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Research article

Assessing the Potential of Biomass Power Generation for Renewable Energy Transition in South Papua Province, Indonesia

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Abstract: This study aims to explore the potential for biomass-based power plant to accelerate the development of renewable energy to replace the role of fossil energy in Merauke district, South Papua Province. The method used in this study is, first, to collect data and analyze the load on the grid system and the portion of the energy mix as well as the availability of woody biomass from forest areas by making a simulation of the development of a 2 x 12 MW Biomass Power Plant. Second, by conducting experiments to obtain woodchip conversion, as the fuel of the Biomass Power Plant, from the wood log and conversion from Biomass Power Plant capacity to the required biomass plantation area. The results provide an overview of the big potency for developing biomass-based power generation by utilizing biomass from the local industrial plantation forest and show the energy transition towards energy independence. This study can be useful for policy makers and opportunities for entrepreneurs or suppliers of wood biomass, as well. For the future, in terms of fuel efficiency, it is necessary to reduce the plantation area as a source of biomass for power plants by reducing the moisture content of the woodchip to increase the calorific value and utilizing the forest residue. Furthermore, the comparison cost study between fossil power plant and biomass power plant, as well as the strategy for preserving the plantation to ensure a steady biomass supply is conducted.

Keywords: renewable energy integration, woodchip, forest, regional development, Papua, biomass, de-dieselization

1. Introduction

The 26th Conference of the Parties (COP26), which has already been held in Glasgow at the end of 2021, has a very ambitious target compared to the Paris Agreement (COP21) [1]. The increase in global temperature needs to be limited to 1.5°C through the world's carbon emission reduction scheme by 2030 and the achievement of Net Zero Emissions (NZE) by 2050 [2], [3], [4], [5]. One way to reduce carbon emissions is by replacing energy sources from fossils with Renewable Energy (RE) [6], [7], [8]. We are presently in the middle of a long-term energy transition in which RE sources are gradually replacing fossil fuels [9], [10].

Based on The National Energy Policy of Indonesia, the renewable energy target in the energy mix is 23% in 2025 and will increase to 31% in 2050 [11]. In 2021, the Ministry of Energy and Mineral Resources (MEMR) of Indonesia mentioned that the potency of renewable energy (consisting of ocean energy, geothermal, bioenergy, wind, hydro, and solar) in Indonesia is 442.1 GW, where 56.9 GW will be coming from bioenergy. The realization up to 2021 for bioenergy is 1,903.5 MW (biomass plantation and waste). There are still many renewable energy sources in Indonesia that have not been fully utilized, including biomass [12], [13]. Currently, various biomass-based power generation technologies are not only used for direct combustion in boilers, either in biomass power plants or co-firing at steam power plant, but are also used for gasification [14], [15]. Biomass is a very promising source of RE in the future [14], [16], is the most sustainable [17], [18], and can be used as a base load in a grid. However, previous variations in the proportion of energy produced by various sources might be classified as energy additions rather than transitions [19]. Whenever the transition is implemented, it is hoped that it will be a sustainable transition [20].

Researchers, decision-makers, and business executives in various countries have been interested in the topic of energy transition and energy independence for many years. Gielen et al. indicated that the key components of that transition are energy efficiency and renewable energy technologies, and their interactions are also crucial [21]. Qadir et al. reported that individual and corporate investors, as well as energy consumers, have been reluctant to make this transition due to a lack of public awareness of the advantages of RE and misconceptions about the related installation and operating costs [22]. According to Perez et al., there are two distinct clusters of countries based on their views on energy security: those that prioritize reliable supplies and view renewable energy as too unstable and expensive to replace fossil fuels, and those that prioritize renewable energy as an industrial opportunity and a way to reduce import dependence [23].

Khan et al. mentioned that the effect of energy transitions on economic growth is significant only in the long run, and economic sustainability influences economic growth in both the short run and the long run, the energy transition is negatively associated with host countries' economic growth, while economic sustainability, renewable energy consumption, non-renewable energy consumption, labor, and capital are positively related to that growth [24]. Guo et al. analyzed that in the last ten years, the use of wood chips and wood pellets for the production of electricity (biopower) has increased and will continue to rise [25]. To most effectively realize their potential for wood-based bioenergy, each nation, and even region, should create independent policy strategies for biomass generation, according to the research [26]. Gustavsson et al. mentioned that a greater reliance on bioenergy could smooth the transition to renewable energy sources from fossil fuels and make it easier to integrate intermittent sources of energy like wind and solar [27].

