Potential development biomass power generation in Bali

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Abstract. Fulfilling Bali’s electricity supply independently, it is crucial to increase the power generation capacity to reduce supply dependence from The Jamali. Until now, the electricity supply for Bali Province has been obtaining from The Jamali electricity system, delivered through a submarine cable. Bali’s electricity consumption reaches 5,032 GWh, with a supply share from The Jamali of 36.9% and local power plants of 63.1%. In this study, the sharing of local power plants will increase to 72.6% in 2038. Bali’s Provincial Government promotes the use of 100% renewable energy sources to meet Bali’s electricity needs independently. The dominant type of fuel used is biomass. Biomass-based energy is low CO₂ emissions, fulfills aspects of sustainability, and contributes to reducing carbon emissions. It is in line with the Paris Agreement targets, supported by several regulations related to the development of renewable energy sources that have been stipulated by the Governments. However, the potential capacity of biomass power plants in Bali is only limited to 147 MW. A possible approach is to obtain it from other regions through regional development plans. South Kalimantan is an area that has an enormous potential land to support biomass plantation, which is estimated to reach 1,266 MW. In this study, analytical research or a feasibility study is to identify potential sources of renewable energy, such as *Anthocephalus cadamba* (jabon), *Gmelina Arborea* (jati putih), *Samanea saman* (trembesi). These plants have the potential to be planted in South Kalimantan. The type of technology that may be suitable for Bali’s biomass power plant is fluidized bed technology, as it has higher conversion efficiency and needs less area for biomass plantation. The identified land area that may develop for biomass plantation in South Kalimantan is around 175,600 ha. Meanwhile, the land area demand for biomass plantation for the Bali power plant is 100,000 ha to 171,000 ha with the fluidized bed technology utilizing *Anthocephalus cadamba* (jabon). The South Kalimantan unused lands and former mines would be sufficient to be used as a biomass plantation area for the Bali power plant with fluidized bed technology utilize *Anthocephalus cadamba* (jabon).

1. Introduction

Energy demand expects to grow continuously as a result of economic growth and population growth. With a reasonably high population growth rate and a rapidly developing national economy, the need for energy supplies to support economic activity has become crucial. However, electricity consumption in Indonesia currently still depends on the use of fossil fuels. Dependence on fossil fuels reaching 85% when the use of RE is still around 15%. It is in stark contrast to the Paris agreement and the goals of sustainable development. Indonesia's National Energy Plan states that by 2025, as much as 25% of Indonesia's electricity supply will come from RE sources. In recent years, regulations to support RE development are drafting as a strategy to achieve emission reduction. It has not been able to encourage investors to seek and develop RE [1]. Besides, RE’s use in Indonesia is still not optimal...
because RE is not yet competitive compared to fossil energy. In achieving energy security, there is a need for a transition from fossil energy sources to RE. Alternative energy sources must be available to minimize supply problems during the process of delivering energy sources. The provinces that are the focus of this research are Bali and Kalimantan.

Bali Island is Indonesia’s leading tourist destination. It is located in the east of Java Island, west of Lombok Island. The total population in 2019 was 4.3 million. The amount of GDP of Bali in 2019 was $58.39 billion [2]. In the past nine years, Bali’s economy grew on average 6.3% per year, which is higher than the national average. Electricity is one of the crucial aspects of Bali people’s lives and the economy. Therefore, its availability must be secured and maintained sustainably. In 2019 Bali electricity consumption was around 5,700 GWh per year. In the past eight years, Bali’s electricity consumption grew by 7.4% on average per year [3]. Bali must be independent in the supply of electricity. More efforts should go into supporting the further development to meet electricity demand, it is a requirement that Bali needs to use green energy sources. One of the candidates for green energy is to supply electricity demand by biomass power plants. It will require the biomass supply for the power plant from other regions. In this study, the biomass is acquired from South Kalimantan because the Bali, East Java, and Lombok islands do not have some plantation activities. Lombok Island is for tourism, and East Java is for industrial and for-food agriculture.

