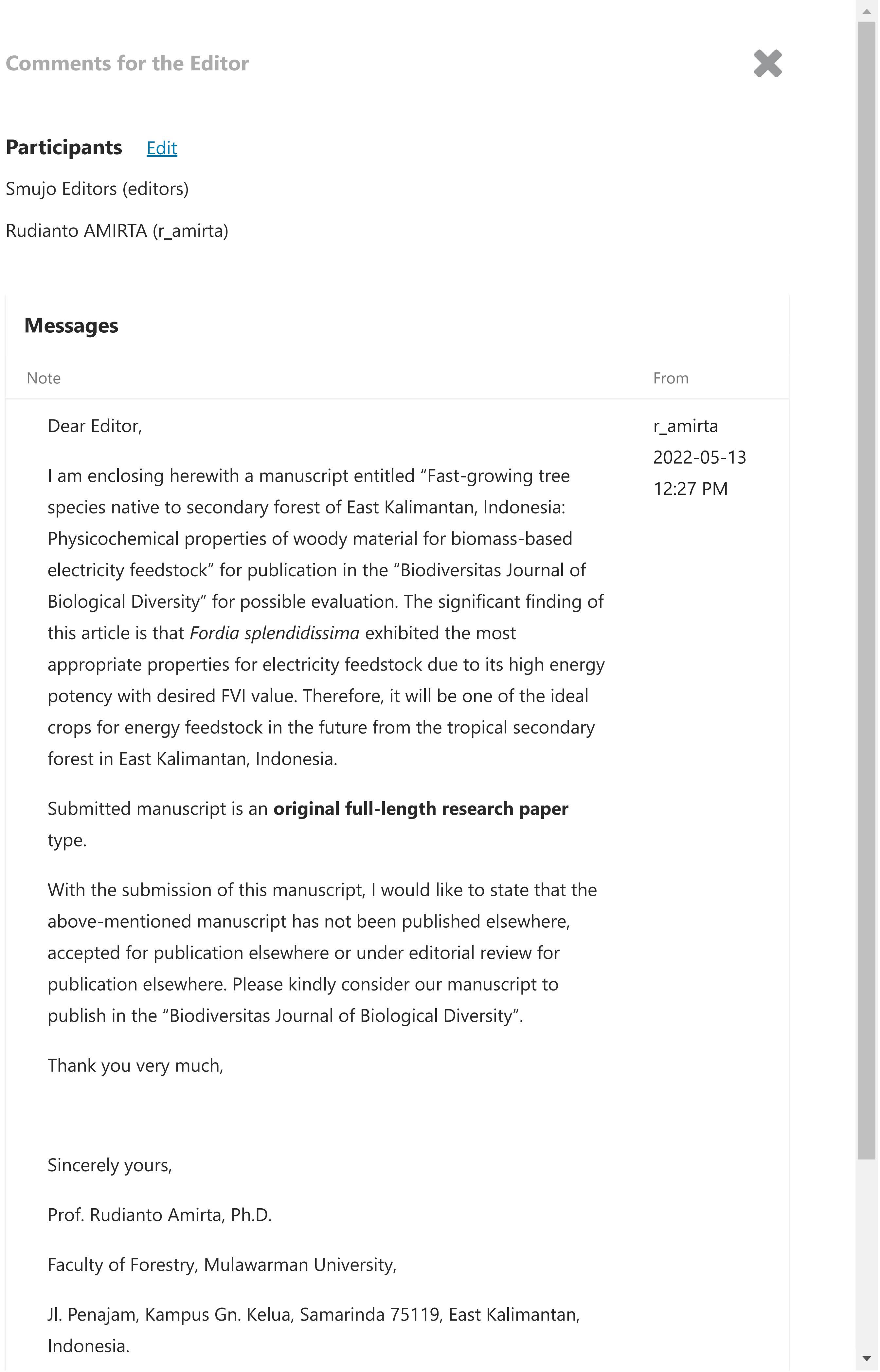


Comments for the Editor

Participants

Smujo Editors (editors)

Rudianto AMIRTA (r_amirta)

Messages

Note	From
Dear Editor, I am enclosing herewith a manuscript entitled “Fast-growing tree species native to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody material for biomass-based electricity feedstock” for publication in the “Biodiversitas Journal of Biological Diversity” for possible evaluation. The significant finding of this article is that *Fordia splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency with desired FVI value. Therefore, it will be one of the ideal crops for energy feedstock in the future from the tropical secondary forest in East Kalimantan, Indonesia. Submitted manuscript is an **original full-length research paper** type. With the submission of this manuscript, I would like to state that the above-mentioned manuscript has not been published elsewhere, accepted for publication elsewhere or under editorial review for publication elsewhere. Please kindly consider our manuscript to publish in the “Biodiversitas Journal of Biological Diversity”. Thank you very much, Sincerely yours, Prof. Rudianto Amirta, Ph.D. Faculty of Forestry, Mulawarman University, Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.	r_amirta 2022-05-13 12:27 PM

Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

YULIANSYAH[1], MUHAMMAD TAUFIQ HAQIQI[1], KRISNA ADIB SETIAWAN[1], AGUS SETIAWAN[1], PRISTIANGGA DWI SAPUTRA[1], HERI SUKMA IQBAL ROMADLON[1], AHMAD MUKHDLOR[1], RICO RAMADHAN[2], RUDIANTO AMIRTA[1♥]

[1]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683. ♥email: ramirta@fahutan.unmul.ac.id.
[2]Department of Chemistry, Faculty of Science and Technology, Universitas Airlangga. Jl. Mulyorejo, Surabaya 60115, East Java, Indonesia.