Cambero et al. reported that the long-term availability of biomass supply with the necessary quality at a competitive price, which relies on a cost-effective design of the forest biomass supply chain, is essential to the viability and feasibility of producing valuable products from forest biomass [28]. Miranda et al. stated that forest biomass (eucalyptus woodchip) has the potential to replace fossil fuels like natural gas, fuel oil, gasoline, and LPG in the thermal energy market for industrial use [29]. A large number of direct and indirect employment would be created for the industry if forest biomass could replace half of the consumption of petroleum derivatives. Ribeiro et al. mentioned that according to the findings, woodchip samples with lower moisture content and better heating value demonstrated lower woodchip consumption, lower generation costs, lower unit variable costs, and a smaller area of eucalyptus plantations were required to supply the woodchip consumption [30].

Based on the above observations, several studies have described biomass as a substitute for fossil energy. However, no one has made a detailed study of the energy transition towards energy independence by utilizing biomass as the main energy source. The challenge is how to design local biomass sources that have high availability and sustainability. Based on these considerations, the aim of this study is to show how biomass from local industrial plantation forests can be a reliable source of biomass for renewable energy in order to avoid fossil fuel imports, and the results of this study can be useful for policymakers and opportunities for entrepreneurs or suppliers of woody biomass.

2. Methods

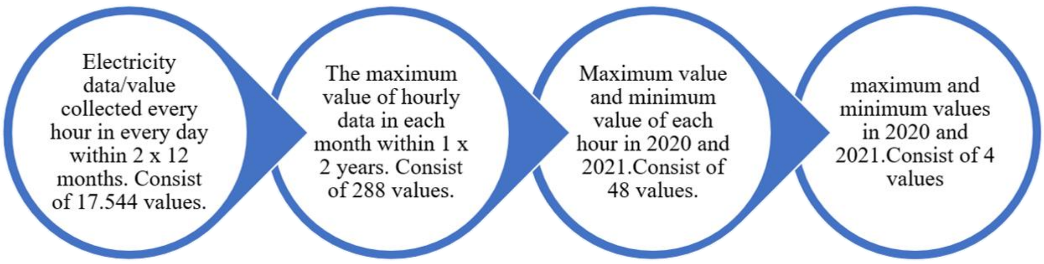
The study was elaborated based on the conditions in the Merauke District, South Papua Province, Indonesia. Figure 1 shows the map of the research location. To find out the potency of the development of biomass-based power generation in this area in energy transition, the study was carried out in three stages: analyzing load profile at the grid system, estimating woodchip consumption for biomass power plant, and calculating wood log volume and woody biomass area.

Figure 1. Map of Merauke District in South Papua Province.

2.1. Load Profile at the Grid System and Energy Mix

By collecting data from relevant agencies and analyzing them, we can obtain the load profile at the grid system in 2020 and 2021. The data collected are combined as one as shown in Figure 2. Through this method, we determine how much the maximum and minimum loads occur.

Figure 2. Flowchart to determine the maximum and minimum electricity load in 2020 and 2021.



The next step is to do research during the same period of the existing 3.5 MW biomass power plant and other kinds of renewable energy in the same area to find out the energy mix. To get the total electricity consumed, E_{tot}, equation (1) is used.

$$E_{tot} = \sum (E_{fo} + E_{re}) \tag{1}$$

where E_{fo} is electricity from fossil (kWh), E_{re} is electricity from renewable energy (kWh). The energy mix, E_m (%) can be calculated by using equation (2).

$$E_m = \frac{\sum E_{re}}{E_{tot}} \tag{2}$$

2.2. Woodchip Consumption for Biomass Power Plant

The research was also conducted in the existing biomass power plant to obtain the woodchip consumption. This woodchip consumption will be used for the 2 x 12 MW power plant as the first scenario, and compared with the woodchip required for the 2 x 12 MW power plant calculated based on the direct method [31], [32], [33], [34], as the second scenario. Woodchip consumption, W_c (tons/MWh) can be calculated using equation (3).

