The potency of wood based electricity production from critical land in Indonesia

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Abstract. Increasing demand for woody biomass as the fuel of renewable power plants must be anticipated by utilizing critical land through land rehabilitation activities using potential woody biomass species. However, there is a lack of information on the potency of such critical land. Therefore this study aims to explore the critical land area suitable for woody biomass cultivation and estimate the electricity production that can be generated from the utilization of the critical land. The study was conducted by determining the priority areas of integrated land to be rehabilitated, identifying the status and function of the critical land area, evaluating its suitability for the woody biomass cultivation, and calculating the potential output of electrical energy. The result shows that there are approximately 3.8 million hectares of critical land, which is suitable for producing woody biomass. This area consists of 2.3 million hectares of non-state forest area and 1.5 million hectares of production forest area. The largest suitable area is located in the Sumatra region, while the smallest was in the Papua region. The suitable area potentially produces electricity as much as 102,953 GWh, should be able to supply electricity of 69.5 million households. Further, the biomass has the potential to be used as co-firing fuel in coal-based power plants to reduce the negative impacts of the use of coal.

1. Introduction

Energy resource is one of the national development capital, but the dominance of the use of energy sources derived from fossil fuels has increased the rate of CO₂ and other greenhouse gas emissions into the air as the leading cause of global warming and climate change [1,2]. In conjunction with the effort to reduce these global problems, the use of renewable energy sources should be initiated and put into priority. In 2018, the use of renewable energy globally outside the use of traditional biomass had reached 11% of the total final energy consumption (TFEC), and this magnitude has increased by 9.6% compared to the previous five years [3].

Indonesia, as one of the largest countries in the world, is also working to increase the use of renewable energy as an active role in addressing the global climate problem. Population and economic growth, as well as world oil price conditions, in fact, also affect energy consumption in Indonesia. In 2018, total energy use in Indonesia was dominated by the transportation sector (40%), industry (36%), households (16%), and 8% by others [4]. From the total energy use, only 9% originated from renewable energy. Comparing several uses of energy types, electricity demand has the most significant growth, with an average of 7% per year. It is projected that in 2050 the use of electrical power will reach nine times the current condition or become 2562 TWh. However, the current electricity
generation from renewable energy is still around 12.4%, while the rest is fossil fuels, including 57% using coal [5].

The Government of Indonesia issued Regulation 79 of 2014, which aims to achieve 23% of energy production from new and renewable energy by 2025. This effort was taken by encouraging the production of electricity from renewable sources, among others from biomass, and reducing coal use to 32-41% by the year 2050. Like other countries, Indonesia, which has extensive land resources, is trying to catch up with the use of renewable energy from biomass. The Government, as stated in the General Plan of National Energy (Rencana Umum Energi Nasional-RUEN) is to encourage the improvement of non-food biomass cultivation as one of the principal renewable energy sources [6]. The use and cultivation of woody biomass-producing plants are also motivated by the ability of plants to absorb CO2 so that it also plays an important role in reducing greenhouse gases [7]. Renewable energy sourced from woody biomass, in the future, is predicted to dominate renewable energy because it can be developed in every place and produced as desired [8].

For a greater use as a power plant fuel, the current obstacle often faced is the continuity of supply of large amounts of biomass and the low heating value of available biomass. To overcome this obstacle, the cultivation of woody biomass as a source of renewable energy began to develop replacing fossil fuels [9]. The demand for woody biomass as a raw material must be balanced with an increase in land area for cultivation purposes. On the other hand, the need for land as a source of food, animal feed, energy, and other economic aspects increases in line with population growth. Conversion of forest cover is frequently done to meet the needs of agricultural land, and if this step is not accompanied by sustainable land management practices, it has led to the occurrence of critical land [10,11]. The process of critical land formation is accelerated by climate change through the increase in the frequency of high-intensity rainfall, which causes a high level of erosion in a barren land and triggers hydrometeorological disasters [12,13]. Based on these considerations, land allocated for woody biomass plantation should not convert productive agricultural land or well-covered forest land. Instead, woody biomass plantation should be developed on the critical lands as rehabilitation efforts whenever possible.

In the global trend, many countries enlarge the effort to utilize the degraded land using fast-growing species to fuel wood-based power plants. Its operations are not only carried out by large corporations but also on a small scale by local communities to anticipate the economic fluctuations that commonly have an impact on changes in energy sources [14-18].

In Indonesia, data on critical land is released by the Ministry of Environment and Forestry, which covers the distribution and area of critical land existing within inside and outside of the state forest area. Not all critical land has the same potency to be developed as a producer of woody biomass. In this regard, scientific considerations must be put into an account for land use planning, namely through land suitability analysis [19]. Therefore, this study aims to explore the critical land area suitable for woody biomass cultivation and estimate the electricity production that can be generated from the utilization of the degraded land.

