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Searching for potential wood biomass for green energy feedstock: A study in tropical swamp-peat forest of Kutai Kertanegara, Indonesia

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Abstract. *Amirta R, Haqiqi MT, Saparwadi, Septia E, Mujiasih D, Setiawan KA, Sekedang MA, Yuliansyah, Wijaya A, Setiyono B, Suwinarti W. 2019. Searching for potential wood biomass for green energy feedstock: A study in tropical swamp-peat forest of Kutai Kertanegara, Indonesia. Biodiversitas 20: 1516-1523.* Recently, much attention has been focused on finding suitable plant species, from different forest ecosystems, having the potential to be used as sources of renewable energy. Most of such information was reported from the lowland forest area and only limited information is available regarding swamp-peat forest species, including their energy potency. Therefore, in this paper, plant diversity and energy potency of swamp-peat forest wood biomass were studied to reveal their potential as green energy feedstock. Physico-chemical characterization of wood biomass was performed using the American Society for Testing and Material (ASTM) protocols. Twenty-seven species of plants, consisting of 23 trees and 4 shrubs, belonging to 19 families were identified, amongst which *Shorea balangeran* had the highest importance value index (87.72%). The results showed that *T. obovata* exhibit the highest suitability to be used as energy feedstock indicated by the highest energy production of 4.60 MWh per ton of dry biomass, followed by *L. indica* (4.56 MWh/ton), *D. excelsa* (5.52 MWh/ton), *F. rukam* (4.20 MWh/ton), *P. galeata* (3.66 MWh/ton), *S. caudatilimbum* (3.61 MWh/ton), *A. elmeri* (3.59 MWh/ton), *G. nervosa* (3.49 MWh/ton) and *G. bancana* (3.42 MWh/ton). The high density of wood species correlated with the high value of energy potency. In contrast, the fast-growing tree and shrub species, such as *K. hospita* (1.76 MWh/ton), *C. odorata* (1.36 MWh/ton) and *O. sumatrana* (1.17 MWh/ton), showed lower energy potency. The most dominant plant species, *S. balangeran* gave only 2.96 MWh energy per ton of dry biomass and it was classified in the middle group of plant species suitable as green energy feedstock, along with other species, such as *C. brachiata*, *C. rotundatus*, *P. javanicum*, *V. umbonata*, *L. speciosa*, *V. pinnata*, and *A. longifolius*. Due to suitable energy properties, growth rate and also adaptability of this woody biomass, they can be exploited to support sustainable supply of biomass feedstock for the green electricity program in the study area.

Keywords: Biomass, feedstock, green energy, plant diversity, swamp-peat forest

INTRODUCTION

Currently, the concerns related to energy production from fossil fuels and associated environmental impacts are increasing. The issue of CO_2 emission from burning of fossil fuels and global warming is being discussed seriously in many developed and developing countries (Han and Shin 2014; Kumar et al. 2015; García and Bacenetti 2019). Indonesia and many other national governments have declared to start production of energy and fuels from renewable sources, mainly biomass. These governments have realized that the bioenergy and biofuel industries will increase the amount of domestic supply of energy and fuels with decrease in subsidy available for promotion of the bioenergy and biofuels (Watanabe et al. 2008). Bioenergy was also developed to replace fossil fuels in energy production in order to decrease greenhouse gas emissions into the atmosphere (Jiankun et al. 2012; Routa et al 2012). The important idea behind this practice is that bioenergy does not cause any net carbon dioxide (CO_2) emissions. The net carbon dioxide (CO_2) emissions from bioenergy were considered to be zero based on the fact that the amount of CO_2 released into the atmosphere during combustion is taken up again by the growth of the next generation plants (Wihersaari 2005; Lattimore et al. 2009).

Kalimantan province of Indonesia has vast areas of forest land with a high diversity of plant species. Massive wood biomass and other materials are produced here in various types of forest lands, such as low land forests, riparian forests and also swamp-peat forests. These forest materials consist of potential biomass feedstock for green energy production. However, even though the diversity of plant species and biomass resources are rich, lack of scientific information on their basic properties, functions, and suitability as the feedstock for energy production, is believed to be acting as the main barrier for effective utilization of the woody biomass (Amirta et al. 2016a). Understanding of the species diversity and richness, biomass productivity and its suitability to be used as the green energy feedstock is important not only for the sustainable supply of biomass-based energy for the community, but also for conserving and managing the swamp-peat forest itself.