Manuscript received: .... Revision accepted: .... 20xx.

ABSTRACT

The conversion of woody biomass into electricity through a thermochemical process has recently attracted significant attention worldwide to promote green energy production. It provides a low-cost and straightforward operation that is promising for developing rural areas, especially areas with limited transportation access. In East Kalimantan Province, almost all remote areas are surrounded by forests with high tree species diversity, which is potential to be utilized for sustainable feedstocks in electric power plants. This study pointed out the energy potential produced from woody biomass of selected fast-growing tree species that is native to East Kalimantan secondary tropical forest: *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull. Arg. and *Schima wallichii* (DC). Their wood physicochemical properties were firstly investigated. Furthermore, the wood quality for solid energy purposes from each species was presented as the fuel value index (FVI). The results revealed that the change from green wood into wood chip effectively removed the moisture content; thus improving efficiency to achieve higher energy potency. Our findings showed that the highest energy potency was obtained from the wood chip of *S. splendidissima* (3.61 MWh/ton), followed by *S. wallichii* (2.98 MWh/ton). A similar pattern was also found in FVI determination showing that wood chip of *S. splendidissima* had the greatest value (8970). Therefore, we observed that the high quality of *S. splendidissima* compared to other selected fast-growing species indicates its high suitability for further large-scale crop plantation to supply wood chips for a biomass-based-electricity generation.

Keywords: Electricity, fast growing, native species, secondary forest, woody biomass.

Running title: Fast growing tree species native to secondary forest.

INTRODUCTION

The exploitation of fossil fuels has significantly increased the degradation of natural resources and the environment. Its combustion corresponding to generate electricity constantly accelerates the global warming potential. According to the report from the International Energy Agency, energy production from fossil fuels sectors is responsible for more than 80% of released carbon dioxide (CO_2) in the atmosphere, or it is estimated to exceed two-thirds of total greenhouse gas (GHC) emission (Ram et al., 2018; Cardoso et al., 2019). Although the Paris Agreement in 2015 implicitly called for shifting away from the domination of fossil fuels, the human population and industrialization are continuously growing, creating a significant challenge on how to mitigate climate change and reduce those harmful GHC effects (Karmaker et al., 2020; Rempel and Gupta, 2020). The United Nations (UN), through the Climate Action Summit in New York in 2019, has set a global plan to achieve net-zero emission by 2050 (Mutezo and Mulopo, 2021). Therefore, many countries have committed to addressing a transition from fossil fuels to renewable energy by implementing a legal policy (Mola-Yudego et al., 2017; Moya et al., 2019; Rincon et al., 2019).

Among all resources, biomass has been considered the most applicated renewable energy globally, with the proportion of 12.4% of the total energy consumption (Wang et al., 2020). Energy production from biomass is expected to meet global energy demands in the future (Bilgili et al., 2017). It offers various advantages over other renewable sources, such as better energy properties and less CO_2 emission (Liu et al., 2014; Tenorio et al., 2015). Woody biomass harvested from the forest is also one of the promising feedstocks to produce energy. Since almost all remote areas in Indonesia are covered by forests with limited transportation access, the approach to use its biomass will be adequate to overcome the electricity limitation in those rural areas. Moreover, it will create an improved economic growth by providing micro or small-scale electricity with a simple and cheaper process. When the wood was burned during the combustion stage, the CO_2 emission can be easily absorbed by available forest plant species through photosynthesis. Thus, the net cycle of CO_2 is always in balance, and this phenomenon is known as neutral carbon (Mäkipää et al., 2015; Proto et al., 2021). It will potentially lead to a zero-emission power system (Johansson et al., 2019). Excellent performance of biomass-based electricity using forest materials has been previously reported (González et al., 2015). Furthermore, it has also been successfully developed in many countries in the world, such as in Brazil (Bacellar and Rocha, 2010), United States (Broughel, 2019), Ghana (Präger et al., 2019), Portugal (da Costa et al., 2020), and Japan (Battuvshin et al., 2020).

East Kalimantan province was reported as one of the most considerable bioenergy potentials in Indonesia due to its high availability of wood biomass resources from forest (Simangunsong et al., 2017). The high diversity of biomass plant species distributed in the tropical rain forest of East Kalimantan was also reported as the most essential biodiversity value in Indonesia for many endemic species compared to other places on the earth (Pio and D'Cruz, 2005). However, the wood harvested from its forest resources was still dominated by Dipterocarpaceae family which was commonly used in the furniture and construction purposes. Although it had promising calorific values, it was considered the low growing tree species that was not desirable for sustainable energy crops (Yuliansyah et al., 2016). On the other hand, fast-growing tree species planted in forest plantation such as *Acacia mangium*, *Anthocephalus cadamba*, *Eucalyptus pellita*, *Gmelina arborea*, and *Paraserianthes falcataria* have been reported to possess low heating value (Amirta et al., 2016; Haqiqi et al., 2022). Therefore, finding suitable plant species having high wood calorific value combined with its fast-growing ability to obtain high biomass yield for energy-electricity production is recently growing (Haqiqi et al., 2018).

