Evaluation on community tree plantations as sustainable source for rural bioenergy in Indonesia

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Abstract. Indonesia has forest plantation resources in rural areas far from the national electricity grid that have potential as feedstock for biomass based electricity generation. Although some fast growing tree plantations have been established for bioenergy, their sustainability has not been evaluated to date. This research aimed to evaluate the growth of several tree species, cultivated by rural communities in Jawa Island, for their sustainability as a source for bio-electricity. For each tree species the biomass was calculated from diameter and height measurements and an estimate made for potential electricity generation based on density of available biomass and calorific content. Species evaluated included *Acacia mangium*, *A. auriculiformis, A. crasicarpa*, *Anthocephalus cadamba*, *Calliandra calothirsus*, *Eucalyptus camaldulensis*, *Falcataria moluccana*, *Gmelina arborea*, *Leucaena leucochephala* and *Sesbania grandiflora*. Among these species *Falcataria moluccana* and *Anthocephalus cadamba* showed the best potential for bioenergy production, with up to 133.7 and 67.1 ton/ha biomass respectively, from which 160412 and 80481 Kwh of electricity respectively could be generated. Plantations of these species could potentially meet the estimated demand for biomass feedstock to produce bioenergy in many rural villages, suggesting that community plantations could sustainably provide much needed electricity.

1. Introduction

Indonesia is facing an electricity energy crisis with an 88.3% electrification ratio in 2015 [1], indicating that power plant development is unable to keep up with demand from a growing population. In the last few decades, the government and the private sector have built power plants that mainly use coal and fossil fuel. However in many remote areas, the need for electricity still cannot be fulfilled. Indonesia's millions of hectares of abandoned land could be planted with fast growing tree species that, with appropriate management, could serve as a feedstock for biomass-based electricity generated in remote areas. The use of biomass energy is very relevant to the Indonesian Government energy policy of development of renewable energy sources to assist in reducing fossil fuel energy use from 49% to 20% of total energy consumption.

Furthermore, the development of bioenergy plantations on abandoned land could reduce or eliminate the displacement of agricultural land for food production to biomass for energy production. Therefore fast growing tree plantations on land not suitable for agriculture would never sacrifice food security.

When burned in a power plant, woody biomass produces less ash than the coal, saving on waste disposal [2]. Also, compared with fossil fuels, the use of biomass energy has lower CO_2 emissions, provides community income, and the residues can be used as fuel and fertilizer [3].

The case for biomass energy plantations in the tropics is promising, with several studies demonstrating their viability. For example, the study of [4] concluded that plantation trees are one of the largest sources of biomass in Thailand, with an annual energy potential of about 174–1600 PJ in 2010. This plantation biomass could supply up to 31.2% of estimated total energy consumption in Thailand at a biomass production cost of US$ 6–13.3 per ton, and with positive net present values for all the plantation options.

Some Indonesian tree species such as gamal, lamtoro, kihiyang, kaliandra, mete, red sengon, mindi, and gmelina are good sources of biomass energy. [5] using proxymate analysis according to the ASTM (*American Society for Testing Material)* standard, showed that stem of gamal, lamtoro, kihiyang, kaliandra, mete, and red sengon can be considered as good source of biomass energy, while mindi, gmelina had lower quality. [6] showed that tree species such as lamtoro, kihujan, turi, gamal, angsana, sengon, gmelina have sufficient caloric value to replace coal utilization in the cement industry, which made their development as a source of energy economically feasible.

Fast growing tree plantations are relatively low risk during cultivation and very popular among local communities to supply raw material for wood industries and provide a good economic return. The establishment of new areas of plantations is encouraged by the Indonesian Government due to their positive environmental impact, climate mitigation action as well as jobs provision [7]. Despite this rapid development most plantations are usually harvested for wood industry products and rarely as a source of bioenergy.