Recently, much attention has been focused on finding suitable renewable energy plant species through research activities including identification of suitable biomass species and analysis of productivity and energy-related properties which can provide high-energy outputs to replace conventional fossil fuel energy sources. Plant sources suitable as wood biomass for energy feedstock purposes can be planted in forest land, using silvicultural practices in the form of fast-growing plantations (Yudego et al. 2017). Fast growing and short rotation coppice (SRC) species are ideal options for increasing the supply of wood biomass. Fast growing ability and shorter rotation cycles allow higher planting densities and thus, higher biomass yields per unit land area (Dillen et al. 2013; Ghaley and Porter 2014). However, only a little information about fast growing and short rotation coppice wood biomass plant species from swamp-peat forests, including their energy potency, is available so far. Most of the information of energy plant species were reported from the lowland forest areas, such as Willow (*Salix viminalis*), Poplar (*Populus trichocarpa*),_ Black Locust (*Robinia pseudoacacia*), and also Acacia (*Acacia melanoxylon*) and Eucalyptus (*Eucalyptus globulus*) trees, commonly used in Denmark, Germany, Poland, Italy, New Zealand and other European countries (Sims et al. 2001; Sims and Venturi 2004; Fiala and Bacenetti 2012; Dillen et al. 2013; Ghaley and Porter 2014; Hauk et al. 2014; Haverkamp and Musshoff 2014; Krzyzaniak et al. 2015; Niemczyk et al. 2018). Similar situation exists in Indonesia forest energy sector where very limited number of plant species, such as *Calliandra calothyrsus*, *Glyricidia sepium*, *Macaranga hypoleuca* and *Vitex pinnata* are known as the energy feedstock (Amirta et al. 2016a; 2016b). Therefore, in this paper, an attempt was made to find out the diversity, productivity and suitability of tree and woody shrub species in the swamp-peat forests of East Kalimantan, Indonesia which has the potential be used as high-quality feedstock for sustainable green energy production.

MATERIALS AND METHODS

Study area

The current research was conducted in the swamp-peat forest area of Muara Siran village (116º48'34.656"E, 0º37'7.093" N), sub-district of Muara Kaman, Kutai Kertanegara District, Indonesia. The swamp-peat forest at Muara Siran village has an area of about 40,598 ha with the annual temperature of 24-30ºC, while the daily temperatures fluctuate between 3ºC to 4ºC. The daily average ambient humidity was 80%, 90% in the morning and down to 70% in the afternoon. The annual precipitation was 2367.27 mm, while the mean monthly precipitation ranged between 108.6 mm to 322.9 mm.