$$W_c = \frac{\sum W_v}{E_{gen}} \tag{3}$$

where W_v is the volume of woodchip in a period t and E_{gen} is the electricity produced by the generator (kWh) and can be calculated using equation (4).

$$E_{gen} = P_{gen} \times h \tag{4}$$

where P_{gen} is the power produced by the generator of the biomass power plant (kW), and h is the duration of power production by the generator (hour). The woodchip required for the 2 x 12 MW biomass power plant can be calculated using equation (5).

$$W_{cph} = \frac{G_s \times (E_s - E_{bfw})}{B_{eff} \times LHV} \tag{5}$$

Where W_{cph} is woodchip consumption (T/h), G_s is generated steam (T/h), E_s is enthalpy of steam (GJ/T), E_{bfw} is enthalpy of boiler feed water (GJ/T), B_{eff} is boiler efficiency (%) and LHV is low heating value of fuel (GJ/T).

2.3. Calculation of Wood Log Volume and the Woody Biomass Area

To determine the volume of logs needed for the power plant, we researched to obtain the conversion of logs into wood chips from natural forests (NF) and plantation forests (PF). By knowing the volume of logs needed, we can estimate how much the area of NF and PF must be prepared to meet these requirements, as shown in Figure 3.

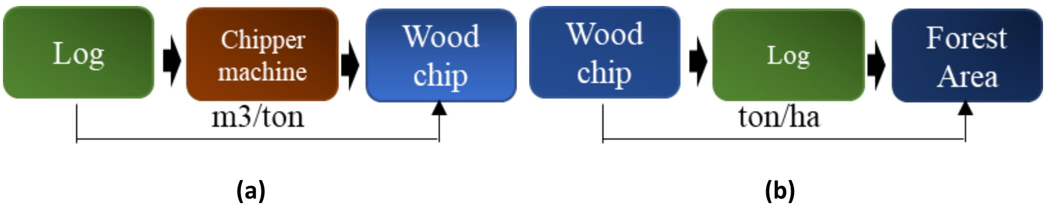


Figure 3. (a) Logs conversion to woodchip; **(b)** woodchip conversion to forest area.

In Figure 4, a silvicultural system is shown where harvesting is carried out as land preparation and then replanting and maintaining trees for a certain period before finally being harvested again [35], [36], [37]. The logs coming from the natural forest are used in the first 5 years. Then planting is carried out in stages in the area so that at the end of the 5th year it can be harvested again. Replanting is also carried out in the same area. This is how the planting and harvesting cycle is carried out.

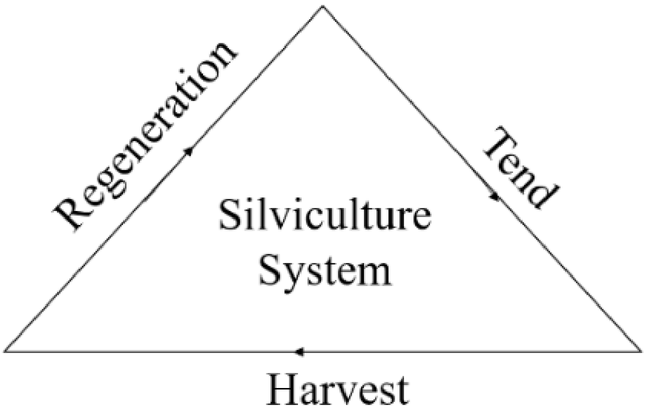


Figure 4. PF of 5 years cycle.

In this study, we also do the same calculation to determine the forest area for the existing biomass power plant. To calculate the number of logs needed, LV (m^3), equation (6) is used.

$$LV = \frac{W_{cph}}{C_{lw}} \tag{6}$$

where C_{lw} is a constant or conversion from log to woodchip (m^3/Tons). To find the area of forest required, A_f (ha), equation (7) is used.

$$A_f = \frac{LV}{D_f} \tag{7}$$

where D_f is the density of the forests (m^3/ha). In this case, the D_f is found from the existing PF company at the location, namely PT ABC with around 160,000 hectare of forest areas. The tree species available are Acacia Crassicarpa, Eucalyptus Pellita, and Melaleuca Leucadendron.