2. Materials and Methods

The framework of this study was designed by employing four main steps in sequences, namely determining the priority areas of degraded land to be rehabilitated; conducting spatial analysis to identify the status and function of forest area on the map of degraded land produced in the first step; evaluating the suitability of critical land for the wood biomass cultivation based on GIS analysis, and finally calculating the potential output of electrical energy from power plants that utilize woody biomass from critical land. All spatial analyses were performed using ArcGIS Desktop 10.

To determine the availability of critical land, a spatial analysis was carried out by delineation of the newest critical land map (2018) released by the Ministry of Environment and Forestry. In the first stage, delineation was carried out by eliminating the polygon in the map that have uncritical, potentially critical, or moderately critical status so that a map with only critical and severe critical levels will be obtained. In the second stage, delineation is carried out by overlaying the map of critical
land that has been produced in the first stage, and the map of state forest functions. In Indonesia, the state forest areas are classified based on their function, namely protected forest areas, conservation forest areas, or production forest areas. The rest of the area is classified as non-state forest areas or commonly called as other use areas. The utilization of critical land as a development land of woody biomass is only possible in the production forest function areas and in the non-state forest area. Based on Government regulation, protected and conservation forest areas are prohibited from being used as locations for timber plantations. The second step of the procedure has produced critical land as the available for woody biomass plantation.

Based on this potential land, a suitability assessment was carried out based on the FAO [20] framework at the order level. Land suitability orders indicate global land suitability and provide an overview that indicates an area of the land is suitable or unsuitable for growing certain woody tree species. The analysis was carried out spatially by applying the maximum limitation method [21], which is the most stringent method in selecting the suitability status of land [19,22]. The woody tree species used in this study include Leucaena leucocephala (lamtoro), Calliandra calothyrsus (kaliandra), Gliricidia sepium (gaman), and Acacia auriculiformis (akasia). They are categorized as multipurpose legume tree species and included as the mainstay/superior species for woody biomass supply [23], as well as suitable for substituting the use of coal [24]. Suitability analysis in the maximum limitation method was then conducted by matching the land characteristics of the proposed critical land, compared to the land requirement of four tree species. The land characteristics consist of a set number of criteria in the form of land resource maps issued by the Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture. These suitability criteria included factors of soil (soil type, solum thickness, texture, and slope) and climate (rainfall, wet month, dry month, air temperature). The land requirement of four species was formulated based on the range of criteria that meet the four species. A critical land area was categorized as suitable if all the plant requirements are in line with the characteristics of the land. On the other hand, if one of the criteria cannot be met, then the area was categorized as unsuitable. This analysis produced a map of suitable areas along with the area information.

Woody-biomass yield and the potential result of electrical power can be calculated based on suitable critical land areas. The calculation is based on a number of assumptions from the references of the previous studies. In this study, there was a scenario for the area of suitable critical land that will be planted gradually in three years. The first woody-biomass harvesting will be carried out on the first stage of the plant at three years after planting. The next year’s harvesting will be applied on the second stage plantation, which will also already reach three years old, and so on following the three-year cycle. After harvesting, the plants will sprout and grow become woody plants, and then the wood will be harvested again after the age of three years. For the four tree species, the average of stand growth was assumed at the rate of 39 m³/ha/yr in 1x1 m² spacing [25-34], bulk density was 0.6 ton/m³, and the calorific value was 4000 kCal/kg [23,32,35,36].

The potential electrical power that can be generated from wood biomass-fueled power plants is calculated annually based on woody biomass that can be produced annually at the age of three years after planting. The converting technology of woody biomass to electrical power can be done through various processes, including direct combustion, gasification, pyrolysis, and anaerobic/aerobic digestion. For solid biomass fuels, the process commonly uses direct combustion because it is the simplest, relatively cheap, and more reliable [37,38]. The calculation of energy conversion used the thermal efficiency assumption of a steam engine. Currently, the efficiency values of woody-biomass fueled power plants are in the range of 25%-40%. In this study, the efficiency rate was set at 25% [39-43]. Based on the amount of electrical output, it can be calculated the number of households that can be served. The calculation uses the 2018 data of average electricity consumption for Indonesian households that amounting 1481 kWh/yr [44].
3. Results and Discussion