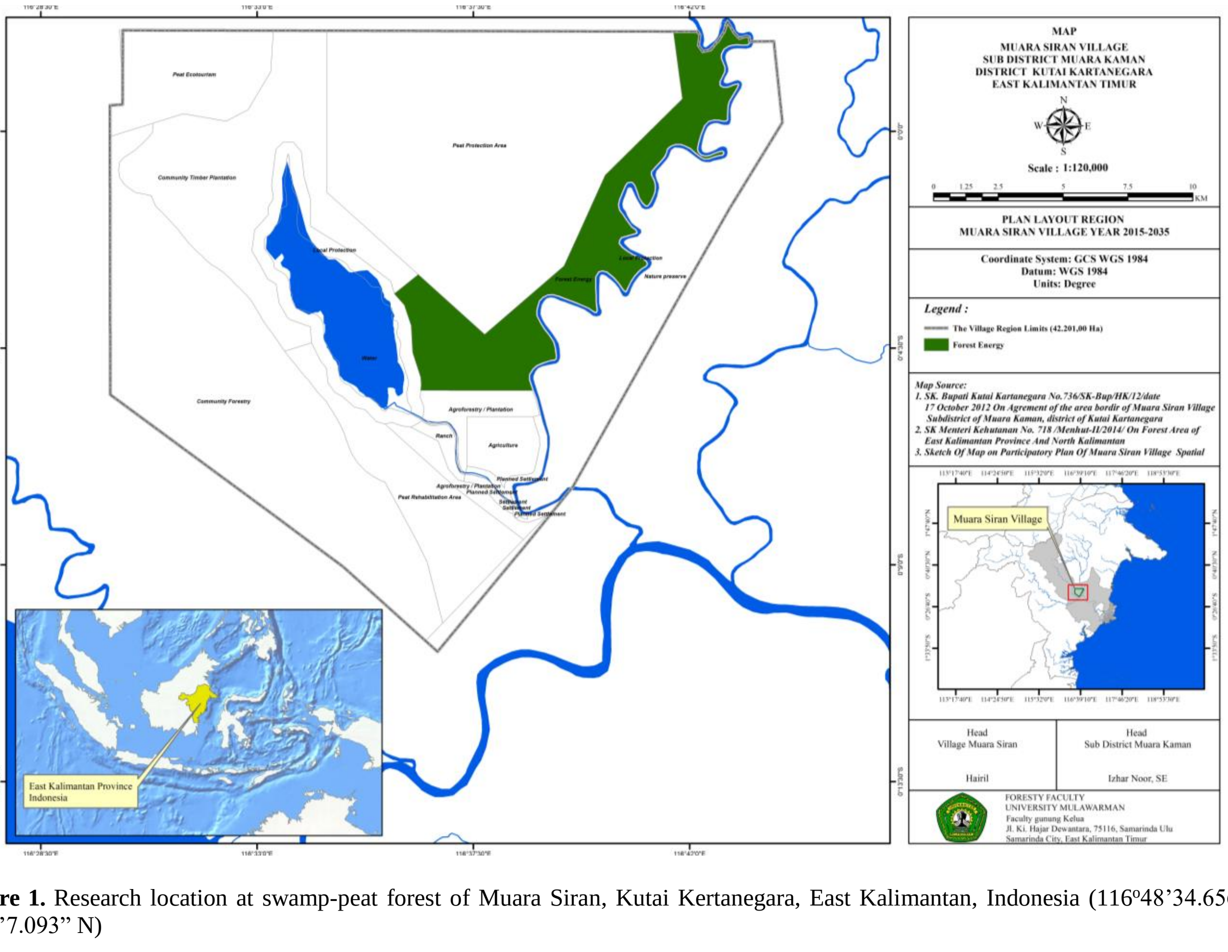

Figure 1. Research location at swamp-peat forest of Muara Siran, Kutai Kertanegara, East Kalimantan, Indonesia (116º48'34.656"E, 0º37'7.093" N)

Diversity of plant species

Ten sampling plots of the size of 20m x 20m which were distributed around the swamp-peat forest of Muara Siran village, Kutai Kertanegara, East Kalimantan were used to collect the data about tree and woody shrub species richness that has the potential to be used as the green energy feedstock. In addition, the importance value index of plant species present in research area was calculated using the formula of Mueller-Dombois and Ellenberg as described and reported by Wiryono et al. (2016).

Collection of biomass of plant species

Biomass in the form of leaves and branches of tree and woody shrub species with diameter about 5-10 cm were collected from swamp-peat forest located at Muara Siran Village, Kutai Kertanegara District, East Kalimantan Province, Indonesia. The plant samples were identified at the Laboratory of Forest Dendrology, Faculty of Forestry, Mulawarman University, Samarinda, Indonesia. The wood samples were debarked, chipped, air dried, and used throughout this study.

Physico-chemical characterization and energy potency of wood biomass

The physicochemical characterization of the collected swamp-peat forest biomass was performed using the common analysis protocol of the American Society for Testing and Material (ASTM) D 7582-12. The various parameters analyzed consist of moisture content, ash value, density, volatile matter, and fixed carbon tests. In addition, to determine the elemental composition of wood biomass such as carbon (C), hydrogen (H) and oxygen (O), and to find out the higher calorific value (HCV), the protocols proposed by Parikh et al. (2005; 2007) was used. Then, the conversion ratio of solid to chip wood and biomass energy potency was calculated based on Francescato et al (2008).

RESULTS AND DISCUSSION

Diversity of plant species

Twenty-seven plant species consisting of 23 trees and 4 woody shrubs, which belong to 19 families, were listed from the ten plots sampled at swamp-peat forest of Muara Siran (Table 1). Among the tree and shrub species studied, *Shorea balangeran* had the highest importance value index (87.72%), followed by *Enterolobium cyclocarpum* (60.10%), *Syzygium caudatilimbum* (21.96%), *Carallia brachiata* (19.31%) and *Kleinhovia Hospita* (13.35%), respectively (Table 1). *S. balangeran* (Dipterocarpaceae) with highest density and frequency was dominant among all plant species in the swamp-peat forest of Muara Siran. Myrtaceae emerged as the family with a maximum of three plant species identified in this study. These species are: *S. caudatilimbum*, *S. chloranthum* and *T. Obovata*. Almost similar with this finding, Thomy et al. (2018) and Yulisma et al. (2018) reported that the most dominant species in Tripa peat swamp forest, Aceh have also belonged to Myrtaceae and Dipterocarpaceae. The dominant presence of Myrtaceae members may be related to their genetic and adaptability factors (Yulisma et al. 2018).

