Potential of biomass as source for electricity at Pulau Panggang Village, North Kepulauan Seribu Subdistrict

U J Siregar¹, M F Arif¹, J Suryana², Y S Indartono³

¹ Department of Silviculture, Faculty of Forestry, Bogor Agricultural University, Jl. Ulin Kampus IPB Darmaga, Bogor, ID
² Department of Forest Product, Faculty of Forestry, Bogor Agricultural University, Jl. Ulin Kampus IPB Darmaga, Bogor, ID
³ ITB Center of New and Renewable Energy Development, Institute of Technology Bandung, Jl. Taman Sari No.126, Bandung, ID

E-mail: siregaruj@gmail.com

Abstract. Biomass as energy source has been used extensively by people in remote areas in Indonesia, although limited to household level as fuel wood or charcoal for daily life. This study estimates the amount of biomass in Pulau Panggang Village, North Kepulauan Seribu District and its potential as fuel for a power plant. Vegetation analysis was conducted to find out stand composition and estimate biomass using allometric equation. Biomass conversion into electricity was done by assuming a power plant with 40% efficiency. Results showed most dominant species are *Casuarina equisetifolia* with IVI value of 138.65 and 123.73 for tree and pole level, followed by *Leucacena leucocephala* and *Acacia crassicarpa*. This study shows that there is 247.45 ton/ha, 986.13 ton/ha, and 798.59 ton/ha of biomass stored in Karya, Pramuka, and Ayer Island respectively. A total of 2032.17 ton biomass could be used to generate 2980.51 MWh of electricity. However, development of plantation forest as a source of renewable fuel for electricity is difficult because limited available land while electricity demand is high.

1. Introduction

1.1. Background

Renewable energy is developed as an alternative to the limited and declining amount of fossil energy. Sunlight, wind, geothermal, and biomass are samples of renewable energy. One source of renewable energy and abundantly found in remote areas in Indonesia is biomass.

Energy consumption from biomass in Indonesia reaches 18% of total energy consumption; its consumption is limited to household sector in the form of firewood and charcoal [1]. The energy consumption in the form of electricity from PLN (Indonesia State Electricity Corporation) in Indonesia comes from power plants using 88% fossil fuels, 8% hydro power and 5% geothermal power [1]. The biomass utilization as energy source has a good potential as stated by the National Energy Council that Indonesia has new and renewable energy potential from biomass which is about 50 GW (Gigawatt) of energy [2].

Energy from biomass is utilized in rural households in the form of firewood for cooking, while in agriculture and forestry industries the biomass waste is used to drive its industries processes [2]. Its great potential, new and renewable nature, and its limited utilization suggest that biomass has opportunities to be developed into a sustainable fuel source. One of biomass utilization as a
sustainable fuel is the utilization of biomass as a fuel for power generation, especially in remote areas that have not yet electricity.

The biomass utilization as a fuel for electricity generation will promote the growth of plantation forest in general, including plantations that are specifically grown to cover the needs for electricity power generation. Different forms of biomass, such as leaves and twigs waste, have the potential to increase the harvesting efficiency when it is incorporated in an uniformly processed product such as wood pellet. Wood pellet is a way to make variable existing biomass becoming uniform, with drier condition and smaller size to facilitate combustion, storage, and distribution, and have greater heat energy when compared to original biomass before being processed.

1.2. Objective
This research was conducted to estimate the potency of biomass in Pulau Panggang Village, North Kepulauan Seribu Subdistrict, which can be used as fuel source of power plant.

2. Method
2.1. Time and location
The research was conducted in August 2015 in Pramuka Island, Panggang Island, Karya Island and Ayer Island, Pulau Panggang Village, North Kepulauan Seribu Subdistrict, Kepulauan Seribu District, DKI Jakarta Province.

![Figure 1. Research location.](image)

Figure 1 shows research site in Karya Island, Pramuka Island, Panggang Island, and Ayer Island, which belongs to Pulau Panggang Village, North Kepulauan Seribu Sub-district. Ayer Island is not yet available on the map, it is located about 4 km to the southwest of Pramuka Island.

2.2. Tools and materials
The tools used in this research are measuring tape (150 cm and 30 m), haga hypsometer, raffia strap, camera, compass, and tally sheet. Primary data were collected from forest stands in Karya, Pramuka, and Ayer Island, while secondary data was taken from the book on Pulau Panggang Sub-district Monthly Government Report for June 2015.