3.1. Critical land in Indonesia

By definition, critical land indicates the condition of land that does not function properly as a medium for the production and growth of cultivated plants or other plants, as mentioned in Law No.37 of 2014 concerning soil and water conservation. A similar understanding is stated in the Decree of the Minister of Forestry No.52/Kpts-II.2001 concerning the management of watershed management, where the critical land is described as the physical condition of land that cannot function well for crop productivity or as a water system management. In Indonesia, the newest data and map of critical land has been released by the Ministry of Environment and Forestry through Decree No. 306/MENLHK/PDASHL/DAS.0/7/2018 concerning on determination of critical land. The information was carried out using a geographic information system (GIS) involving land cover type, erosion level, and slope. Spatial analysis was done for the entire critical land in Indonesian, and the level has been classified into five critical levels, namely uncritical, potentially critical, moderately critical, critical, and severely critical. The results of these data analysis showed that from the total 190.5 million hectares land area of Indonesia, there are critical land areas with each category as displayed in Figure 1.

![Figure 1. Classification area of critical land](image)

Based on the criticality level, the land prioritized for rehabilitation is the area with a critical and severely critical level, and hence the total area is around 14 million hectares. However, not all of these areas are legally available for the activities of wood biomass production, because each part of the land has a functional status that will affect its management system. From the area of 14 million hectares, an analysis of the functional status of the area has been carried out based on forest area map issued by the Ministry of Environment and Forestry, and the results are presented in Table 1.

| Level          | Land Status Area (million Ha) | Total |
|---------------|-------------------------------|-------|
|               | Non-State Forest Area | Production Forest | Protected Forest | Conservation Forest |
| Critical      | 3.4                          | 3.6    | 1.5             | 0.7               | 9.3               |
| Severe Critical | 2.1                          | 1.5    | 0.8             | 0.3               | 4.7               |
| Total         | 5.5                          | 5.1    | 2.4             | 1.0               | 14.0              |

Table 1 shows that the critical lands that can be cultivated to produce woody biomass are in the status of the non-forest area covering 5.5 million ha and/or area with production forest function...
covering 5.1 million ha. The development of woody-biomass feedstock in the non-forest area in the context of critical land rehabilitation can be proposed using a community forest scheme. In the state forest area with the function of production forest, the cultivation of wood biomass can be done through an industrial plantation forest (HTI) scheme, community plantation forest (HTR), or using one of social forestry (PS) programs. Although critical land is not the ideal place for cultivation but the implementation of appropriate land management practices will be able to increase biomass production and thus land productivity. In addition to the selection of the appropriate species, optimization of critical land management is done by optimal fertilization, harvest time management, and water availability handling, especially in the early stages of tree growth [45].

3.2. Suitable area of the critical land
Table 1 shows the area of degraded land in the non-state forest area and the production forest area is 10.5 million ha. Even though this area is quite large, in reality, not all of this area is suitable to be developed for the production of wood biomass. From the analysis of land suitability, several factors of soil and climate conditions are considered as limiting factors for land suitability analysis. The analysis shows that only about 3.8 million hectares of critical land are suitable for the production of woody biomass, which consists of the non-state forest area of 2.3 million Ha and in the production forest area of 1.5 million Ha with the distribution as shown in Figure 1.

Figure 2 shows that the most widely distributed of degraded land has lain in the Sumatera region. The suitable land is mostly found in the Provinces of North Sumatera, Riau and South Sumatra with a total area of around 1.5 million hectares. North Sumatera has the largest suitable area, along with the degraded land in this province, which is the province with the largest critical land area, covering an area of about 1.3 million hectares. In addition to the Sumatra region, another region that has a quite large is the Java region with an area of around 1 million hectares. In this region, West Java Province has the largest area for suitable critical land in relation to biomass production. The region with the smallest suitable area is the Papua region with 169 thousand hectares, while the other regions have a suitable area at around 300 thousand hectares.

3.3. The potency of electricity production
Wood biomass plantations are predicted to be the primary source of renewable energy on a global scale in the near future. Various studies have predicted that the use of woody biomass is a potential...
energy source with magnitude up to 115 EJ/yr in 2050 [46]. Among several wood biomass supply systems, short-rotation energy forests provide advantages over traditional wood-planting systems that require longer harvest time intervals. This study used fast-growing woody species, namely *Leucaena leucocephala* (lamtoro), *Calliandra calothyrsus* (kaliandra), *Gliricidia sepium* (gamal), and *Acacia auriculiformis* (akasia). In Indonesia, the wood of these species are commonly utilized as firewood, and this is true because they are bearing good properties in terms of wood properties (density and calorific value), sprouts quickly after pruning, dense branching, and good adaptability on marginal land [47].

The first woody-biomass harvesting was simulated and done in the third year after planting (could be in the second year for the better land characteristics). Based on annual yield, electricity power resulted from the biomass-based power plant is presented in Table 2. The last column indicates the number of households can be supplied based on recent national data of average electricity consumption.