3. Results and Discussion

3.1. Load Profile

Figure 5 and Figure 6 show the load profile for 2020 and 2021, respectively. The maximum load consumption in 2020 is 24,300 kW at 7 pm, and the minimum load is 10,700 kW at 2 am. The maximum load consumption in 2021 is 22,733 kW at 7 pm, and the minimum load is 13,723 kW at 4 am.

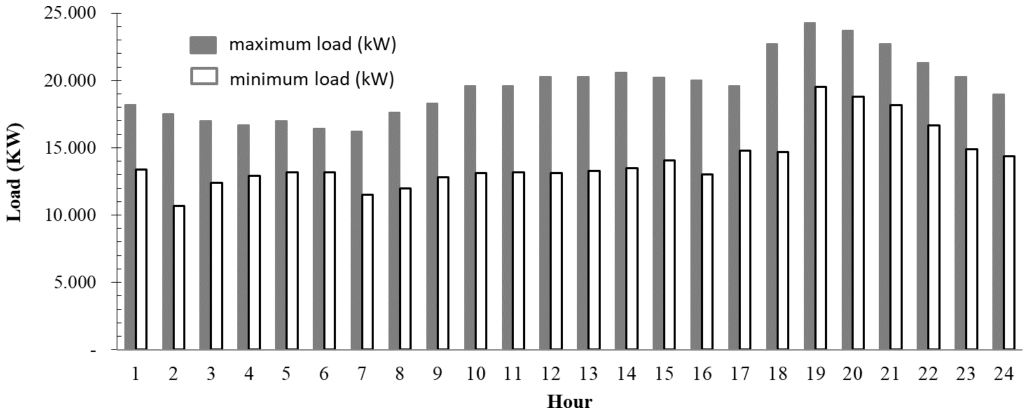


Figure 5. Load profile on the grid system in 2020.

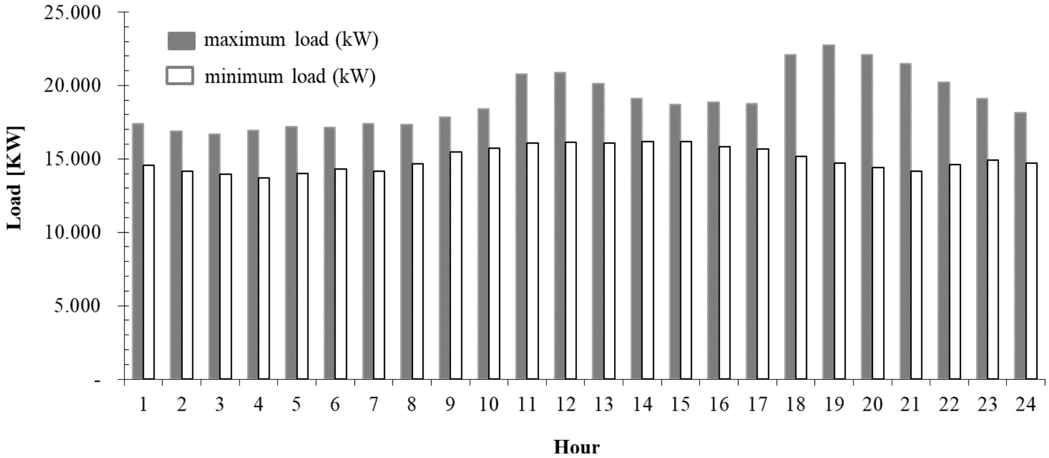


Figure 6. Load profile on the grid system in 2021.

3.2. Energy Mix

In this area, the energy used was initially derived from fossils/oil diesel, initially. Since 2020, an energy mix with renewable energy from biomass has been started. Applying equation (1) and (2) will get the result of the total electricity consumption in 2020 and 2021. Figure 7(a) shows the electricity consumption in 2020 is 151,498,170 kWh with 93.25% coming from diesel oil and 6.74% from biomass. Figure 7(b) shows the electricity consumption in 2021 is 150,623,022 kWh, with 86.35% coming from diesel oil and 13.65% from biomass.