2.3 Research procedure
2.3.1. Vegetation analysis. The vegetation analysis was done using lane plot method or combination between transect and line compartment method. There were 15 plots in 3 lanes on 3 islands, i.e. Pramuka Island, Karya Island and Ayer Island. The 20 x 20 m plots were used to measure trees and 10 x 10 m plots were used to measure poles as shown in figure 2. Data taken in vegetation analysis were tree diameter at breast height (dbh), total tree height, and free-branch tree height. The types level of
sapling and seedling were not taken because the data used were only types that have a diameter of ≥10 cm.

![Figure 2. Observation plots.](image)

Although the sites were plantation forest, line plots method or combination between transect and line compartment method was used in this research because the area condition was not suitable for establishment of a circular plot. For example, forest in Ayer Island has an elongated oval-shaped area with a width of no more than 25 m, that when using circular plot with radius of 17.8 m, there will be a part of the plot in the sea. In addition, lane plots technique was selected to see the type of vegetation grown in the seashore up into the forest. Vegetation analysis was conducted in the three islands namely Karya Island, Pramuka Island and Ayer Island, those three islands were chosen because it have considerable area of forest and the distance was not too far from each other.

The pole and tree-level vegetation analysis data were analyzed to determine the stands composition as described by the Importance Value Index (IVI). IVI is derived from the sum of Relative Density (RDe), Relative Dominance (RDo), and Relative Frequency (RF) with the formula:

- IVI = RDe + RDo + RF (for pole and tree level)
- IVI = RDe + RF (for sapling and seedling level)
- Density = \( \frac{\text{Number of species A}}{\text{Area sampled (ha)}} \times 100\% \)
- Relative Density = \( \frac{\text{Number of species A}}{\text{Total density of all species}} \times 100\% \)
- Frequency = \( \frac{\text{Number of quadrats with species A}}{\text{Total number of quadrats sampled}} \times 100\% \)
- Relative Frequency = \( \frac{\text{Frequency of species A}}{\text{Total frequency of all species}} \times 100\% \)
- Dominance = \( \frac{\text{Area sampled (ha)}}{\text{Dominance of a species A}} \times 100\% \)
- Relative Dominance = \( \frac{\text{Total dominance of all species}}{\text{Dominance of a species A}} \times 100\% \)

The importance value index result is used to determine the dominance of a species against other species in its stands, and can be used as reference of which species can grow well and potential to be developed in Kepulauan Seribu.

2.3.2. Estimation of potential stand biomass. Estimation of stand biomass is done by analyzing the data of tree diameter at breast height (dbh) and total tree height using [3] in [4]. This approach is used because of the unavailability of allometric equations for measuring tree volume or biomass, and the Biomass Expansion Factor (BEF) stand is used due to the lack of specific BEF data of a tree species. The estimation formula of biomass is:

\[
\text{Stand biomass} = \sum \text{(Tree volume} \times \text{WD}) \times \text{BEF stand}
\]

- Stand biomass = above ground biomass
- Volume (m³)
- WD = wood density (ton/m³)
- BEF = biomass expansion factor (Table 1)
Table 1. Default BEF value according to IPCC Guidelines (2003).

| Climate zone | Forest type | Minimum dbh (cm) | BEF (with bark) |
|--------------|-------------|------------------|-----------------|
| Tropical     | Pine        | 10               | 1.3 (1.2 – 4.0) |
|              | Hardwood    | 10               | 3.4 (2.0 – 9.0) |

The tree volume in stand biomass is calculated using the formula [4]:

\[ V = 0.25\pi \times \left( \frac{\text{Dbh}}{100} \right)^2 \times H \times F \]

- \( V \) = tree volume in m³
- \( \pi = 3.14 \)
- \( \text{Dbh} \) = diameter at breast height in cm
- \( H \) = total tree height in m
- \( F \) = form factor of stem or tree (0.6)

Those formula are used to measure the tree volume from diameter at breast height (dbh) and total tree height data. According [4], the F factor of stem or tree (f value) can use the general f value of 0.6 if form factor of specific tree species is not available.

2.3.3. Estimation of electric energy potential. The estimation of electric energy potential uses a biomass approach as a fuel which is converted into wood pellet (WP) and subsequently used as fuel in a steam power plant. The electric energy potential from the predicted biomass is calculated to cover the electrical energy demand in Pulau Panggang Village, North Kepulauan Seribu Subdistrict.

Energy estimation is derived from calculated biomass potential, then it is used as fuel of electric power generation. Biomass that converted into wood pellet has 19.8 MJ/kg energy [5]. According [6], 1.5 ton of biomass can be converted into 1 ton of wood pellet.