The development of fast growing tree species plantations as a source of bioenergy in Indonesia has not been well investigated, with most information on the potential for bioenergy from forest plantations available at experimental plot level. To assist with the further development of tree-based electricity generation, the objective of this study is to evaluate fast growing tree species in community forests as a potential source for bioelectricity.

2. Methodology

The study sites in West and East Jawa include a range community forests in lower (900 mm) to higher (over 4000 mm) annuall rainfall areas, each planted with fast growing tree species such as sengon, jabon and gmelina as cash crops either as agroforests or as monocultures. For each study site tree diameter at breast height (DBH), and tree height were measured and used with tree age to develop growth models and estimate biomass production. The theoretical electricity generation from the biomass (Table 1) was calculated using a formula developed by [8]. The opportunity for bioelectricity generation was then derived from the amount of land area available for planting with tree species often used as an energy source. The available lands included community forest and marginal land, and areas both in and out of designated forest.

Table 1. Calculation formula for conversion from biomass to electricity

Biomass : WP[a]	Calor (GJ/ton)[b]	Electricity (GWh)[b]	Efficiency 40%[c]
1.5: 1	1 ton WP = 19.8 GJ	1 GJ = 1 x 2.7^{-5} GWh	1 GJ = 1 x 1.1^{-4} GWh

Note : WP=wood pellet;
[a]Based on experiment;
[b][8];
[c][9]

Estimation of biomass from a plantation was done using allometric equations as shown in Table 2.

Table 2. Allometric equations for *A. mangium*, *P. falcataria* and other tree species

No	Tree Species	Allometric Equation	Source
1	*A. mangium*	$AGB = 0.199\ D^{2,148}$	[10]
2	*P. falcataria*	$AGB = 0.1126\ D^{2,3445}$	[11]
3	Other tree species	$AGB = \rho.V.BEF$ $V = 0.25\pi.(D/100)^2H.F$	[12]

Note: AGB =above ground biomass (kg);
D =diameter at breast height (cm);
ρ =specific weight (kg/m^3);
V =volume (m^3);
BEF =biomass expansion factor;
H =height (m);
F =tree form factor

3. Results and Discussions

3.1. Species utilized as bioenergy

The West Jawa (including Banten) sites in the Perum Perhutani area focused on the Government Forest Company districts of KPH Bandung Selatan, KPH Banten, KPH Garut, KPH Majalengka, KPH Tasikmalaya and KPH Sukabumi. District tree species, age and growth data are shown in Table 3.

Table 3. Tree stand characteristic for each species in West Jawa

District	Species	Age (yr)	Average height (m); Diameter (cm)	Planting space (m)	Tree growth (m3/ha/yr)	Biomass for energy (kg/ha/yr)
Bandung	*Pinus merkusii* (pinus)	65	50; 30	5x5	19.4 ± 1.3	2945
Banten and Tasikmalaya	*Paraserianthes falcataria* (sengon)	8	14; 20	5x5	22.9 ± 2.8	1183
Garut	*Calliandra calothyrsus* (kaliandra)	30	3; 18	1x1	32.7 ± 1.4	21909
Majalengka	*Acacia mangium* (acacia)	10	20; 35	6x6	23.3 ± 1.5	2175
Sukabumi	*Antocephalus cadamba* (jabon)	5	20; 30	5x5	25.4 ± 1.5	1246

In the wet conditions of Bandung, *Pinus* produced 19.4m^3/ha/year, similar to estimates of [13], who each reported average increments of around 19.5 m^3/ha/year. If we assume that 40% of biomass is potentially used for energy wood, and that wood density is 550kg/m^3, the pine can supply 7.76 m^3/ha/year at 46% water content, equal to 2945 kg/ha/year at 15% water content.

For a mature sengon tree, fresh trunks have a water content of 78% and can produce a total of 0.51 m^3 consisting of 0.30 m^3 of industrial wood per tree, and the remaining 0.21 m^3 can be used for energy wood. In other words, as much as 41 % volume of sengon trees can be used as energy wood. Based on

Table 3, if in one hectare there were 400 trees and the specific gravity is 340 kg/m^3, the sengon up to 6 years can potentially supply 9.4 m^3/ha/year or 1183 kg/ha/year of energy wood at 15% water content.