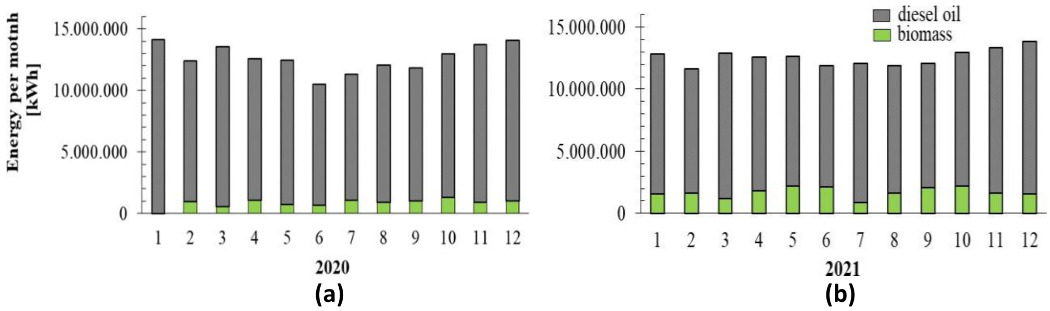


Figure 7. Energy mix in: **(a)** 2020; **(b)** 2021.

3.3. Simulation of 2x12 MW Biomass Power Plant Development

3.3.1. Woodchip Consumption

To find out how much woodchip consumption volume will be used, by researching existing biomass power plant, and by applying Equation (3) and Equation (4), as shown in Figure 8 the following results are obtained: Figure 8(a) shows the woodchip consumption in 2021 is 1.84 T/MWh and in Figure 8(b) shows the woodchip consumption in 2022 is 1.89 T/MWh. The average moisture content of this woodchip is 42.8%.

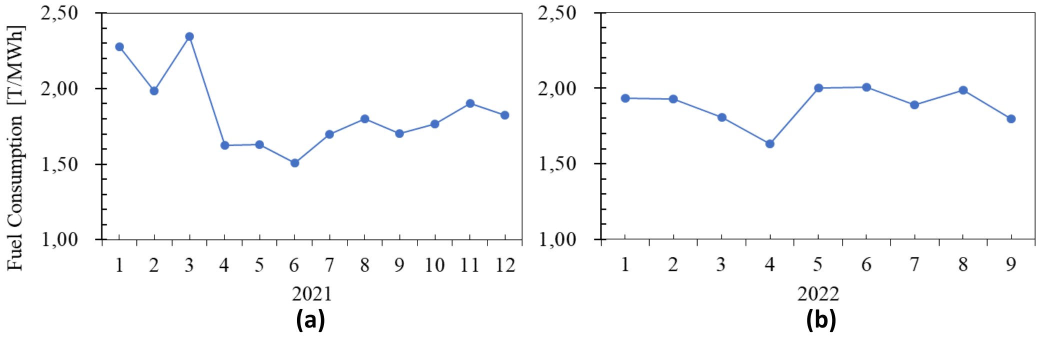


Figure 8. Woodchip consumption for the existing 3.5 MW Biomass Power Plant: **(a)** in 2020; **(b)** in 2021.

Figure 9 shows the relationship between the operation hours in a year and the woodchip consumption. As the first scenario, and by using 1.89 T/MWh, in Figure 9(a) we can find out that when the operating hours in a year are 4,380; 5,256; 6,132; 7,008; 7,880; and 8,760, the woodchip consumption needed per year (T/y) is 198,677; 238,148; 278,148; 317,883; 357,618; and 397,354, respectively.