Wood pellet as fuel is used to generate electrical energy. The energy from wood pellet in MJ (megajoules) is converted into energy in kWh (kilowatt hour), unit used in electricity with a conversion of 1 kWh = 3.6 MJ [7]. The steam power plant used is assumed to have an efficiency of 40% [8] which means it is only 40% the electrical energy that can be produced from fuel energy that used.

3. Results and discussion

3.1. Profile of Pulau Panggang Village

Based on the Decree of the Governor of DKI Jakarta Province Number: 1986/2000 dated July 27, 2000, regarding the Solution, Establishment, Stipulation of Boundaries and Name of Kelurahan (Village) in North Kepulauan Seribu Subdistrict, Kepulauan Seribu District, DKI Jakarta Province, Panggang Island has area of 62.10 ha. Pulau Panggang Village is a group of islands consisting of 13 islands. Panggang Island and Pramuka Island are two islands which become settlement area for residents. Other islands have their own allocations such as resort, tourism, office, cemetery and lighthouse.

Pulau Panggang Village has 5 RW (neighbourhood community) of which 3 RW of 21 RT (neighbourhood block) are in Panggang Island, and 2 RW of 8 RT are in Pramuka Island. Panggang Island has an area of 9 ha with most land use is settlements with a population of 4219 people. Pramuka Island which has an area of 16 ha is the administrative center of North Kepulauan Seribu Subdistrict with facilities of office, hospital and the only secondary school in Kepulauan Seribu District. Besides an administrative center, Pramuka Island is also a settlement with a population of 1813 people.
The needs of electricity as much as 1789 families in North Kepulauan Seribu Subdistrict is fulfilled by submarine electrical installation from PLN. The submarine electricity installation has reached the islands in Kepulauan Seribu region except Sebira Island which is located in the northernmost of Kepulauan Seribu. Houses in Panggang Island and Pramuka Island have been using electricity of 1,300 watt capacity and only a few still use 900 watt with the cost around Rp150,000 to Rp225,000 each month. Residents mentioned that submarine power cable has been supplying a stable electricity without frequent power failure.

3.2. Vegetation analysis of Karya Island

Karya Island is an island designated for offices and a public cemeteries. This island has an area of 6 ha. Vegetation analysis was conducted in forest that located in the northwest of island with an area of about 1.6 ha. The forest bordered by cemeteries in the south and offices in the east. It is a plantation forest planted around 2006 after the solar panel project was completed.

The direct survey showed that the forest consisted of *Casuarina equisetifolia* tree in the coastal area while it was planted with *Leucaena leucocephala*, *Acacia crassicarpa*, *Hibiscus tiliaceus* and *Terminalia catappa* inside. At a glance, the forest is like natural forest which is untouched with scatter litters and emerge shoots from fallen tree stump.

![Per cent age of IVI Tree Pole](image)

**Figure 3.** Importance value index of Karya Island.

Figure 3 shows the IVI percentage of vegetation analysis in Karya Island. Vegetation analysis showed that the dominant trees in the forest were *A. crassicarpa* and *L. leucocephala* with IVI value of 116.68% and 96.03%, followed by *Hibiscus* sp. with IVI value of 36.19%. *C. equisetifolia* is found in plot 1 which is located in the coast with IVI value of 51.11% for the tree level and 61.12% for the pole level. The IVI value for the largest pole level is *L. leucocephala*, followed by *C. equisetifolia*, *T. catappa*, and *A. crassicarpa*.

3.3. Vegetation analysis of Pramuka Island

Pramuka Island is the center of North Kepulauan Seribu Subdistrict. Pramuka Island is primarily designated as the administrative center. In addition, there is also settlement area that has support facilities such as hospital, upper secondary school which is the only one in Kepulauan Seribu, and government office. The island has an area of 16 ha with the remaining forest covering about 1.8 ha located in the north of island.

The forest in Pramuka Island is proprietary plantation forest. The landowners intentionally allow the existence of the forest when other lands in the island have converted into residences and lodges. There is *C. equisetifolia* which is the largest tree in this forest with diameter of 74.48 cm. It is estimated that this forest has existed for more than 20 years. The inner forest is planted with *T. catappa*, *Calophyllum inophyllum*, *A. crassicarpa*, *Guettarda speciosa*, *Bruguiera* sp. and *L. leucocephala*. The trees in this forest have a larger size than the trees in other two islands with average diameter size about 36 cm and maximum height 27 m.
The vegetation analysis (figure 4) shows the tree species in forest of Pramuka Island grow evenly with IVI value of 68.65% for *T. catappa*, 58.73% for *A. crassicarpa*, 45.89% for *G. spesiosa*, and 88.34% for *C. equisetifolia* which grown in seashore. *A. crassicarpa* dominated at pole level with IVI value of 183.63%, followed by *L. leucocephala* and *H. tilliaceus* with IVI value of 66.08% and 50.29%. Although it did not measure, there are a number of seedlings and saplings level around the *A. crassicarpa* tree.