The investigation of native species can be an important step to search for the suitable plant biomass species to be cultivated as energy crops in some remote areas. In East Kalimantan Province, many local fast-growing species are characterized as non-commercial species, even known as species with high adaptability to grow well in their origin ecosystem. They are mainly found in plant communities at secondary forest succession. Commonly used as firewood by local people, those species still have less attention for further large-scale utilization, especially for energy production. These species will promise future plantation of short-rotation wood crops to provide sustainable raw materials with the faster-growing ability. However, further wood physicochemical analysis was necessary to meet the requirements for an ideal energy crop. Herein, this study reported the comparison of wood physicochemical properties of selected fast-growing tree species that are native to East Kalimantan forest to be used as feedstocks in electricity production.

MATERIALS AND METHODS

Study area

Wood biomass materials and leaf samples from some fast-growing native species were collected at secondary forest of Mulawarman University Educational Forest (KHDTK Fahutan UNMUL, Samarinda), Samarinda City, East Kalimantan Province, Indonesia (0°25'10"LS – 0°25'10"LS and, 117°14'00"BT-117°14'14"BT - 300 ha).

Biomass plant species

Medium trees with the diameter of 6-8 cm recognized as native fast-growing species naturally grown on secondary tropical rain forest associated in East Kalimantan were pointed out. Identification through leaf herbarium specimen of each species was deposited at Laboratory of Forest Dendrology and Ecology, Faculty of Forestry, Mulawarman University. In this study, six species were identified namely *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull.Arg. and *Schima wallichii* (DC). They belong to different family groups including elaeocarpaceae, moraceae, fabaceae, lauraceae, euphorbiaceae and theaceae, respectively. The woody biomass samples were debarked to analyze dry bark-wood ratio, following by converting into wood chip before proceeded to laboratory analysis.

Determination of wood physicochemical properties and energy potency

The total moisture and proximate compositions of wood materials were carried out according to ASTM D 7582-12 method. The lost weight of the samples after reaching the constant weight in a hot air oven at 105°C was calculated to determine the moisture content. For proximate analysis, the samples were dried and grounded into smaller size (±60 mesh). The measurements consisted of two steps in a furnace. The first step was done by heating from 300-575°C for 3 hours. The loss of weight was measured and noted as substance of volatile matter (VM). Then, the temperature was increased to reach 950°C for 2 hours to heat the remaining samples. After cooling down to room temperature, the residual weight was measured in ash content while the lost weight was fixed carbon (FC).

The ultimate compositions of wood biomass including carbon (C), hydrogen (H), and oxygen (O) were estimated based on the following Equation (Parikh et al., 2007):

$$C\ (\%) = (0.637 \times FC) + (0.455 \times VM) \quad (1)$$

$$H\ (\%) = (0.052 \times FC) + (0.062 \times VM) \quad (2)$$

$$O\ (\%) = (0.304 \times FC) + (0.476 \times VM) \quad (3)$$

Measurement of wood density (kg/m^3) was conducted by drying the wood samples at 105°C following Henry et al., 2010. The wood calorific value (MJ/kg) was accomplished in a bomb calorimeter in accordance with the standard from EN-ISO 15400:2011 following by calculation of energy-electricity potency according to Francescato et al. (2008). Those measurements were classified into green wood and wood chip. Furthermore, the fuel value index (FVI) was calculated using the equation as follow (Jain and Singh, 1999):

$$\text{FVI} = \frac{\text{Calorific value x wood density}}{\text{Ash content x moisture content}} \tag{4}$$