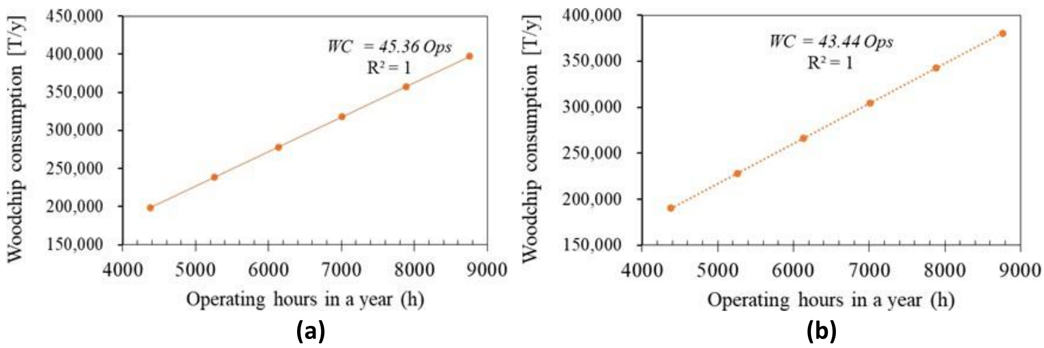


Figure 9. Woodchip consumption: **(a)** scenario 1; **(b)** scenario 2.

In the second scenario, G_s is 18.3 T/h, E_s is 779.41 kcal/kg, E_{bfw} is 120.93 kcal/kg, B_{eff} is 80%, *LHV* is 2,373 kcal/kg. By applying equation (5), the woodchip consumption of 2 x 12 MW biomass power plant is obtained at 43.53 T/h; while using equation (3) will get the woodchip consumption at 1.81 T/MWh. Figure 9(b) shows the relationship between the operating hours of the power plant and the required woodchip consumption within one year. The figure shows that when operating hours are 4,380; 5,256; 6,132; 7,008; 7,880; and 8,760, the woodchip consumption needed per year (T/y) is 190,267; 228,321; 266,374; 304,428; 342,481; and 350,534, respectively.

3.3.2. Forest Area Needed

From Table 1 and Table 2, the conversion values from log volume (m³) to the weight of woodchip (T) are determined for both the NF and PF. For the NF, the conversion value is 0.85 T/m³, while for the PF, it is 0.74 T/m³. The biomass density is 90 m³/ha for the NF and 150 m³/ha for the PF.

Table 1. Conversion log from NF to woodchip.

No.	Log			Woodchip		Log to Woodchip (kg/m³)
	Diameter (m)	Length (m)	Volume (m^3)	Volume (m^3)	Weight (kg)	
1	0.250	2.8	0.137	0.357	118.0	857.51
2	0.200	2.8	0.088	0.229	78.0	887.40
3	0.225	2.8	0.111	0.289	96.2	864.30
4	0.250	2.8	0.137	0.357	118.0	858.96
5	0.215	2.8	0.102	0.264	86.8	854.70
6	0.230	2.8	0.116	0.302	101.3	871.00
7	0.220	2.8	0.106	0.277	91.3	858.00
8	0.175	2.8	0.067	0.175	57.1	848.10
9	0.200	2.8	0.088	0.229	74.6	848.25
10	0.150	2.8	0.049	0.129	42.8	864.60
11	0.240	2.8	0.127	0.329	107.0	845.00
12	0.235	2.8	0.121	0.316	103.8	855.40
13	0.185	2.8	0.075	0.196	65.9	876.02
14	0.200	2.8	0.088	0.229	77.8	884.90
15	0.225	2.8	0.111	0.289	95.6	859.14
16	0.195	2.8	0.084	0.217	70.6	845.00
17	0.230	2.8	0.116	0.302	101.7	874.66
18	0.225	2.8	0.111	0.289	95.8	860.60
19	0.175	2.8	0.067	0.175	58.5	869.06
20	0.170	2.8	0.064	0.165	56.1	883.16
21	0.165	2.8	0.060	0.156	51.4	858.95
22	0.163	2.8	0.058	0.152	50.9	871.60
23	0.220	2.8	0.106	0.277	85.7	806.00
24	0.250	2.8	0.137	0.357	114.3	832.03

The forest area required for the 2 x 12 MW biomass power plant in the first scenario, and by applying equation (6) and (7), both for the natural forests and plantation forests, is shown in Table 3. When the power plant operates for 7,884 hours in a year, the total area of natural forest needed in the first 5 years is 23,156 ha, while the plantation forest area is 16,087 ha. When the power plant is fully operated for 365 days a year, the total area of natural forest needed in the first 5 years is 25,729 ha, while the plantation forest area is 17,875 ha.