Bali Province electricity demand is currently supplied by local power generation and the Java electricity grid connected to Bali through subsea cables. However, this dependence has a high risk due to the potential for natural disasters such as earthquakes and Tsunami generated from subduction zones around the coast of Bali that may disrupt the electricity supply. Supporting Bali’s electricity supply, electricity demand projection is critical to plan the generation and distribution of electricity. Bali’s Provincial Government is currently promoting 100% RE sources to meet the island’s electricity needs. The output of this study analyzed or employed a feasibility study to identify potential RE sources, mainly biomass, to meet the electricity needs in Bali Province. Biomass is carbon neutral, sustainability, and contributes to reducing GHG emissions. It is in line with the Paris Agreement targets. Government support several regulations related to the development of RE sources. The Minister of Energy and Mineral Resources of the Republic of Indonesia has released No. 4421 K / 20 / MEM / 2015, dated 15 October 2015, stating that Bali Province has designated as one of the National Areas for Clean Energy [4].

In achieving efficiency and optimize the supply of electricity, an independent electric power system is required. In supporting RE’s target portion, more real efforts and actions are necessary to achieve this ambitious target. Bali has limited resources to develop RE. The potential capacity for biomass power generation in Bali will reach 147 MW [1]. A possible approach is to obtain it from other regions through regional development plans. Several provinces outside Bali have great potential for RE. It has proven that Kalimantan has enormous land potential and can use as a productive forest for biomass plantation. Bali and Kalimantan’s potential biomass power plants’ capacity is estimated to reach 1,266 MW [1]. Besides, Kalimantan is confirmed to be the new capital city in Indonesia, so energy demand will also increase rapidly. Kalimantan is already facing a long-term deforestation problem. Protected forests are slowly becoming extinct due to nature and humans. Some of the lands currently still neglected and have not been explored and used well even though it has high economic value and environmental quality. Therefore, a set of policies developed to use this abandoned land as a productive plantation with high-value crop varieties. The desired variation can benefit Indonesia’s energy mix plan when converted into wood pellets for biomass power generation. In this study, the analysis or feasibility research was to identify potential wood biomass power generation from the forest in Bali.

2. Method
The electricity generation capacity and the need for biomass used for its fuel are from the projected electricity production and the type of power generation technology. In general, there are three biomass-fuelled power plant technologies, namely stoker, bubbling fluidized bed (BFB), and
Circulated fluidized bed (CFB). Meanwhile, the area of biomass plantations is from the biomass requirements and productivity from biomass plantations.

2.1. Biomass power generation capacity and biomass requirements
The generating capacity is from the electricity production divided by the capacity factor, is mathematically expressed in the equation below:

\[ P_{i,t} = \frac{E_t}{FC \times 8670} \]  

Where \( P \) [MW] is biomass power plant capacity, \( E \) [MWh] is electricity production, \( FC \) is factor capacity, \( i \) is power generation technology, and \( t \) is the year. 8,670 is the constant of hours in a year. The biomass requirement for fuel in power plants calculates from the electricity production divided by electricity generation efficiency.

\[ F_{i,t} = \frac{E_t 	imes 0.0036}{\eta_i} \]  

Where \( F \) [TJ] is the demand for biomass fuels, \( E \) [MWh] is electricity production, \( \eta \) is efficiency, \( i \) is power generation technology, and \( t \) is the year. 0.0036 is the constant of conversion MWh to TJ.

2.2. Productive biomass plantation area
The area of productive land calculated from the biomass requirement divided by the productivity of the plantation. The land area for each type of biomass and power generation technology calculated by the equation below:

\[ A_{i,j,t} = \frac{F_{i,t} \times 10^{12}}{HV \times 4184 \times Y \times P} \]  

Where \( A \) [Ha] is the area of production land, \( F \) [TJ] is the demand for biomass fuels, \( HV \) [kcal/kg] is the heating value of biomass, \( Y \) [m³/ha] is the plantation productivity, \( P \) [kg/m³] is the density of biomass, \( i \) is the power generation technology, \( j \) is the type of biomass, and \( t \) is the year. \( 10^{12} \) is the constant conversion TJ to Joule, and 4,184 is the constant conversion kcal to Joule.

3. Results and Discussions
Figure 1 shows that the current power generation capacity in Bali is 930 MW by the capacity mix. Bali electricity demand is from the Jawa grid connected through subsea cable (360 MW). According to the Bali power generation projection carried out in parallel with this study [5], the Bali biomass power plant can grow from 263 MW in 2030 to 453 MW in 2050.
Indonesia has enormous potential for biomass as an alternative energy source. Biomass is a RE source that needs to prioritize its development, with an estimated potential capacity of around 49.8 GW [1]. However, only about 3.25% used for electricity generation. To meet the RE’s target portion as stipulated in the Paris Agreement, the Government will continue to encourage biomass power plants, especially by utilizing wood pellets on a large scale, especially in Bali Province. The development of wood biomass-based power plants is still at an early stage, not yet realized. Meanwhile, several power plants in Indonesia have used agricultural waste as raw material. Based on EBTKE statistics, data on the Bioenergy Power Plant’s installed capacity, as shown in Table 1.