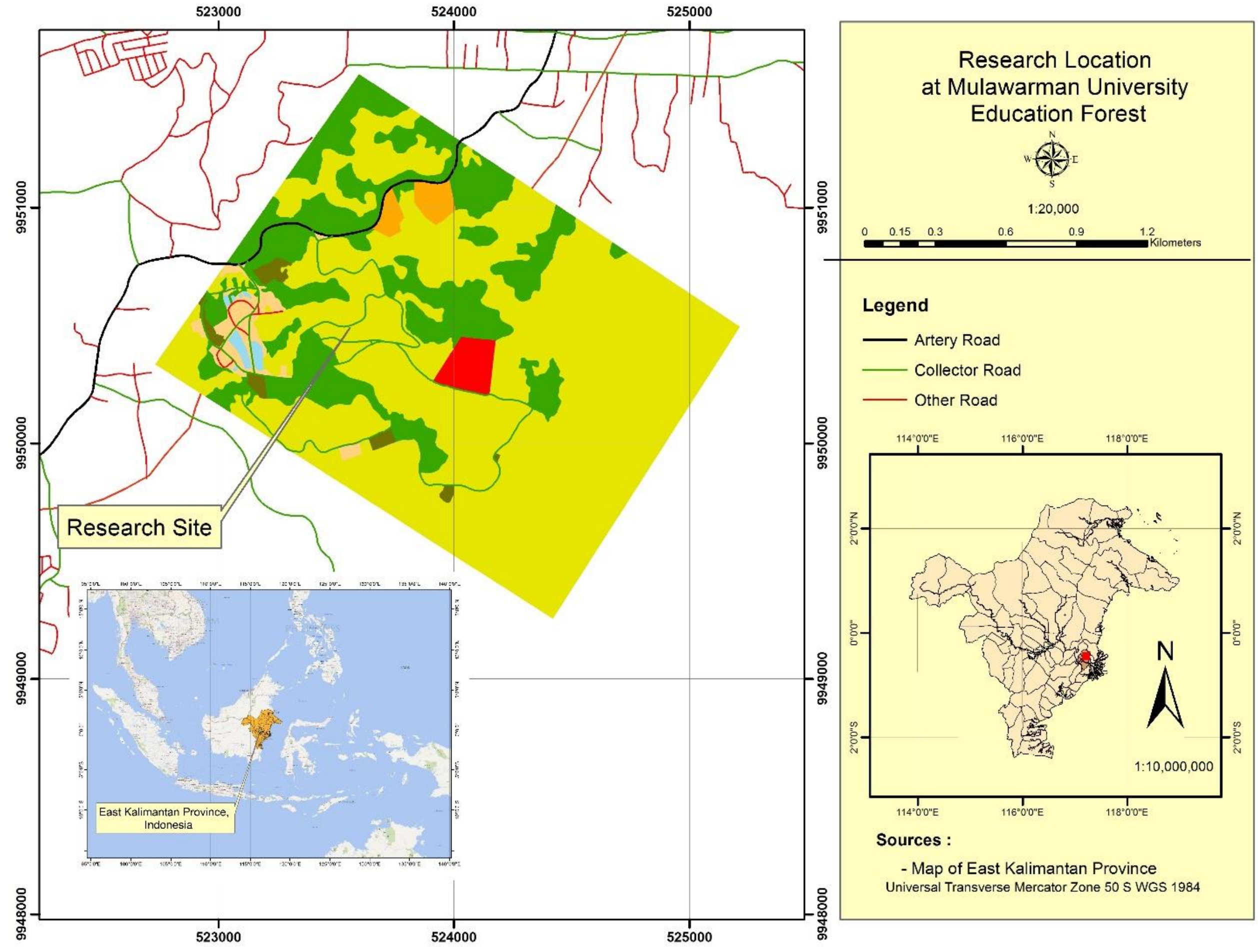
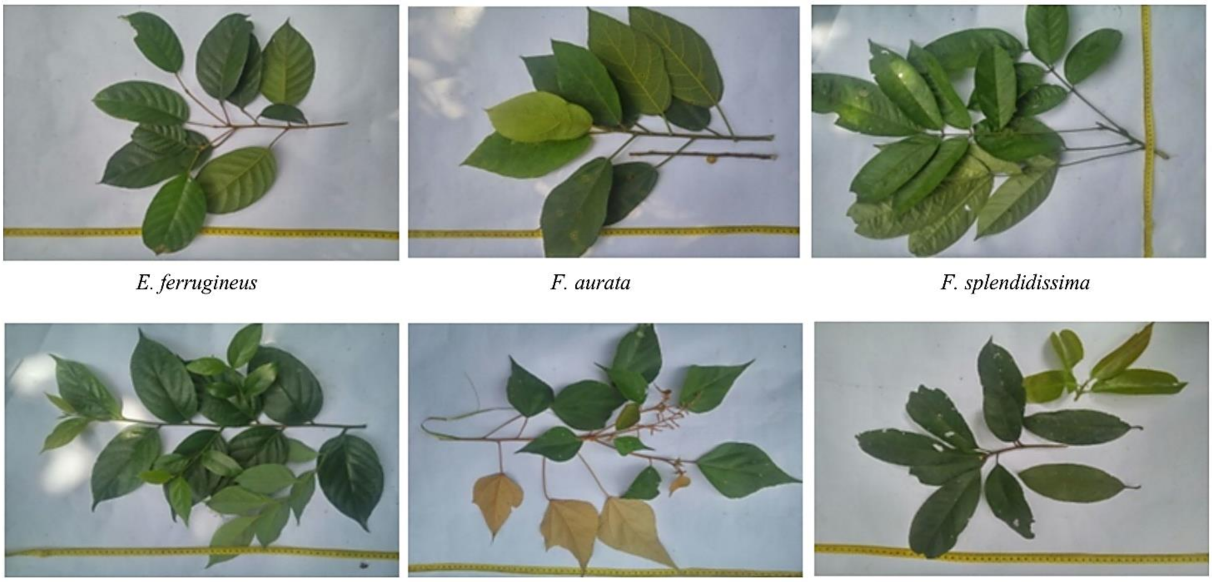


Figure 1. Research location conducted at Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia (0°25'10"LS – 0°25'10"LS and, 117°14'00"BT-117°14'14"BT).



E. ferrugineus *F. aurata* *F. splendidissima*

L. lucida *M. paniculatus* *S. wallichii*

Figure 2. Fresh leaf shape varities of some fast-growing native tree species collected from secondary forest of Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia.