### 3.4. Vegetation analysis of Ayer Island

Ayer Island is a property island, it has an area of 2.9 ha. Ayer Island is a group of islands composed of several small islands and larger islands, it is also referred as Air (water) Island by the residents. The larger island which is main island has elongated oval-shape with a width of not more than 25 m. Another large island has elongated shape in the western, it is overgrown by *C. equisetifolia*. The small islands in Ayer Island area planted with mangroves and *C. equisetifolia*. The trees in Ayer Island forests are estimated about 12 years old.

Vegetation analysis showed that Ayer Island was almost entirely planted by *C. equisetifolia* (figure 5). *C. equisetifolia* at the tree level has an IVI value of 300% which means no other species grows at the tree level other than *C. equisetifolia*. At the pole level, *C. equisetifolia* still dominates with an IVI value of 239.94%, but found other types of *H. tilliaceus* and *Bruguiera sp.* with IVI value of 38.35% and 21.71%. *C. equisetifolia* tree in Ayer Island forest has an average diameter of 20 to 30 cm with maximum diameter of 43 cm.
3.5. Vegetation analysis of three islands

Figure 6. Total importance value index.

The importance value index of vegetation analysis in the three islands as a whole is presented in figure 6. The result of the IVI calculation as a whole showed *C. equisetifolia* is the dominant species grown in Kepulauan Seribu area with the IVI value of 138.65% for tree level and 123.73% for pole level. The next dominant type was *L. leucocephala* with the IVI value of 16.49% for tree level and 90.02% for pole level, followed by *A. crassicaarpa* with the IVI value of 51.69% for tree level and 38.95% for pole level. Other species that grow in Kepulauan Seribu at tree level are *Acacia crassicarpa* with an IVI value of 51.69% and *T. catappa* with an IVI value of 39.67%.

3.6. Estimation of biomass and energy potential

Biomass represents the total dry weight of organic matter from living creatures, both of above and below of soil surface. Biomass is expressed in units of ton per hectare. Estimation of stand biomass is done by using [3] in [4] which is an estimation of above ground biomass.

| Island  | Area (ha) | Stand age (years) | Biomass (ton/ha) |
|---------|-----------|-------------------|------------------|
| Karya   | 1.6       | 9                 | 247.45           |
| Pramuka | 1.8       | 20                | 986.13           |
| Ayer    | 1.6       | 12                | 798.59           |
| **Total** | **3.0**  |                   | **2032.17 ton**  |

Biomass estimation in the three islands is presented in table 2. From the measurements at the research sites in the three islands, the potential of biomass is 2032.17 ton in 3 ha area, the largest biomass potential is in Pramuka Island which has a value of 986.13 ton/ha. The next largest biomass potency is Ayer Island that has a value of 798.59 ton/ha and followed by Karya Island that has a value of 247.45 ton/ha. Pramuka Island has the greatest biomass potential because value because its trees in Pramuka Island are more numerous, have larger volume, and older than the other stands in two islands. As stated by [9], stored biomass is affected by age, composition, and stand structure.
### Table 3. The energy potential of biomass in wood pellet form.

| Biomass (ton) | Wood pellet (ton) | Energy\textsuperscript{a} (GJ) | Energy\textsuperscript{a} (MWh) | Energy listrik\textsuperscript{b} (MWh) |
|---------------|------------------|-------------------------------|-------------------------------|-----------------------------|
| 2032.17       | 1354.78          | 26 824.64                    | 7451.29                      | 2980.51                     |

\textsuperscript{a}Energy from wood pellet in GJ (Gigajoules) and MWh (Megawatt hour).

\textsuperscript{b}Electrical energy that produced in MWh (Megawatt hour).

The calculation result of biomass total potency that presented in table 3 showed that from 2,032.17 ton of biomass can produce 1,354.78 ton wood pellet. The energy contained in 1,354.78 ton of wood pellet is 26,824.64 GJ of energy or equivalent to 7,451.29 MWh of energy if it is converted into electricity unit. If the energy from the biomass is used as a fuel of power generator engine that has a 40% efficiency, then it can generate electrical energy of 2,980.51 MWh.