In general, it was found that the plant species were grown using two different regeneration systems, i.e., natural and artificial, that played an important role in revegetation, sustainable production and also conserving the swamp-peat forest ecosystem. The tree and shrub plant species of swamp-peat forest were also used by local community to support their biomass need for many purposes. The plant biomass of many species such as *A. dumosa, A. elmeri, A. longifolius, C. rotundatus, C. brachiata, F. rukam, S. balangeran, T. obovata, V. pinnata*, and *V. umbonata* was used as firewood, construction materials and for making furniture. In addition, *G. nervosa* and *K. hospita* were used traditionally as herbal medicine. Recently, the active compound of *K. hospita* was reported as a potential herbal medicine for curing liver cancer (anti-cancer), along with seven species of *Macaranga* (Arung et al. 2009; 2018).

Physico-chemical analysis of swamp-peat forest plant species

The use of biomass species for energy purposes should be carefully evaluated, analyzing logistical aspects of their location, transport, biomass heterogeneity and also storage. In addition, appropriate physicochemical and energy properties should be known. Accordingly, physicochemical characteristics of tree and shrub plant biomass collected from swamp-peat forest of Muara Siran were analyzed. The results demonstrated that the average of green moisture contents (after cutting) and wood densities of swamp-peat forest biomass were 43.41% and 0.58 g/cm^3, respectively (Table 3). It was found that, after chipping and air drying processes, the average of moisture content of wood biomass decreased significantly from 43.41% to 11.11%. Chipping and air drying were effectively reduced the moisture content from the wood biomass as much as expected. The low moisture content (MC) of wood chip was appropriate to the requirement for biomass energy feedstock (MC $\leq$ 15%). Thus, similar to some earlier reports, we also proved that chipping and air drying effectively reduced the moisture content from the wood biomass (Pérez et al. 2014; Sixto et al. 2015; Amirta et al. 2016a). According to earlier reports of McKendry (2002), Brammer and Bridgwater (2002), Pereira et al. (2012) and Pérez et al. (2014), this feature favors thermochemical conversion since high moisture content harms the performance of the conversion systems. It is possible to burn any type of biomass, but in practice, combustion is feasible only for biomass with a moisture content of <50%, unless the biomass is pre-dried. Further, the lower moisture content of the biomass (less than 30%) is also suitable for the gasification process (McKendry 2002; Widjaya et al. 2018).

Table 1. Plant species collected from the sampling plots located at swamp peat forest of Muara Siran, Kutai Kertanegara, East Kalimantan, Indonesia

Plant species	Family	Local name	Category	Utilization	Regene-ration
Adinandra dumosa Jack	Pentaphylacaceae	Kayu harang	Tree	Firewood	Artificial
Alseodaphne elmeri Merr.	Lauraceae	Medang	Tree	Firewood	Artificial
Artocarpus longifolius Becc.	Moraceae	Terap hutan	Tree	Construction	Natural
Cananga odorata (Lam.) Hook.f. & Thomson	Annonaceae	Kenanga	Tree	Medicine	Natural
Carallia brachiata (Lour.) Merr.	Rhizophoraceae	Bakau	Tree	Furniture	Artificial
Combretocarpus rotundatus (Miq.) Danser	Anisophylleaceae	Perepat	Tree	Construction	Artificial
Dillenia excelsa (Jack) Martelli ex Gilg.	Dilleniaceae	Simpur	Tree	Construction	Artificial
Dracontomelon dao (Blanco) Merr. & Rolfe	Anacardiaceae	Sengkuang	Tree	Furniture	Natural
Enterolobium cyclocarpum (Jacq.) Griseb.	Fabaceae	Sengon buto	Tree	Firewood	Artificial
Eurya nitida Korth.	Pentaphylacaceae	Bunga	Shrub	Firewood	Natural
Ficus hispida L.f.	Moraceae	Kebolo	Shrub	Firewood	Artificial
Flacourtia rukam Zoll. & Moritzi	Salicaceae	Rukam	Tree	Furniture	Artificial
Garcinia bancana Miq.	Clusiaceae	Asam gendis	Tree	Firewood	Natural
Garcinia nervosa Miq.	Clusiaceae	Manggis hutan	Tree	Medicine	Natural
Kleinhovia hospita L.	Malvaceae	Tahongai	Tree	Medicine	Natural
Lagerstroemia speciosa (L.) Pers.	Lythraceae	Bungur	Tree	Firewood	Natural
Leea indica (Burm. f.) Merr.	Vitaceae	Mali	Shrub	Medicine	Natural
Litsea robusta Blume	Lauraceae	Tiju	Tree	Construction	Natural
Octomeles sumatrana Miq.	Tetramelaceae	Binuang	Tree	Construction	Natural
Pternandra galeata Ridl.	Melastomataceae	Temberas	Tree	Firewood	Natural
Pterospermum javanicum Jungh.	Malvaceae	Bayur	Tree	Construction	Artificial
Shorea balangeran Burck	Dipterocarpaceae	Kahoi	Tree	Construction	Natural
Syzygium caudatilimbum (Merr.) Merr. & L.M.Perry	Myrtaceae	Bluma	Tree	Construction	Natural
Syzygium chloranthum (Duthie) Merr. & L.M.Perry	Myrtaceae	Bumbun	Shrub	Construction	Natural
Tristaniopsis obovata (Benn.) Peter G.Wilson & J.T.Waterh.	Myrtaceae	Pelawan	Tree	Construction	Natural
Vatica umbonata Burck	Dipterocarpaceae	Mas intan	Tree	Construction	Natural
Vitex pinnata L.	Lamiaceae	Laban	Tree	Firewood	Natural