RESULTS AND DISCUSSION

Plant biomass species

Generally, tropical forest area provides better environmental condition for plants to produce a sustainable biomass with high yield. This condition will lead to its potential wide-range application in biomass-based conversion technology, such as electricity generation. However, previous study demonstrated that forest biomass species with high energy content were commonly produced from low growing species (Amirta et al., 2016). In the large-scale electricity production, utilization of the low growing species in energy feedstocks requires slow harvest cycle period with high-cost operation. Therefore, in this study, woody materials obtained from selected fast-growing species, including *E. ferrugineus*, *F. aurata*, *F. splendidissima*, *L. lucida*, *M. paniculatus*, and *S. wallichii were assessed for the purpose of energy-electricity feedstock.* Those species are abundant and native to secondary forest of East Kalimantan in which the local people traditionally used their wood as firewood for cooking activity. Nevertheless, literature describing those plant species for further industrial application is still rare. The measurement of bark and wood proportion of each species was summarized in Table 1. It was notice able that three species including *E. ferrugineus, F. aurata,* and *F. splendidissima* had the lowest bark-wood ratio (0.7). The highest bark proportion was obtained from *S. wallichiii*, followed by *M. paniculatus*, and *L. lucida* with the value of 12.95%, 11.22%, and 7.80%, respectively. It has been reported earlier that stem bark of *E. ferrugineus* was potential for malaria-like symptoms treatment (Ismail et al., 2015). On the other hand, *S. wallichii* bark could be utilized as an antimicrobial agent (Dewanjee et al. 2008). Hence, due to these interesting properties, it could potentially enhance their application for both energy feedstocks and natural medicine products. Since the stem bark produced high quantity of ash (Pérez et al., 2008), its removal from wood when used for energy production through thermochemical conversion is necessary.

Table 1. Wood and bark ratio of some fast-growing tree species native to secondary forest of East Kalimantan, Indonesia.

Plant Species		**Bark Proportion**	**Wood Proportion**	**Bark-Wood Ratio**
Latin name	**Local name**	**(%)**	**(%)**	
E. ferrugineus	Belau	6.37	93.63	0.07
F. aurata	Kayu ara	6.65	93.35	0.07
F. splendidissima	Makumpit	6.70	93.30	0.07
L. lucida	Madang	7.80	92.20	0.08
M. paniculatus	Balik angin	11.22	88.78	0.13
S. wallichii	Puspa	12.95	87.06	0.15
Average		**8.62**	**91.39**	**0.10**

Wood physicochemical properties

Moisture content, density, and chip capacity of woody materials examined from some selected native tree species were summarized in Table 2. It has been previously reported that the percentage of wood moisture content depends on the plant species, season, and condition of storage (Mancini and Rinnan, 2021). In green condition, the highest wood moisture content was obtained from *S. wallichii* (59.25%), while the lowest moisture content could be found on *F. splendidissima* (40.37%). The conversion of the wood into chip form evidently reduced their moisture content. As shown by Table 2, all wood chips revealed lower percentage of moisture compared to that of the green wood conditions. It was found that the average moisture content of wood chips was 9.58%. It seems that wood chip form could easily evaporate the amount of water. Surprisingly, this situation could also provide benefits to considerably increase the achieved calorific value due to the water loss phenomenon (Figure 3A). According to the measurement of wood density, it was found that the highest wood density was obtained from *F. splendidissima* (750 kg/m^3). The second and third largest were found at *E. ferrugineus* (580 kg/m^3) and *S. wallichii* (550 kg/m^3) wood, respectively. The average value of wood density from all species used in this study was 510 kg/m^3. Meanwhile, their form changes into wood chip needed high capacity of storage. It was found that the average value of wood chip of all species was 201 kg per m^3 of storage area. The high wood density contributed to increase the efficiency of wood chip storage. As could be observed from *F. splendidissima*, its wood chip (300 kg/m^3) was the most efficient storage capacity among all woody materials used. Especially for the large-scale operation, high density of wood chip potentially contributes to produce low energy production cost (Bahadori et al., 2014). In contrast, low wood density affects the fast burning of reactor, high transport costs, and high storage capacity (de Oliveira et al., 2013).

Table 2. Moisture content, wood density and chip capacity of some fast-growing tree species native to secondary forest of East Kalimantan, Indonesia.

Plant Species		Moisture content (%)		Wood density	Chip capacity
Latin name	**Local name**	**Green wood**	**wood Chip**	**(kg/m^3)**	**(kg/m^3)**
E. ferrugineus	Belau	49.77	9.34	580	229
F. aurata	Kayu ara	56.90	9.62	490	193
F. splendidissima	Makumpit	40.37	9.81	760	300
L. lucida	Madang	50.64	9.64	350	138
M. paniculatus	Balik angin	52.85	9.52	330	130
S. wallichii	Puspa	59.25	9.53	550	217
Average		**51.63**	**9.58**	**510**	**201**