#### 3.7. Plantation forest for energy needs

Pulau Panggang Village, Kepulauan Seribu Utara Subdistrict, has 1789 families. The monthly electricity cost ranges from Rp 150,000 to Rp 225,000 or about 100 to 150 kWh per month per household with electricity price Rp 1,509.80 for 1300 VA power. The electricity need of 1789 households in Pulau Panggang Village reaches 178.90 MWh per month or 2,146.80 MWh per year, if each family is calculated using 100 kWh of electricity each month.

The estimated amount of electricity of 2980.51 MWh from biomass can covers the electricity needs in Pulau Panggang Village within 16 months without any replanting. Plantation forest development for sustainable biomass as a fuel for power generator is essential, whereas the energy demand in Pulau Panggang Village, North Kepulauan Seribu Subdistrict, is 2146.80 MWh each year can be fulfilled sustainably if it gets biomass supply of 1463.73 ton/year.

Table 4 shows the potential biomass that can be obtained from plantation forest with *Paraserianthes falcataria* and *Anthocephalus cadamba* species at 5 years old in the area of 5 ha which is the total area of forest in research location.

### Table 4. Comparison of energy needs in *P. falcataria* and *A. cadamba* plantation forests.

| Type       | Forest area\textsuperscript{a} (ha) | Biomass (ton) | Electricity (MWh) |
|------------|-----------------------------------|---------------|-------------------|
| *P. falcataria* | 5                                 | 632.08        | 927.05            |
| *A. cadamba*    | 5                                 | 509.07        | 746.64            |

\textsuperscript{a}Forest area in the three islands of research location.

*P. falcataria* is a fast-growing tree species. This species is able to grow fast with an increase in diameter of 4-5 cm year and a height increase of 4 m/year until the age of 5 years [10]. *P. falcataria* plantation forest with plant spacing of 3 m × 3 m and a diameter of 20 cm at the end of 5-year rotation is estimated to produce biomass of 126.42 ton/ha. The available forest area is 5 ha (table 4), if it is planted with *P. falcataria* species, it is estimated to produce 632.08 ton of biomass at the end of 5 years rotation. If divided into 1 ha per age class of 5 age classes, the biomass need can only be fulfilled 8.6% per year. Fulfillment of sustainable biomass needs with *P. falcataria* requires an area of 11.5 ha/year with total of 58 ha.

Another fast growing species that can be used is *A. cadamba*. According to [11], *A. cadamba* is able to grow with an increase in diameter of 4 cm/year and an increase in height of 3 m/year. The plantation forest of *A. cadamba* with plant spacing of 3 m × 4 m and diameter of 20 cm at the end of 5 years rotation is estimated to produce 101.81 ton/ha of biomass [5]. In table 4, if 5 ha of available forest is planted with *A. cadamba* species, it is estimated to be able to produce 509.07 ton of biomass.
at the end of a 5 year rotation. If the area of 5 ha is divided into 1 ha/one age class of 5 age classes, the biomass need with *A. cadamba* can only be fulfilled 7% per year. Fulfillment of sustainable biomass needs with *A. cadamba* requires an area of 14.3 ha/year with a total of 72 ha.

The development of plantation forest as a source of biomass for power generator fuel is strongly recommended, but in Kepulauan Seribu case it is impossible. The main reason for this case is the unavailability of area or land. Area of the island which is land in Pulau Panggang Village, North Kepulauan Seribu Subdistrict, is only 6.21 ha. That amount is not yet reduced by the area that used for settlement, privately owned land, and national park area. Full biomass supply for electricity with plantation forests that require 58 ha of area with *P. falcataria* and 72 ha with *A. cadamba* is very unlikely. So biomass utilization as energy source should be supported by other alternative sources of electricity such as solar or wind power.

4. Conclusion and suggestion

4.1. Conclusion

The biomass stored in the forest has great potential as a source for energy, however utilization of biomass from plantation forests in Kepulauan Seribu area as the only energy source is not possible due to unavailability of land. The available biomass in Karya Island, Pramuka Island and Ayer Island are respectively 247.45 ton/ha, 986.13 ton/ha and 798.59 ton/ha, and it is capable of producing 2980.51 MWh of electricity. Biomass can be used as a fuel source by converting it into wood pellet first for easy handling of the material.

4.2. Suggestion

For renewable energy development in Pulau Panggang Village, North Kepulauan Seribu Subdistrict besides biomass, other sources, such as solar and wind energy could be utilized for power generator.

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