The West Java Kaliandra, planted in Garut in 1980, has been managed by the community for firewood by cutting and trimming the stems. Consequently, although the standing stock is quite old, the stem diameter is relatively small. From the cut stems, abundant shoots have grown, giving rise to short and dense tree form. Although the diameter at the base of the trunk is 15-20 cm, because of frequent trimming, the diameter of stems available for cutting is 2-4 cm; these branches were trimmed and weighed to evaluate biomass for bioenergy in this study. The average weight of kaliandra branches with twigs on each tree was 2.2 kg (oven-dry) and 2.5 kg (air-dry) showing that this part of the branch could potentially be used as raw material for wood pellets or firewood. Based on a Kaliandra wood density of 670 kg/m^3 and a plantation spacing of 1 x 1 m yielding 10,000 branches per ha every year, these branches with twigs could produce 32.7 m^3/ha/year, equivalent to 21909 kg/ha/year of biomass for bioenergy.

Observation on acacia trees indicated that the weight of the wet industrial wood assortment was 420 kg, while the total weight of the average acacia tree including the stem, branches and twigs was 830 kg. Total weight of wet biomass, which could be utilized for energy (including the tip of the stem, branches and twigs) is equal to 410 kg from each tree, or approximately 49.40% of the total weight of the tree biomass. Acacia fresh wood has a moisture content of about 42%, which made the potential for air-dried wood (15% moisture content) from all acacia trees for energy equal to 332.043 kg. If there are 278 trees/ha and the specific gravity is 700 kg/m^3, the acacia can potentially supply 11.5 m^3/ha/year or 2175 kg/ha/year of energy wood.

The weight for Jabon industrial wood was 245 kg, while total weight of the tree including stems, branches and twigs was 327 kg. Accordingly, wet weight of wood, which can be utilized for energy wood (including the tip of the stem, branches and twigs) is approximately 82 kg per tree, or about 25% of the total biomass. The moisture content of wet Jabon wood is 56% whereas for air-dried wood is 15% moisture. If there were 400 trees/ha and the specific gravity is 330 kg/m^3, jabon plantation can potentially supply 6.4 m^3/ha/year or 1246 kg/ha/year of energy wood.