Proximate and ultimate analysis was carried out by various laboratory tests. The proximate analysis includes ash, fixed carbon, and volatile matter (Table 3). These parameters strongly affected performance of combustion, pyrolysis, and gasification of wood biomass in the thermochemical conversion process (Tursunov and Abduganiev, 2020). Ash content of all woody materials showed less than 5%, which demonstrated their high potency utilized for raw materials of energy production. The low value of ash residue (<5%) resulted from the combustion process has a positive impact to increase the efficiency stage and to avoid damage of the electricity reactor (Shao et al., 2011). Nimmanterdwong et al. (2021) stated that the ash in biomass directly related to the mineral and inorganic element absorbed by plants from the ground via the root cells, while its percentage differently depended on the soil properties, rocks, chemical treatment, and available metal contents. The volatile matters of all woody materials in this study were in the range of 73.83 – 75.87%, whereas the fixed carbons were in the range of 12.96–14.82%. It has been reported that heat decomposition of cellulose and hemicellulose in biomass is sources of volatile matters, whereas lignin is a source of char due to its richness in carbon atoms (Vega et al., 2019). The ultimate compositions, including C (carbon), H (hydrogen), and O (oxygen), were presented in Table 4. This investigation is very essential to determine the theoretical air-fuel ratio in the thermochemical system and to predict the released pollution (Telmo et al., 2010). The average value of C, H, and O was 42.72%, 5.35%, and 39.70%, respectively. It was clearly observed that all woody materials contained C higher than O, indicating its high suitability used as the energy feedstock since high C content will increase the obtained calorific value. Moreover, the C content with the value of more than 40% in this study was in line with that of C content of various tropical woods reported earlier (Amirta et al., 2016; Amirta et al., 2019; Yuliansyah et al., 2019; Mukhdlor et al., 2021).

Table 3. Proximate analysis of some fast-growing tree species native to secondary forest of East Kalimantan, Indonesia.

Plant Species		Ash Content	Fixed Carbon	Volatile Matter
Latin name	**Local name**	**(%)**	**(%)**	**(%)**
E. ferrugineus	Belau	2.29	14.23	74.14
F. aurata	Kayu ara	2.30	13.53	75.55
F. splendidissima	Makumpit	1.62	13.85	74.72
L. lucida	Madang	1.71	14.82	73.83
M. paniculatus	Balik angin	2.69	13.36	74.43
S. wallichii	Puspa	1.64	12.96	75.87
Average		**2.04**	**13.79**	**74.76**

Table 4. Ultimate analysis of some fast-growing tree species native to secondary forest of East Kalimantan, Indonesia.

Plant Species		Carbon	Hydrogen	Oxygen
Latin name	**Local name**	**(%)**	**(%)**	**(%)**
E. ferrugineus	Belau	42.80	5.34	39.62
F. aurata	Kayu ara	42.54	5.33	39.60
F. splendidissima	Makumpit	42.82	5.35	37.78
L. lucida	Madang	43.03	5.35	39.62
M. paniculatus	Balik angin	42.38	5.31	39.49
S. wallichii	Puspa	42.78	5.38	40.05
Average		**42.72**	**5.34**	**39.70**

Wood quality for energy feedstocks

The investigation of fuel wood quality of native species is presented in Figure 3. The important parameters were calorific value, wood chip conversion value, energy-electricity potency, and fuel value index. According to Figure 3A, the conversion of green wood (original solid form) into wood chip form significantly enhanced the average calorific value up to 0.5-fold. It was calculated that the average calorific value of all examined woods at the green form (7.92 MJ/kg) increased to 17.01 MJ/kg at the wood chip condition. We found that those results were in line with decreasing the amount of moisture content on wood samples when converted into wood chips (51.63% to 9.58%) (Table 2). It has been also reported by Deboni et al. (2020) that lower moisture content is considered one of factors that significantly influence increased calorific value of woody biomass as solid energy sources. The high proportion of moisture content in fuel wood could result in a delayed ignition and devolatilization (Lu et al., 2008). In this work, although it promised high energy content, the wood chip form consequently required larger storage area (m^3) per ton wood chip biomass compared to the green wood form, as could be derived from Figure 3B.