For the second scenario, it is shown in Table 4 that when the power plant operates for 7,884 hours in a year, the total area of natural forest needed in the first 5 years is 22,176 ha, while the plantation forest area is 15,406 ha. When the power plant is fully operated for 365 days a year, the total area of natural forest needed in the first 5 years is 24,640 ha, while the plantation forest area is 17,118 ha. By using the same calculation, it is found that for the existing 3.5 MW biomass power plant, the area for natural and plantation forest needed is 3,593 ha and 2,496 ha, respectively.

Table 2. Conversion log from PF to woodchip.

No.	Log			Woodchip		Log to Woodchip (kg/m³)
	Diameter (m)	Length (m)	Volume (m³)	Volume (m³)	Weight (kg)	
1	0.150	2.8	0.049	0.129	36.65	741.00
2	0.170	2.8	0.064	0.166	47.93	754.56
3	0.175	2.8	0.067	0.176	50.26	746.70
4	0.200	2.8	0.088	0.229	64.69	735.80
5	0.150	2.8	0.049	0.128	36.51	738.15
6	0.155	2.8	0.053	0.138	39.42	746.46
7	0.200	2.8	0.088	0.229	65.15	741.00
8	0.135	2.8	0.040	0.104	29.30	731.43
9	0.100	2.8	0.022	0.057	16.34	743.40
10	0.120	2.8	0.032	0.082	23.45	741.00
11	0.120	2.8	0.032	0.082	23.55	744.05
12	0.150	2.8	0.049	0.129	36.65	741.00
13	0.100	2.8	0.022	0.057	16.29	741.00
14	0.125	2.8	0.034	0.088	25.30	736.67
15	0.150	2.8	0.049	0.129	36.71	742.30
16	0.200	2.8	0.088	0.229	65.17	741.24
17	0.200	2.8	0.088	0.229	65.15	741.00
18	0.140	2.8	0.043	0.112	31.92	741.00
19	0.100	2.8	0.022	0.057	16.35	743.86
20	0.130	2.8	0.037	0.097	27.90	751.09
21	0.125	2.8	0.034	0.089	25.45	741.00
22	0.150	2.8	0.049	0.129	36.75	743.10
23	0.100	2.8	0.022	0.056	16.32	742.49
24	0.100	2.8	0.022	0.057	16.29	741.00

Table 3. Forests area needed in the first scenario.

Operating hours (h)	Woodchip consumption (T/y)	Natural Forest			Plantation Forest		
		Logs (m³/y)	Area (ha/y)	Area (ha/5y)	Logs (m³/y)	Area (ha/y)	Area (ha/5y)
4,380	198,677	231,558	2,573	12,864	268,120	1,787	8,937
5,256	238,412	277,870	3,087	15,437	321,744	2,145	10,725
6,132	278,148	324,181	3,602	18,010	375,368	2,502	12,512
7,008	317,883	370,493	4,117	20,583	428,992	2,860	14,300
7,884	357,618	416,804	4,631	23,156	482,616	3,217	16,087
8,760	397,354	463,116	5,146	25,729	536,240	3,575	17,875

Table 4. Forests area needed in the second scenario.

Operating hours (h)	Woodchip consumption (T/y)	Natural Forest			Plantation Forest		
		Logs (m³/y)	Area (ha/y)	Area (ha/5y)	Logs (m³/y)	Area (ha/y)	Area (ha/5y)
4,380	190,267	221,757	2,464	12,320	256,771	1,712	8,559
5,256	228,321	266,108	2,957	14,784	308,125	2,054	10,271
6,132	266,374	310,459	3,450	17,248	359,479	2,397	11,983
7,008	304,428	354,811	3,942	19,712	410,833	2,739	13,694
7,884	342,481	399,162	4,435	22,176	462,188	3,081	15,406
8,760	380,534	443,513	4,928	24,640	513,542	3,424	17,118

The simulation graph for the growth of the biomass power plant and the necessary forest area are displayed in Figure 10. Power plant operation hours throughout the year were simulated at 4,380; 5,256; 6,132; 7,008; 7,884; and 8,760 hours. The necessary forest area is calculated using equation (5)-(7). As may be observed, Figure 10 (b) shows that the area needed is smaller than Figure 10 (a).