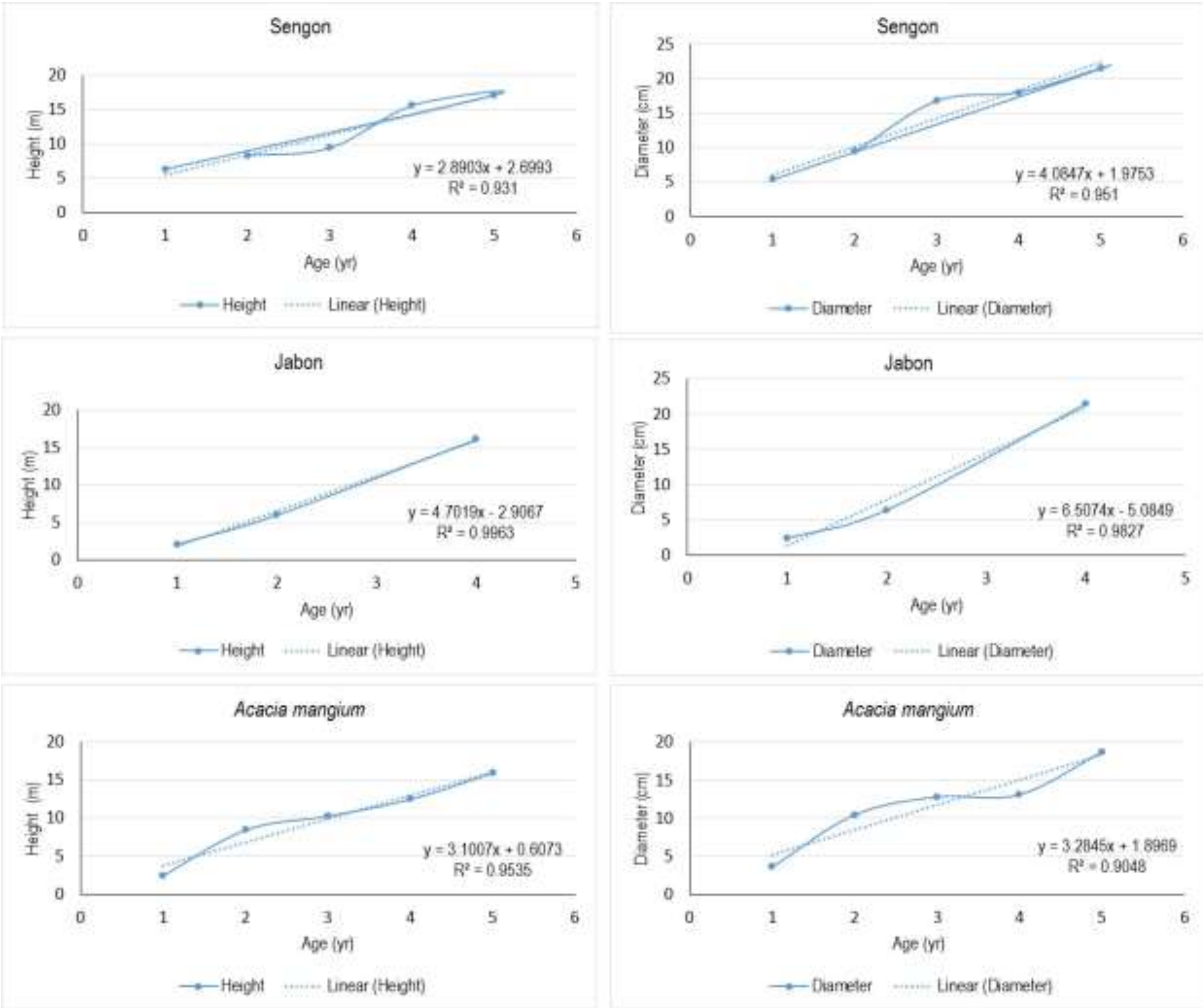

Figure 1. Growth model for height and diameter of sengon, jabon, and acacia plantations in West Jawa

In order to obtain estimation of tree growth in West Jawa, three fast growing tree species at different ages (sengon, jabon and acacia) were randomly selected in several community plantations for more detailed measurement of diameter and height relationship with age (regression equations given in Figure 1). In general all fast growing tree species studied increased growth rate to 5 years of age, although some species showed a decrease in growth, e.g. sengon showed decrease after only 2 years old and acacia after 3 years of age. Some unprecedented factors might affect those stands, such as early harvest by community for some selected trees, which left smaller trees in the field.

In East Jawa, the study focused on the four Districts of Malang, Situbondo, Kediri, and Bangkalan. In Malang, the study was located at Desa Mulyerejo, Kecamatan Ngantang. The location has 600 – 2800 m asl altitude and has Regosol/Entisol soil type with 2240-3850 mm/year annual rainfall. Potential species found in the location was sengon. In Kediri, the study was located at KPH Kediri, BKPH Pare that has 381 – 561 m asl altitude and Regosol soil type with 1886 mm/year annual rainfall. The main species in the location was also sengon. In Situbondo, the study was located at LMDH Sumber Jaya, Desa Sumberejo, Kec Banyuputih. This location has Latosol/Aluvial soil type with 994 – 1503 mm/year annual rainfall. Species found in the location was gmelina (*G. arborea*). The last area was located at Desa Kombangan, Kecamatan Geger. It has Litosol soil type with 2586 mm/year annual

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rainfall. Species found in the location was kaliandra (*C. calothirsus*). Average of measurement result for each location is shown in Table 4.