Table 2. Top five plant species based on their importance value index in the study area, Muara Siran, Kutai Kertanegara, East Kalimantan, Indonesia

Plant species	Family	Local name	Rdo	RF	RDe	IVI
Shorea balangeran	Dipterocarpaceae	Kahoi	45.67	12.50	29.55	87.72
Enterolobium cyclocarpum	Fabaceae	Sengon buto	41.69	2.50	15.91	60.10
Syzygium caudatilimbum	Myrtaceae	Bluma	1.50	10.00	10.45	21.96
Carallia brachiata	Rhizophoraceae	Bakau	5.22	5.00	9.09	19.31
Kleinhovia hospita	Malvaceae	Tahongai	1.99	5.00	6.36	13.35

Note: Rdo: relative dominance; RF: relative frequency; Rde: relative density; and IVI: importance value index

The results of this study showed that biomass of plant species of swamp-peat forest in Muara Siran may be classified into three different classes of wood density: low, middle and high densities that related to their growing ability, basic properties and also characteristic of each species studied. Among 27 plant species studied, we found that 4 species belonged to low density (0.2-0.4 g/cm$^{3)}$, 12 species to middle-density group (0.4-0.6 g/cm^3), while other 11 species to high-density group (0.6 > 0.9 g/cm^3) of wood plant species. The species with low and middle density of wood biomass, such *O. sumatrana, C. odorata, K. hospita*, and *E. Cyclocarpum*, positively correlated with their high-speed growth ability and they commonly belonged to pioneer plant species. The low-density biomass will consume fast in the reactor (gasifier/burner). Moreover, the low density of biomass (bulky) will also lead to high transport and storage costs, and in many cases, it is associated with high humidity that can make it impossible to be used (de Oliveira et al. 2013; Widjaya et al. 2018; Albashabsheh and Stamm 2019). In contrast, the species with high density of biomass, such as *P. galeata, D. excelsa, T. obovata*, and *L. Indica,* generally required longer time to grow and mature. In line with the previous studies, physicochemical properties of biomass commonly varied with plant species, and it will greatly affect the utilization of the resources (Vassilev et al. 2010).

Table 3. Moisture content (MC), wood density and conversion ratio of solid wood to wood chip of plant species collected from swamp-peat forest of Muara Siran, Kutai Kertanegara, East Kalimantan, Indonesia

Plant species		Moisture content (green wood) (%)	Moisture content (wood chip) (%)	Wood density (g/cm^3)	Wood chip conversion ratio (kg/m^3)
Latin name	**Local name**				
Adinandra dumosa	Kayu harang	41.04	11.08	0.53	266
Alseodaphne elmeri	Medang	41.40	8.67	0.67	336
Artocarpus longifolius	Terap hutan	39.22	12.99	0.55	276
Cananga odorata	Kenanga	52.36	12.42	0.29	146
Carallia brachiata	Bakau	52.47	10.16	0.60	301
Combretocarpus rotundatus	Perepat	45.13	12.86	0.65	326
Dillenia excelsa	Simpur	41.17	10.54	0.88	442
Dracontomelon dao	Sengkuang	41.78	10.75	0.62	311
Enterolobium cyclocarpum	Sengon buto	37.29	12.77	0.40	201
Eurya nitida	Bunga	51.32	11.45	0.51	256
Ficus hispida	Kebolo	60.10	13.33	0.49	246
Flacourtia rukam	Rukam	43.94	9.97	0.67	336
Garcinia bancana	Asam gendis	41.11	11.58	0.67	336
Garcinia nervosa	Manggis hutan	43.96	11.21	0.63	316
Kleinhovia hospita	Tahongai	43.76	14.18	0.34	171
Lagerstroemia speciosa	Bungur	50.56	12.44	0.55	276
Leea indica	Mali	28.71	8.46	0.92	462
Litsea robusta	Tiju	44.12	11.20	0.53	266
Octomeles sumatrana	Binuang	49.35	7.43	0.22	110
Pternandra galeata	Temberas	35.37	12.16	0.72	362
Pterospermum javanicum	Bayur	38.77	9.36	0.51	256
Shorea balangeran	Kahoi	47.74	10.18	0.59	296
Syzygium caudatilimbum	Bluma	42.73	10.74	0.68	342
Syzygium chloranthum	Bumbun	52.36	14.27	0.51	286
Tristaniopsis obovata	Pelawan	30.42	9.82	0.90	452
Vatica umbonata	Mas intan	37.63	10.35	0.57	286
Vitex pinnata	Laban	38.31	9.61	0.57	286
	Average	43.41	11.11	0.58	294