**Table 2. Potential woody-biomass and electricity resulted from suitable critical land**

| Region             | Suitable Area (Ha) | Production (m³/yr) | Woody Biomass (ton) | Electricity (KWh) | Household Supplied |
|--------------------|--------------------|-------------------|--------------------|-------------------|--------------------|
| Sumatera           | 1,554,067          | 60,608,594        | 36,365,156         | 42,292,676,983    | 28,556,838         |
| Jawa & Bali        | 1,010,560          | 39,411,846        | 23,647,108         | 27,501,586,068    | 18,569,606         |
| Kalimantan         | 399,382            | 15,575,902        | 9,345,541          | 10,868,864,321    | 7,338,869          |
| Sulawesi           | 311,516            | 12,149,129        | 7,289,477          | 8,477,661,915     | 5,724,282          |
| Maluku & Nusa      | 338,223            | 13,190,715        | 7,914,429          | 9,204,480,693     | 6,215,044          |
| Tenggara           | 169,303            | 6,602,823         | 3,961,694          | 4,607,449,954     | 3,110,040          |
| Papua              |                    |                   |                    |                   | 69,515,679         |
| Total              | 3,783,051          | 147,539,008       | 88,523,405         | 102,952,719,935   | 69,515,679         |

Remark: b=a*1/3*39m³/ha/yr*3yr; c=b*0.6 ton/m³; d=c*1,000kg*4,000kCal/kg*0.001163kWh; e=d/1481 kWh

Table 2 indicates that around 3.8 million hectares of suitable critical land are potentially available to support the electricity demand of 69.5 million households. The area of critical land, if fully optimized, can generate 102,953 GWh of electricity each year. This amount represents 44% of national electricity consumption for all sectors (234,618 GWh). By utilizing critical land to produce a renewable energy source, the electricity demand for all households totally in 2018 at a rate of 98,832 GWh can be fulfilled. However, the amount of electrical energy that can be produced from the critical land in Java and Bali regions is still below the region's total electricity demand, reaching as high as 61,594 GWh in 2018 [44]. For the Java and Bali regions, the use of renewable energy cannot rely solely on woody biomass due to limited land resource areas. Alternatively, the potential woody biomass will be used as an alternative fuel in coal-based power plants, knowing as co-firing or co-combustion.

The efforts to use biomass that are gradually replacing coal in power plants are starting to get a lot of attention from researchers due to several better advantages in terms of lower emission, ash content, sulfur, and classification of woody biomass as a carbon-neutral fuel [48]. The trial conducted by [49] showed that every MWh of electricity produced, there was a reduction in CO₂ emissions from 915 kg to 403 kg when co-firing with a ratio of 1:1 for woody biomass and coal. This research showed that substitution of woody biomass is significantly able to reduce the net CO₂ and NOₓ emission, without striking change in energy efficiency.

The Government of Indonesia is encouraging the development of biomass-based power plants through the issuance of the Ministry of Energy and Mineral Resource Regulation (Permen) Number 27 of 2014 and updated with Permen number 21 of 2016 which regulates the mechanism and tariffs for purchasing electricity from biomass power plants. By issuing this policy, the private sector is expected to be able to sell renewable electricity at more competitive prices. The latest policy of PT PLN (State Electricity Company) through its Board of Directors’ Regulations has instructed to implement the co-
firing of coal-fired steam power plants with biomass-based fuels. This effort is expected to accelerate the renewable energy mix without the need to build a new power plant [50]. This regulation should be supported by available wood biomass feedstock in sufficient quantities and competitive prices.

Increasing wood biomass production can be done by applying an intensive silviculture system and enhance with efforts in the form of using superior seeds and maintaining plants. In calliandra and acacia plants, the use of superior seeds can increase plant growth to 65 and 72 m³/ha/year, respectively [29]. In addition, low soil fertility can be overcome by applying organic matter, effective mycorrhizae, and fertilization [45,51] In the case of Leucaena species, the use of superior cultivars (Taramba) accompanied by fertilization of NPK 250 kg/ha/yr can produce 64 m³/ha/yr wood biomass [31].

4. Conclusion
From 14 million hectares of critical land area in Indonesia, there are 3.8 million hectares that are suitable for producing woody biomass. This area consists of 2.3 million hectares of non-state forest area and 1.5 million hectares of production forest area. The largest suitable area is located in the Sumatra region, while the smallest was in the Papua region.

The suitable area potentially produces electricity as high as 102,953 GWh and can supply 69.5 million households. The woody biomass resulted from critical land is also potential to be used as cofiring fuel in a coal-based power plant. Its application will have a significant impact on reducing CO₂ and NOx emissions without much-reducing energy efficiency.

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