Table 4. Average tree diameter and height in four Districts of East Jawa

Location	Species	Height (m)	Diameter (cm)	Age (Months)	Planting Space
Malang	*P. falcataria*	1.0	1.0	6	3 x 2 m
		8.3	8.4	30	3 x 2 m
		18.0	34.5	44	3 x 2 m
Kediri	*P. falcataria*	0.7	0.8	1	3 x 2 m
		8.1	8.8	2	3 x 2 m
		13.5	14.1	3	3 x 3 m
		17.3	21.4	4	3 x 3 m
		22.0	22.3	5	3 x 2 m
Situbondo	*G. arborea*	7.4	10.2	6	unregular
		10.0	17.0	7	3 x 2 m
		39.8	18.0	20	unregular
Bangkalan	*C. calothirsus*	6.1	2.2	8	1 x 1 m
		6.4	4.0	2	1 x 1 m

Based on this measurement result, regression equations were made as shown in Figure 2.

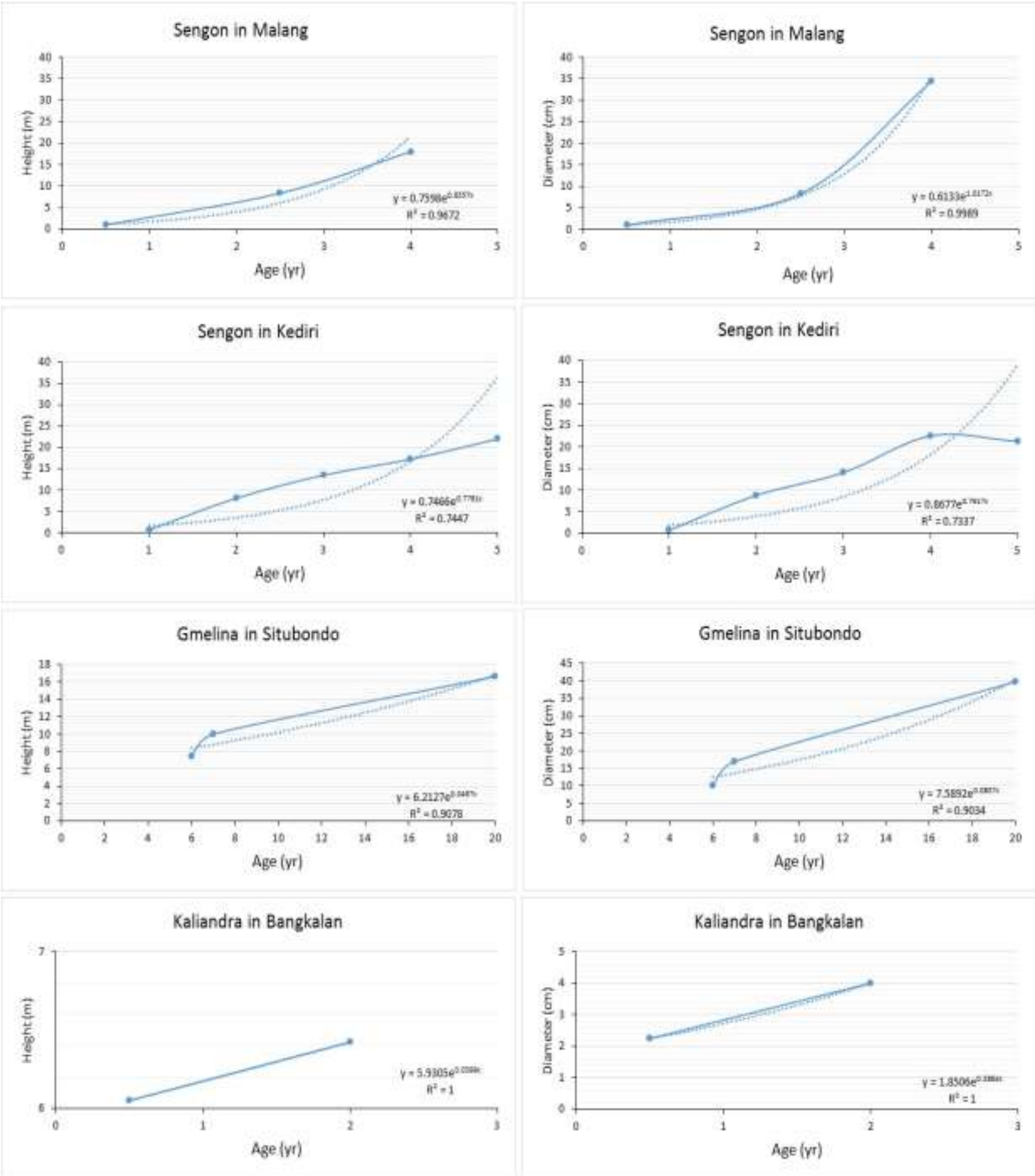

Figure 2. Growth model for height and diameter of sengon, gmelina, and kaliandra in East Jawa

3.2. Comparison on Biomass and Potentially Generated Energy

Based on height, diameter, and density measurement, the biomass value and potential wood pellet production rates were calculated, including electricity generation potential as shown in Table 5.

Table 5. Electricity characteristics resulted from some wood species

Location	Species	Age (yr)	Biomass (ton/ha)	Wood pellet (ton/ha)	Electric power (Kwh/ha/yr)	40% machine efficiency (Kwh)
West Jawa	Sengon	4	36.2	24.1	108467	43387
	Akasia	4	61.0	40.6	182878	73150
	Jabon	3	67.1	44.7	201203	80481
East Jawa	Sengon	4	133.7	89.1	401030	160412
	Jabon	3	56.4	37.6	169074	67630

Remark: electricity used by a house hold in a year = 450 watt x 24 hours x 30 days x 12 months

Sengon was found in all locations with the highest biomass occurring in East Jawa community forests. Utilization of one hectare of sengon as raw material for wood pellets can potentially supply electricity for 103 households. As a source of biomass, the growth of jabon species was better in the higher rainfall conditions of West Jawa compared to East Jawa.