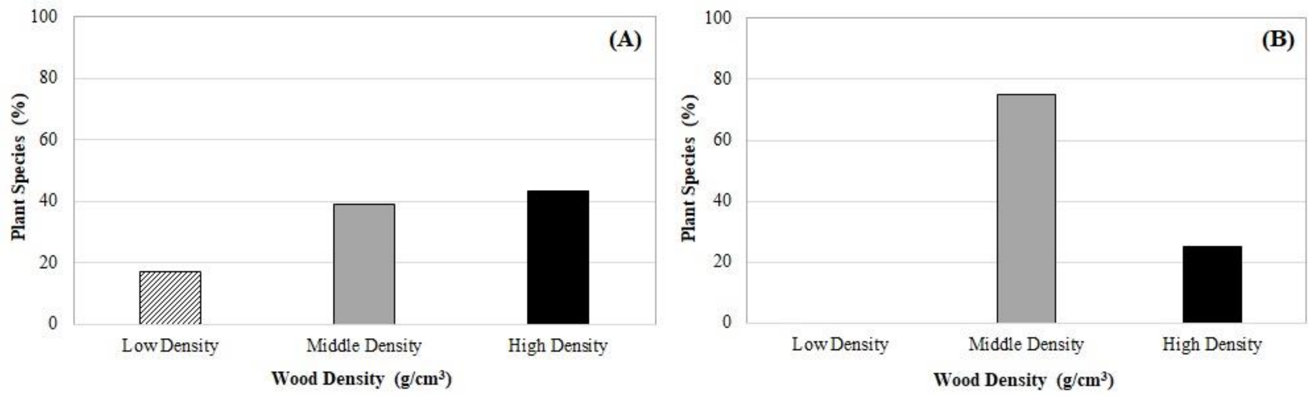

Figure 2. Wood density comparison among (A) trees and (B) woody shrubs collected from swamp-peat forest of Muara Siran, Kutai Kertanegara, Indonesia

Since the purpose of this research was to find out the energy potency of wood biomass, a series of laboratory tests have been conducted to evaluate the proximate, ultimate and also calorivic value of the sample. The results indicated the high proportion of volatile matter in biomass of trees and shrubs (70.04%) (Table 4). These high values allow biomass to get ignited easily. The high volatile matter (from 70 to 86%) will improve the combustion rate of the biomass during the devitalization phase. On the contrary, low volatile matter causes high smoke from incomplete combustion, and it also releases toxic gases (Van Loo and Koppejan 2008). Volatile matter and fixed carbon were also known to play important roles in flame stability during combustion (Virmond et al. 2012). The results also showed low average value of ash content (1.98%). The low ash content leads to better suitability of fuels for thermal utilization. In contrast, high ash content causes high dust emissions and negatively affects combustion efficiency (Ivanova et al. 2018).

Table 4. Proximate analysis of biomass of plant species collected from swamp-peat forest of Muara Siran, Kutai Kertanegara, Indonesia