Table 1 Capacity of the bioenergy power plant in Indonesia by the source of biomass [3]

| Region      | Biomass source | Capacity (MW) |
|-------------|----------------|---------------|
| Sumatera    | Palm waste     | 3,335         |
|             | POME           | 9             |
|             | Sugar cane     | 66            |
|             | Paper          | 955           |
| Borneo      | Palm waste     | 91            |
| Java-Bali   | Palm waste     | 2             |
|             | Sugar cane     | 142           |
|             | MSW            | -             |
| Sulawesi    | Palm waste     | 11            |
| Papua       | Sugar cane     | 11            |
|             | Palm waste     | 4             |
| Total       |                | 1,626         |

However, because of the limited potential of biomass in Bali, a possible approach is to obtain it from other regions. South Kalimantan Province is 530 Km from Bali Province and is one of the provinces with an enormous biomass potential of around 1,266 MW. It is the basis for selecting biomass utilization locations to build a biomass power plant in Bali. However, it is undeniable that Kalimantan’s forest resources have a promising economic function in timber or tree trunks that value the economy. Besides, there are critical lands that have not to utilize optimally. To support wood biomass-based power generation, The Indonesian Government has promoted the concept of Energy Plantation Forest.
South Kalimantan Province areas that are shaped inland by 38,744 km\(^2\). The use of land in South Kalimantan, mostly forest (30.16%). Approximately 26.09% used for plantations and 10.98% for rice. Use of land for the residential-only about 2.33% and about 1.44% for mining. The total area that has utilized is 37,530 km\(^2\), so the total untapped area is 1,213 km\(^2\) [2]. The forest area in South Kalimantan has been planted with various species, shown in Table 2.

Table 2. Total area of plantation and production by type of plant [2]

| District/city          | Akasia | Bambu | Jati   | Mahoni | Sengon  | Jabon | Waru | Jati putih | Suren |
|------------------------|--------|-------|--------|--------|---------|-------|------|------------|-------|
| Tanah Laut             | 7,784  | 3,960 | 45,192 | 62,019 | 115,018 | 3,240 | 0    | 19         | 0     |
| Kotabaru               | 60,666 | 5,038 | 227,636| 6,558  | 187,769 | 85    | 0    | 254        | 0     |
| Banjar                 | 8,279  | 3,927 | 122,559| 51,855 | 61,046  | 2,204 | 0    | 131        | 20    |
| Barito Kuala           | 2,081  | 8,325 | 1,328  | 14     | 9,510   | 0     | 20   | 250        | 0     |
| Tapin                  | 985    | 7,132 | 49,163 | 2      | 5,018   | 0     | 0    | 0          | 0     |
| Hulu Sungai Selatan    | 5,018  | 3,240 | 61,046 | 0      | 189     | 0     | 0    | 0          | 0     |
| Hulu Sungai Tengah     | 55     | 1,880 | 19,261 | 0      | 189     | 0     | 0    | 0          | 0     |
| Hulu Sungai Utara      | 0      | 1,394 | 735    | 0      | 0       | 0     | 0    | 0          | 0     |
| Tabalong               | 300    | 1,148 | 6,758  | 4,466  | 759     | 0     | 0    | 300        | 0     |
| Tanah Bumi             | 3,472  | 1,612 | 7,890  | 7,484  | 10,191  | 4,608 | 20   | 0          | 0     |
| Balangan               | 0      | 1,365 | 735    | 0      | 0       | 0     | 0    | 0          | 0     |
| Kota                   | 0      | 0     | 200    | 200    | 1,475   | 0     | 0    | 0          | 0     |
| Banjarmasin            | 14,785 | 10    | 3,849  | 10,208 | 20,710  | 0     | 6    | 0          | 0     |
| South Borneo           | 98,952 | 63,252| 567,365| 183,674| 415,209 | 13,297| 46   | 1,143      | 20    |

South Kalimantan also has former mines lands. Mine reclamation for RE is an initiative developed. It can contribute to mitigation action plans and regional development goals, such as rehabilitating critical land and reclamation of abandoned mines. Potential of biomass cultivation for mine reclamation focused on biomass from *Anthocephalus cadamba* (jabon), *Gmelina Arborea* (jati putih), and *Samanea saman* (trembesi). Wood pellets produced by pressing sawdust with low moisture content (below 10%) burnt with high combustion efficiency. The best raw material for wood pellets comes from *Gmelina Arborea* (jati putih). One kilogram of wood pellets is equal to 4,282 kcal [6].