Development of energy wood species is also initiated by community groups or the private sector. Table 6 shows the community forest area in each province that can be optimized for energy wood production. The Government should open the opportunity to utilize critical land for forest plantations to become a main source of energy. If it can be realized, the number of houses without electricity can be decreased. Up to 2013 there are 2.4 million house without electricity in West Jawa and 1.8 million in East Jawa at 2015 [14].

Table 6. Potential of energy wood development and resulted electricity

Location	Community forest (ha)[a]	Degraded land (ha)[b]	Total (ha)	Number of community Potentially get electricity	
				Household	Village[c]
West Jawa	973 860	1 387 711	2 361 571	48 884 155	21 853
East Jawa	659 414	2 126 619	2 786 033	114 946 792	54 451

[a][15];
[b][16];
[c]based on average household in each village [17]

Table 5 shows the number of households and villages that could receive electricity, based on total land area potentially available for plantations of energy wood species. West Jawa shows high potential to develop energy wood, although available land is not as high as in East Jawa. In West Jawa, potential electricity using woody biomass can support 21853 villages. East Jawa with higher available land for tree plantations, could potentially generate electricity from wood biomass to light 54451 villages. In West Jawa, jabon tree species potentially has the biggest role in supporting new electricity from woody biomass, while in East Jawa, sengon has the most potential.

4. Conclusions

Tree species found in West and East Jawa as energy sources were akasia (*Acacia mangium*), Jabon (*Anthocephalus cadamba*), Kaliandra (*Calliandra calothirsus*), *Gmelina arborea*, Sengon (*Falcataria moluccana* or *Paraserianthes falcataria*).