Plant species		Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Calorific value (kCal/kg)
Latin name	**Local name**				
A. dumosa	Kayu harang	73.71	12.23	1.00	4327
A. elmeri	Medang	74.53	12.28	0.43	4690
A. longifolius	Terap hutan	68.52	15.85	3.38	4563
C. odorata	Kenanga	69.53	12.46	2.41	4230
C. brachiata	Bakau	67.48	16.75	1.42	4661
C. rotundatus	Perepat	68.73	14.09	2.15	4350
D. excelsa	Simpur	65.88	17.71	3.72	4539
D. dao	Sengkuang	72.37	13.13	2.31	4407
E. cyclocarpum	Sengon buto	72.73	14.79	0.57	4664
E. nitida	Bunga	71.57	13.80	1.84	4491
F. hispida	Kebolo	71.05	14.19	2.64	4532
F. rukam	Rukam	70.30	16.92	0.58	5408
G. bancana	Asam gendis	71.76	13.99	0.84	4525
G. nervosa	Manggis hutan	71.19	15.76	0.91	4857
K. hospita	Tahongai	71.45	13.95	0.60	4634
L. speciosa	Bungur	66.75	15.91	2.52	4822
L. indica	Mali	70.68	14.62	2.52	4360
L. robusta	Tiju	68.74	14.33	4.76	4287
O. sumatrana	Binuang	70.04	14.48	1.87	4619
P. galeata	Temberas	71.69	14.17	1.55	4522
P. javanicum	Bayur	67.44	18.25	1.52	5213
S. balangeran	Kahoi	65.58	15.63	4.95	4432
S.caudatilimbum	Bluma	68.27	17.21	1.94	4678
S. chloranthum	Bumbun	67.77	16.44	2.77	4616
T. obovata	Pelawan	74.44	12.18	1.38	4507
V. umbonata	Mas intan	68.49	15.96	1.43	4672
V. pinnata	Laban	70.37	15.37	1.37	4550
	Average	70.04	14.91	1.98	4598

Table 5. Ultimate analysis of biomass of plant species collected from swamp-peat forest of Muara Siran, Kutai Kertanegara, Indonesia

Plant species		Carbon (%)	Hydrogen (%)	Oxygen (%)
Latin name	**Local name**			
A. dumosa	Kayu harang	41.33	5.21	38.80
A. elmeri	Medang	41.73	5.26	39.21
A. longifolius	Terap hutan	42.96	6.03	37.43
C. odorata	Kenanga	39.57	4.96	36.88
C. brachiata	Bakau	43.63	5.73	37.21
C. rotundatus	Perepat	41.34	5.11	37.78
D. excelsa	Simpur	43.91	5.73	36.57
D. dao	Sengkuang	41.29	5.17	38.44
E.cyclocarpum	Sengon buto	42.67	5.17	39.12
E. nitida	Bunga	41.35	5.15	38.26
F. hispida	Kebolo	42.63	5.23	37.96
F. rukam	Rukam	44.73	5.47	38.61
G. bancana	Asam gendis	41.56	5.18	38.41
G. nervosa	Manggis hutan	42.77	5.40	38.51
K. hospita	Tahongai	45.62	5.52	38.25
L. speciosa	Bungur	45.33	5.13	36.61
L. indica	Mali	41.47	5.14	38.09
L. robusta	Tiju	40.40	5.01	37.08
O. sumatrana	Binuang	41.09	5.10	37.74
P. galeata	Temberas	41.65	5.18	38.43
P. javanicum	Bayur	42.33	5.47	37.00
S. balangeran	Kahoi	41.84	5.23	35.80
S.caudatilimbum	Bluma	44.78	5.06	37.73
S. chloranthum	Bumbun	44.59	5.92	37.26
T. obovata	Pelawan	41.63	5.25	39.14
V. umbonata	Mas intan	43.86	5.42	37.45
V. pinnata	Laban	43.73	5.53	38.00
	Average	42.58	5.32	37.84

Moreover, from the ultimate analysis, we found that the average value of carbon, hydrogen and oxygen contents of wood biomass was 42.58%, 5.32%, and 37.84%, respectively (Table 5). The average of carbon, hydrogen and oxygen contents of plant biomass collected in the current study indicate that they belong to good quality of fuel biomass, and suitable to be used as green energy feedstock. Wood biomass could be used as fuel/green energy when the carbon content varied between 30-60%, 5-6% of hydrogen, 30-40% of oxygen, and the other elements are less than 1%, respectively (Ivanova et al. 2018).

Furthermore, among twenty-seven samples tested, highest calorivic value of wood biomass was obtained from *F. rukam* (5408 kCal/kg) which was followed by *P. javanicum* (5213 kCal/kg) and *G. nervosa* (4857 kCal/kg), respectively. Interestingly, these plant biomass were not used locally as firewood materials (Table 4). Instead, they were used as traditional herbal medicine, construction wood, and furniture materials. In contrast, the lowest calorific value was obtained from *C. odorata* (4230 kCal/kg). This phenomenon was acceptable, since we knew that suitability of wood biomass as energy feedstock was not directly linked only to a single factor such as calorific value, but it should be connected and combined with other energy properties. According to McKendry (2002) and Huhtinen (2005), a combination of properties such as moisture content, calorific value, fixed carbon, volatile matter, ash content and chemical composition of wood biomass are important and should be considered for dry biomass conversion process.