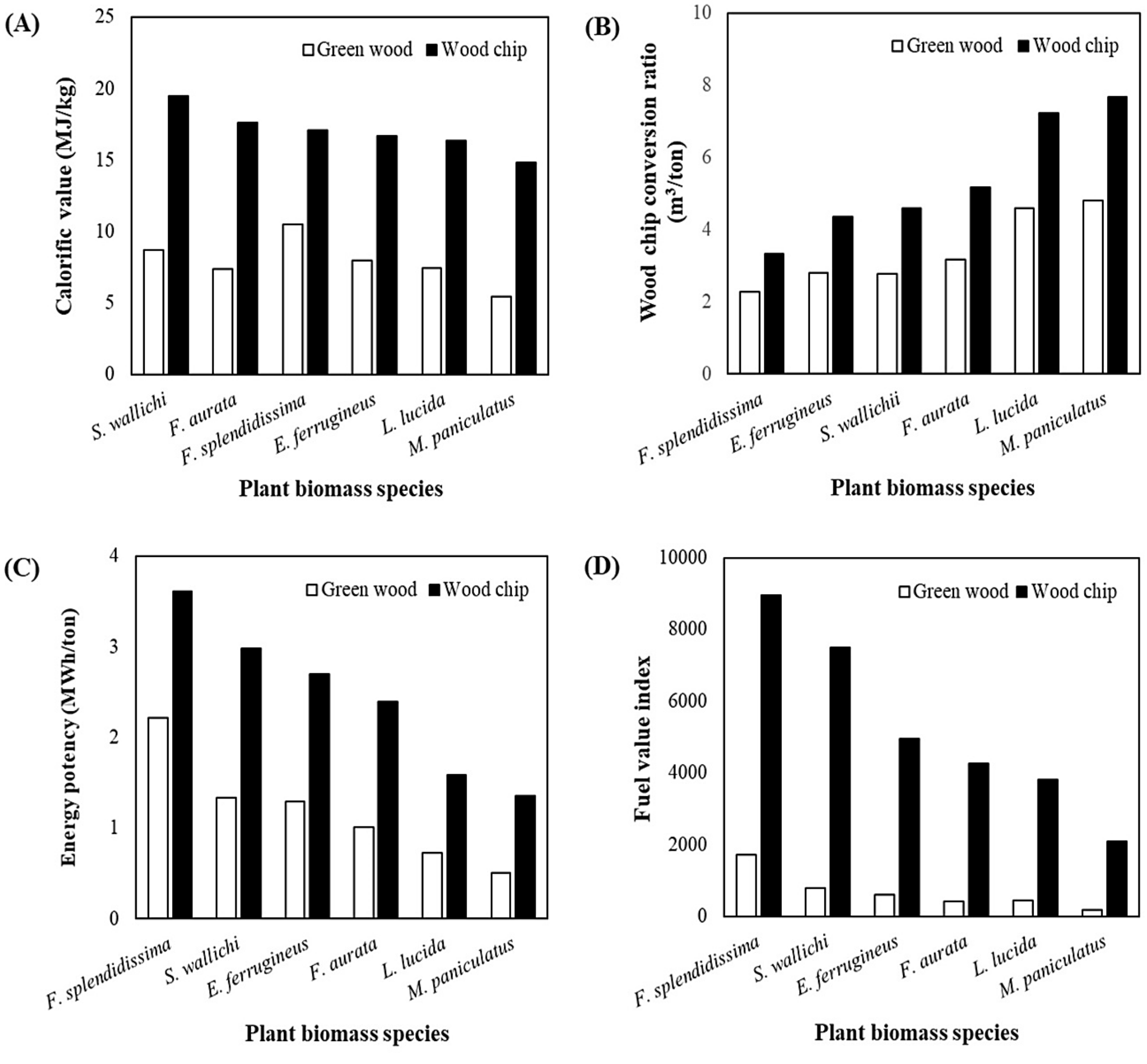


Figure 3. Analysis of some fast-growing tree species native to secondary forest of East Kalimantan, Indonesia for electricity feedstock: Wood calorific value (A), wood chip conversion ratio (B), energy potency (C) and fuel value index (D).

In order to compare the suitability of woody materials from selected native species, further measurement of energy potency in MWh per ton biomass was performed (Figure 3C). The results showed that *F. splendidissima* exhibited the highest energy potency in both green wood (2.21 MWh/ton) and wood chip (3.61 MWh/ton) form. Although *S. wallichii* and *F. aurata* possessed high calorific value (Figure 3A), *F. splendidissima* had higher energy-electricity potency than those species due to its high wood density (760 kg/m^3). Interestingly, even though *F. splendidissima* is considered fast-growing species, this species was classified as high wood density (< 600 kg/m^3), whereas *S. wallichii* and *F. aurata* were characterized as middle wood density (400 – 600 kg/m^3). Having similar pattern with calorific value results, the energy potency of all woody materials to generate electricity demonstrated significantly enhanced value after converting into wood chip due to the moisture removal. Based on our previous study, fast-growing species in lowland community forest, such as *Gmelina arborea*, *Anthocephalus cadamba*, *Acacia mangium*, and *Paraserianthes falcataria* had relatively low energy potency (1.37 – 1.70 MWh/ton) (Amirta et al., 2016). Another study also reported that fast-growing and shrub species found in tropical swamp-peat forest of Kutai Kartanegara in East Kalimantan generated low energy potency: *Kleinhovia hospita* (1.76 MWh/ton), *Cananga odorata* (1.36 MWh/ton), and *Octomeles sumatrana* (1.17 MWh/ton) (Amirta et al., 2019). However, our findings in this study indicated that fast-growing species native to secondary forest in East Kalimantan, especially *F. splendidissima,* could produce woody materials with superior energy capacity for electricity production.

The bioenergy potential of each fast-growing native species was represented by Fuel Value Index (FVI) (Figure 3D). The FVI is an essential assessment for screening desirable biomass species for solid fuel (Bhatt and Tomar, 2002). This measurement was also used by Niemczyk et al. (2018) to rank the quality of 10 poplar cultivars in northern Poland. The FVI was calculated by using combinations of some influencing factors, including ash content, moisture content, calorific value, and wood density. In this study, we found that wood chips containing low moisture content increased the FVI result from each wood tested. The average FVI of the wood chip which had the value of 5267 was significantly higher than that of the green wood condition with an average value of 698. The greatest FVI was obtained from *F. splendidissima* (8970), followed by *S. wallichii* and *F. ferrugineus* with the value of 7502 and 4958, respectively. A high FVI value of wood biomass was observed because of low ash content, low moisture content, and high density (Pérez et al. 2014). We concluded that wood chip revealed lower moisture content compared to origin form (green condition), indicating its high suitability to produce sustainable green energy.