Jabon and sengon were two species which could potentially be adapted and developed as biomass energy plantations for electricity in West and East Jawa, due to their widespread occurrence and rapid growth. Estimation for Jabon and sengon showed those species potentially resulting up to 133.7 and 67.1 ton/ha biomass respectively, as well as 160412 and 80481 Kwh of electricity respectively.

Some problems still need to be addressed, such as the price competition between wood for energy and industrial wood, village condition (no population vs availability of lands), electricity price by a National Electricity Company (PLN), and social engineering.

References

[1] Kementerian Energi dan Sumberdaya Mineral [KESDM] 2016 *Statistik Ketenagalistrikan 2015* Edisi no.29 (Jakarta: Ditjen Ketenagalistrikan)
[2] Electric Power Research Institute (EPRI) 1995 *Making Biopower Work for Utilities: A Rationale for Near-Term Investment in Integrated Biomass Power Systems Project #3407* (December)
[3] Nienow S, Mc Namara K T, Gillespie A R and Preckel P V 1999 A Model for the Economic Evaluation of Plantation Biomass Production for Co-firing with Coal in Electricity Production *Agricultural and Resource Economics Review* April 1999.
[4] Sajjakulnukit B and Verapong P 2003 Sustainable biomass production for energy in Thailand *Biomass and Bioenergy* **25** 557 – 570
[5] Mulyasari T 2013 Characteristics of some wood species as biomass energy raw materials *Undergraduate Theses* (Bogor: Faculty of Forestry, Bogor Agricultural University)
[6] Cahyono T D, Coto Z and Febrianto F 2008 Heat value analysis and economic feasibility of wood utilization as coal substitution in cement factory *Forum Pascasarjana* **31** 105-176
[7] Elauria J C, Castro M L Y and Racelis D A 2003 Sustainable biomass production for energy in the Philippines *Biomass and Bioenergy* **25** 531-540
[8] Oak Ridge National Laboratory [ORNL] 2008 *Conversion Factors for Bioenergy* (North Carolina: North Carolina State University)
[9] Smith W R 1982 *Energy From Forest Biomass.* (Washington: Academic Press)
[10] Krisnawati H, Adinugroho C W, Imanudin R 2013 *Pedoman Penggunaan Model Alometrik untuk Pendugaan Biomassa dan Stok Karbon di Indonesia* (Bogor: Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi, Badan Penelitian dan Pengembangan Kehutanan – Kementerian Kehutanan)
[11] Siringoringo H H and Siregar C A 2006 Model persamaan allometrik biomassa total untuk estimasi akumulasi karbon pada tanaman Sengon *Jurnal Penelitian Hutan dan Konservasi Alam* **3** 541-553
[12] Krisnawati H, Adinugroho C W and Imanudin R 2012 *Model-Model Alometrik untuk Pendugaan Biomassa Pohon pada Berbagai Tipe Ekosistem Hutan di Indonesia* (Bogor: Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi, Badan Penelitian dan Pengembangan Kehutanan – Kementerian Kehutanan)
[13] Hartoyo and Nurhayati 1976 Rendemen dan sifat arang dari beberapa jenis kayu Indonesia *Laporan Penelitian* no.62 (Bogor: Lembaga Penelitian Hasil Hutan)
[14] Kompas 2015 Ada 1,7 juta rumah tangga di jatim belum nikmati listrik *Harian Kompas* 6 Oktober 2015
[15] Dephut 2013 *Profil Kehutanan 33 Provinsi* (Jakarta: Pejabat Pengelola Informasi dan Dokumentasi (PPID))
[16] Kemenhut 2015 Penetapan peta dan data hutan dan lahan kritis nasional tahun 2013 *SK Dirjen BPDASPS No. SK.4/V-DAS/2015*
[17] BPS 2014 *Data sosial dan kependudukan* (Jakarta: Badan Pusat Statistik)