The wood biomass properties should be considered as a unit of energy factor to give an appropriate indication of suitability of wood biomass to be used as green energy feedstock. Based on this condition, twenty-three tree and four shrub species were evaluated completely. The results showed that *T. obovata* exhibit the highest suitability to be used as energy feedstock indicated by the highest energy production of 4.60 MWh per ton of dry biomass, , followed by *L. indica* (4.56 MWh/ton), *D. excelsa* (5.52 MWh/ton), *F. rukam* (4.20 MWh/ton), *P. galeata* (3.66 MWh/ton), *S. caudatilimbum* (3.61 MWh/ton), *A. elmeri* (3.59 MWh/ton), *G. nervosa* (3.49 MWh/ton) and *G. bancana* (3.42 MWh/ton) (Figure 3). The high density of wood species very much correlated with and clearly affected the high value of energy potency. Similar phenomenon was also reported from the wood biomass collected from the lowland community forest (Amirta et al. 2016a). In contrast, the fast-growing tree and shrub species, such as *K. hospita* (1.76 MWh/ton), *C. odorata* (1.36 MWh/ton) and *O. sumatrana* (1.17 MWh/ton), showed lower energy potency. The most dominant plant species, *S. balangeran* gave only 2.96 MWh energy per ton of dry biomass and it was classified in the middle group of plant species suitable as the green energy feedstock, along with other species, such as *C. brachiata*, *C. rotundatus*, *P. javanicum*, *V. umbonata*, *L. speciosa*, *V. pinnata*, and *A. longifolius*. Due to suitable energy properties, growth rate and also adaptability of this woody biomass, we really believe that they can be exploited to support sustainable supply of biomass feedstock for the green electricity program in the area.

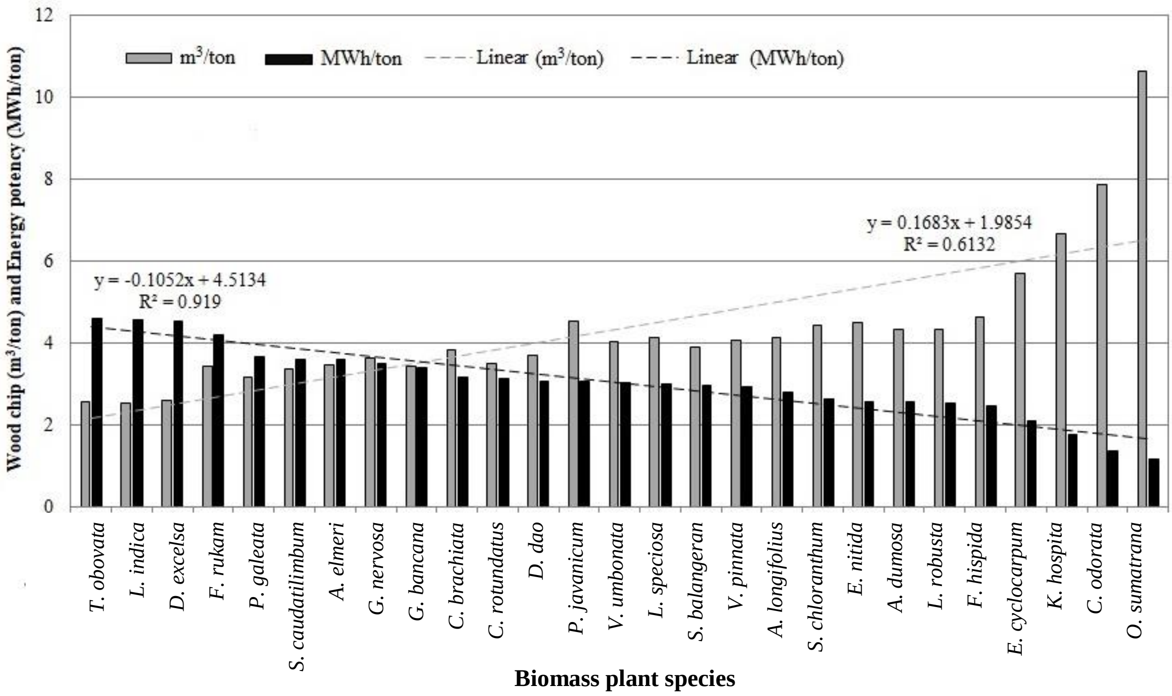

Figure 3. Comparison between wood chip conversion ratio and energy potency from tree and shrub species collected from swamp-peat forest of Muara Siran, Kutai Kertanegara, Indonesia

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