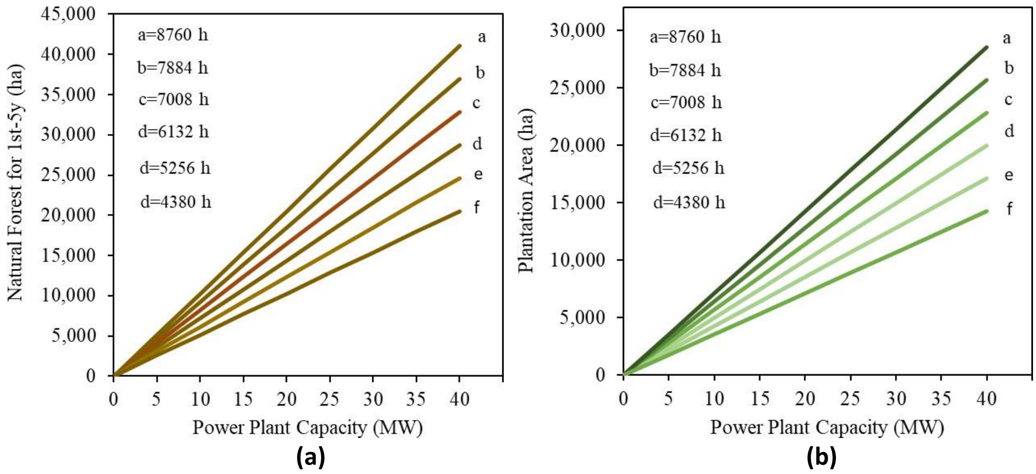


Figure 10. Simulation on the growth of biomass power plant and areas required: **(a)** natural forest; **(b)** plantation forest.

Based on what has been explained before, four things need to be discussed further. First, how to reduce the forest area that will be required for efficiency. And it is related to the calorific value of the woodchip. When the calorific value is high, the moisture content is low [38]. When the moisture content is higher, it causes the calorific value to get lower. With the higher calorific value, the consumption of the woodchip is getting lower and will impact the volume of the logs [39]. Then the area of the forests will be less. Thus, for the efficiency of the power plant, and to reduce the required forest area, it is necessary to reduce the moisture content of the woodchip [40], [41], [42]. Second, forest residue [43] needs to be considered as the power plant's fuel rather than being left in the field and eventually rotting. Therefore, it is necessary to conduct a study to calculate the volume of forest residue per ha. Third, the comparison of electricity power generation costs in terms of fuel between Biomass Power Plants and the local fossil power generation. Fourth, the strategy to maintain the forest for the sustainability of biomass supply. Preserving forest sustainability by replanting areas that have been harvested with certain strategies can keep energy independence maintained.

The concept mentioned above can be applied to areas where biomass resources are available in sufficient quantities such as PF where management is based on the principle of sustainability. The contribution of this study is as an input for the authorities in the supply of electricity, that the energy transition, as well as energy independence, can be realized by using biomass. For future research, this study can be continued by combining biomass derived from PF with biomass derived from waste, both from agriculture and woodworking mills. Then, research on whether in that area biomass waste can replace the role of biomass from PF, in terms of availability, sustainability, and from an economic standpoint.

4. Conclusions

To realize the government's program in energy transition, the author has taken the study in one island in the eastern part of Indonesia. As a result, it has demonstrated the enormous potential for developing biomass- based power generation, by utilizing biomass from the local industrial plantation forest, and shows the energy transition toward energy independence. In order to maximize fuel efficiency in the future, plantation areas must be reduced in order to provide biomass for power plants. This can be achieved by increasing the calorific value of woodchips by reducing their moisture content and by utilizing forest residue. In addition, a cost comparison between biomass and fossil fuel power plants will be conducted, along with a plan for maintaining the plantation to guarantee a consistent supply of biomass.

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