Table 3. Characteristics of *Anthocephalus cadamba* (jabon), *Gmelina arborea* (jati putih) and *Samanea saman* (trembesi) plants [6]

|                     | *Anthocephalus cadamba* (jabon) | *Gmelina arborea* (jati putih) | *Samanea saman* (trembesi) |
|---------------------|---------------------------------|--------------------------------|-----------------------------|
| Wood Productivity   | 20                              | 14.4                           | 10-25                       |
| Calorific value     | 4,150.6                         | 4,282.51                       | 3,900.90                    |
| Ash content (%)     | 0.77                            | 0.51                           | 1.18                        |
| Density (gr/cm\(^3\)) | 0.4                            | 0.44                           | 0.33                        |
| Moisture (%)        | 58.54                           | 51.74                          | 49.45                       |
| Volatile matter (%) | 72.01                           | 71.48                          | 67.64                       |
| Fixed-C (%)         | 16.63                           | 18.26                          | 16.89                       |
The biomass’s size and density are also crucial because they affect the rate of heating and drying during the process [7]. Large particles heat up more slowly than smaller ones, resulting in larger particles producing more char and less tar [8]. The type of handling equipment is also determined by the size, shape, density, moisture content, and fuel composition. The wrong design will impact the combustion/gasification process’s efficiency and may damage the handling system. Table 4 gives an overview of biomass technology, feedstock and the requirements on particle size and moisture content.

Table 4. Biomass Power Generation Technologies and Feedstock Requirements [9]

| Biomass conversion technology | Commonly used fuel types |
|------------------------------|-------------------------|
| Stoker grate boilers         | Sawdust, non-stringy bark, shavings, end cuts, chips, hog fuel, bagasse, rice husks, and other agricultural residues | 6 – 50 mm | 10 – 50% | 4 to 300 MW many in 20 to 50 MW ranges |
| Fluidized bed combustor (BFB or CFB) | Bagasse, low alkali content fuels, mostly wood residues with high moisture content, others, no flour or stringy materials | <50mm | <60% | Up to 300 MW (many at 20 to 25 MW) |

The selection of raw materials for biomass-based power plants will affect the technology chosen, syngas quality, and raw materials availability. Meanwhile, the content of hydrogen, oxygen, and carbon in raw materials greatly determines the calorific value, nitrogen, and sulfur content in the raw material directly reflected in syngas’ chemical properties. The fuel requires a high-quality syngas composition with a composition of about 18-20% H₂, 18-20% CO, 2-3% CH₄, 12% CO₂, 2.5% H₂O, and the rest is N₂. If the usual decomposition process is changed using thermal decomposition techniques using water vapor, the gas composition changes to 50% CO, 40% H₂, and 10% other gases (CH₄, CO₂, N₂, and inert) [9]. Gas resulted from the gasification process can be used directly as fuel for the bioenergy manufacturing process. However, the tar formed as a byproduct of thermal decomposition or pyrolysis of cellulosic materials will disturb the environment. Faced the excessive transformation, it is necessary to develop a thermal decomposition process of efficient and clean biomass from pollutants. It is required to pay attention to the type of reactor used, the type of biomass, the type of reagent, and the operating conditions.

Table 5. Advantages and Disadvantages of fluidized bed gasifier [9]

| Advantages | Disadvantages |
|------------|---------------|
| Fluidized bed gasifiers | BFB | CFB |
| Lifetime | 20 year | 20 year |
| Efficiency | 35% | 36% |
| Capacity Factor | 0.6 | 0.6 |
| Creates a homogenous, good quality producer gas | Complicated control needs |
| Can accept a range of feedstocks and particle sizes | Slow response to load changes |
| Excellent heat transfer performance through contact with bed materials | Increased cost and complexity |
| Large heat storage capacity | Less efficient heat exchange than BFB |
| Good temperature control | Temperature gradients in the reactor vessel |

Table 5 shows that selecting the type of generation technology and determining the amount of generating capacity necessary to meet service demand and estimate the biomass demand. The composition contained in biomass will also affect the technology used. Over 80% of the biomass used
for energy purposes goes through the combustion route. There are two primary components of a combustion-based biomass plant: 1) the biomass-fired boiler produces steam, and 2) the steam turbine, then used to generate electricity. The two most common forms of boilers are stoker and fluidized beds. Stoker boilers burn fuel on a grate, producing hot flue gases then used to produce steam. The ash from the combusted fuel is removed continuously by the fixed or moving grate. There are two general types of stokers. Underfeed boilers supply both the fuel and the air from under the grate. Overfeed boilers provide the fuel from above the grate and the air from below.

