influence on the economic price. Followed by the price of wood, harvester productivity, wood productivity, supply of biomass, distance. and CAPEX. An increase in yield by 20% will change the price from IDR 862,730 per ton to IDR 739,009 while a decrease in yield by 20% will increase the price to IDR 1,052,234. An increase in the price of wood by 20% will increase the economic price to IDR 957,685 and a decrease in the price of wood by 20% will reduce the economic price to IDR 761,713. Efforts that can be made to adjust the ability to purchase biomass from the CFPP Rembang include increasing the yield or lowering the price of wood.

IV. DISCUSSION

Biomass supply chain optimization is carried out with various objectives which are often defined as objective functions. Obtaining the smallest total cost is one of the most used objective functions. In addition, there is also optimization to get the maximum profit. Table 9 shows the mapping of research objectives used in several studies related to biomass supply chain management. In particular, the optimization objective carried out in this study will also take the minimal cost function which is most widely used in previous studies.

Table 9. Research objective of biomass supply chain management (adapted from Imansuri et al. (2019))

Study	Min. Total Cost	Max Total Profit	Max NPV	Multiple Objective
Eksioglu, dkk. (2009)	■			
Vera, dkk. (2010)			■	
Čuček, dkk (2012)				■
Kim, dkk.(2011)		■		
Marin, dkk.(2012)			■	
Zhang dan Hu (2013)	■			
Sharma, dkk.(2013)	■			
Bernardi,dkk.(2013)				■
Paulo, dkk.(2014)	■			
Grigoroudis,dkk.(2014)	■			
Roni,dkk.(2014)	■			
Mohseni,dkk.(2014)	■			
Jonrinaldi, dkk.(2017)	■			
Imansuri, dkk.(2019)	■			

The performance of this assessment is the minimum total cost incurred by each Coal-Fired Power Plant unit for the distribution scheme offered. The total cost used in this system consists of the cost of purchasing biomass raw materials and transportation costs to send biomass from the industry to the Coal-Fired Power Plant. The lower the total cost of the Coal-Fired Power Plant, the more effective the distribution scheme offered. Meanwhile, the economic analysis will include a comparison of the analysis of NPV (Net Present Value), IRR (Internal Rate of Return), and PBP (Payback Period). results of study are discussed about what, how, why and the discussion is strengthened by the results of previous research.

V. CONCLUSION

Implementation of co-firing requires site-specific fuel costs at each location. The amount of capital investment required depends on the type of biomass, the biomass ratio of the planned co-firing method, and the specific CFPP conditions. CFPP Rembang has a generating capacity of 2x315 MW in the type of Pulverized Coal boiler with a coal requirement of ± 6,718 Tons/day with a CF of 70%, so the coal required is 1,716,449 Tons/year. The regulation of biomass fulfillment for CFPP Rembang is based on a 5% quota, which is 327 tons/day equivalent to 85,821 tons/year from the potential for biomass from energy plantations of 801 tons/day equivalent to 204,647 tons/year. The required capital cost is IDR 35,877,483,160 for sawdust biomass processing for 5% co-firing of CFPP Rembang.

The economic price of biomass becomes feasible with NPV > IDR 5,252,097,371, IRR = 11.1% and Payback Period = 7.7 Years provided that if CFPP Rembang buys biomass at a price of IDR 862,730/Ton. Sensitivity analysis is used to determine the steps to optimize the adjustment of the ability to purchase biomass from CFPP Rembang where the reference limit for the highest reference price for biomass is IDR 782,006. Efforts that can be made to adjust the ability to purchase biomass from the CFPP Rembang include increasing the yield by 20% or reducing the price of wood by 20%.

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