In BFB gasifiers, the reactive gases pass through the reactor bed at the minimum velocity required to achieve a bubbling effect where the “bubbles” flow upwards through the bed material. At the top of the inert material, the bubbles burst, and then the bed material falls back into the bed. In CFB gasifiers, the gas velocities are higher than the minimum fluidization point, resulting in the circulation of the inert bed materials in the gas stream. The bed particles exit the top of the reactor with the gas-producing, and must then separated in a cyclone recirculated to the reactor.

The development of a biomass power plant in Bali takes about 1-2 years [10]. Based on the assumption, this development will implement starting in 2020 with biomass supply obtained independently in Bali. However, beginning in 2030, biomass supply for Bali biomass power plants will come from South Kalimantan. As mentioned previously, the Bali biomass power plant is estimated to grow from 263 MW in 2030 to 453 MW in 2050. Meanwhile, the potential for biomass power plants in Bali is only 147 MW.

The biomass power plant alternatives are stoker technology, bubbling fluidized bed, and circulating fluidized bed. Each selected technology’s biomass demand was estimated to meet the power generation capacity, which will affect the total biomass plantation area. Figure 3 shows the result of the estimation of biomass demand. Figure 3 shows that the highest biomass demand would come from stoker because it has the lowest conversion efficiency.

![Figure 3 Projection of biomass consumption in 2030-2050](image-url)

Figure 4 shows the prediction of areas needed for producing biomass energy based on the type of plant and technology.
There is a requirement for a significant amount of land area for supplying biomass to Bali power plants. From 2030 to 2050, the land requirements will increase from 100,000 ha to around 171,000 ha with fluidized bed technologies utilize jabon. On the other hand, the land requirements will increase from 210,000 ha in 2030 to 364,000 ha with stoker technology utilize trembesi in 2050.

As mentioned previously, the remaining land (unused land) plus former mine lands in south Kalimantan is 175,600 ha. As a result, comparing the requirement of area plantation land and the available unused land, South Kalimantan would be able to meet biomass demand from Bali power plants with fluidized bed technology utilize jabon. South Kalimantan remained land would not be able to meet Bali biomass demand with stoker technology utilize trembesi. According to the current information, Several South Kalimantan areas have already had a plantation of *Anthocephalus cadamba* (jabon) and *Gmelina Arborea* (jati putih). These plants can use as resources to meet biomass demand in Bali. Further assessment is needed to quantify these plant resources.

Another aspect is the shipment of the biomass from South Kalimantan to Bali island (530 km). The amount of wood to be shipped is in the range of 800,000 tons per year (2030) to 1.4 million tons per year (2050). Wood ports may need to build in South Kalimantan and Bali northern region around Singaraja. Location and size of the power plants considered for distribution efficiency of the plants and balancing the electricity network as well as the system of woodland transportation within Bali. Unlike other fossil power plants like coal, where the size may be in the order of hundreds of megawatt per unit, biomass power plants are typically much smaller i.e in the range of 25 to 40 MW per unit [9]. Therefore many (tens) biomass power units must be installed in Bali in several locations.

### 4. Conclusions

1. To create a green energy system in Bali, biomass power plant in Bali is projected to increase from 263 MW in 2030 to 453 MW in 2050.
2. The type of plantation that may develop to supply biomass in Bali is *Anthocephalus cadamba* (jabon), *Gmelina arborea* (jati putih) and *Samanea saman* (trembesi). This plant has the potential to be planted in South Kalimantan.
3. The type of technology that may be suitable for Bali biomass power plant is fluidized bed technology, higher conversion efficiency and less land area for biomass plantation.
4. The identified land area that may utilize for biomass energy plantation in South Kalimantan is around 175,600 ha. Meanwhile, the required land area for biomass energy plantation for Bali power plant is in the range of 100,000 ha to about 171,000 ha with fluidized bed technology utilize *Anthocephalus cadamba* (jabon).
5. The South Kalimantan unused lands and former mines area would be sufficient to be used as an area for biomass plantation for biomass power plant with fluidized bed technology utilize *Anthocephalus cadamba* (jabon).

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