Finally, all woody materials obtained from fast-growing native species to secondary forest of East Kalimantan were suitable for electricity feedstock due to the low content of ash and high proportion of carbon. When each wood biomass was converted into wood chip form, the efficiency of their utilization in energy feedstocks (calorific value, storage capacity, energy-electricity potency, and FVI) was gradually increased since this form was able to remove moisture effectively. In contrast, the green wood showed inefficient use since it might take longer time to dry; thus the cost of energy production will also increase. Among all biomass tested, wood chip of *F. splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency (3.61 MWh/ton) with desired FVI value (8970). Furthermore, the high adaptability in the local ecosystem combined with its high wood density and fast-growing ability will be the promising characteristics that allow *F. splendidissima* to be one of the ideal crops for energy feedstocks in the future. In general, this study successfully demonstrated the physicochemical properties of selected fast-growing native species in the tropical secondary forest in East Kalimantan, Indonesia to generate electricity in rural communities especially to develop economic sector in this province.

ACKNOWLEDGEMENTS

The current study was financially supported by the Project Implementation Unit of Islamic Development Bank – PIU IsDB (Grant No. 402/UN17.45/DL/2021 for Yl, RA, and MTH), and the research funding for lecturers and students from the Faculty of Forestry, Mulawarman University.

REFERENCES

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Londong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast-growing wood species for energy production. Nusantara Biosci 8(1): 22-31. DOI: https://doi.org/10.13057/nusbiosci/n080106.

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(6): 1516-1523. DOI: https://doi.org/10.13057/biodiv/d200605.

Bacellar AA, Rocha BR. 2010. Wood-fuel biomass from the Madeira River: A sustainable option for electricity production in the Amazon region. Energy policy 38(9): 5004-5012. DOI: https://doi.org/10.1016/j.enpol.2010.04.023.

Bahadori A, Zahedi G, Zendehboudi S, Jamili A. 2014. Estimation of the effect of biomass moisture content on the direct combustion of sugarcane bagasse in boilers. Int J Sustain Energy 33: 349–356. DOI: https://doi.org/10.1080/14786451.2012.748766.

Battuvshin B, Matsuoka Y, Shirasawa H, Toyama K, Hayashi U, Aruga K. 2020. Supply potential and annual availability of timber and forest biomass resources for energy considering inter-prefectural trade in Japan. Land Use Policy 97: 104780. DOI: https://doi.org/10.1016/j.landusepol.2020.104780.

Bhatt BP, Tomar JMS. 2002. Firewood properties of some Indian mountain tree and shrub species. Biomass Bioenergy 23: 257-260. DOI: https://doi.org/10.1016/S0961-9534(02)00057-0.

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S. 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew Sustain Energy Rev 71: 830-845. DOI: https://doi.org/10.1016/j.rser.2016.12.109.

Broughel AE. 2019. Impact of state policies on generating capacity for production of electricity and combined heat and power from forest biomass in the United States. Renew Energy 134: 1163-1172. DOI: https://doi.org/10.1016/j.renene.2018.09.058.

Cardoso J, Silva V, Eusébio D. 2019. Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal. J Clean Prod 212: 741-753. DOI: https://doi.org/10.1016/j.jclepro.2018.12.054.

da Costa TP, Quinteiro P, Arroja L, Dias AC. 2020. Environmental comparison of forest biomass residues application in Portugal: Electricity, heat, and biofuel. Renew Sustain Energy Rev 134: 110302. DOI: https://doi.org/10.1016/j.rser.2020.110302.

de Oliveira JL, da Silva JN, Pereira EG, Filho DO, Carvalho DR. 2013. Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification. Renew Sustain Energy Rev 21: 52–58. DOI: https://doi.org/10.1016/j.rser.2012.12.025.

Deboni TL, Simioni FJ, do Rosário JDA, Costa VJ. 2020. Quality of biomass from old wood waste deposits in Southern Brazil. Biomass Bioenergy 143: 105841. DOI: https://doi.org/10.1016/j.biombioe.2020.105841.

Dewanjee S, Maiti A, Majumdar R, Majumdar A, Mandal SC. 2008. Evaluation of antimicrobial activity of hydroalcoholic extract *Schima wallichii* bark. Pharmacologyonline 1: 523-528.

Francescato F, Antonini E, Bergomi LZ. 2008. *Wood Fuels Handbook: Production, Quality Requirements, Trading*. Legnaro, Italy: AIEL-Italian Agriforestry Energy Association.

González A, Riba JR, Puig R, Navarro P. 2015. Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. Renew Sustain Energy Rev 43: 143-155. DOI: https://doi.org/10.1016/j.rser.2014.11.013.

Haqiqi MT, Yuliansyah, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf. Series: Earth and Environmental Science 144: 012041. DOI :10.1088/1755-1315/144/1/012041.

Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R Yuliansyah, Suwinarti W, Amirta R. 2022. Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency. Biodiversitas 23(5): 2389-2394. DOI: https:/doi.org/10.13057/biodiv/d230516

Henry M, Besnard A, Asante WA, Eshun J, Adu-Bredu S, Valentini R, Bernoux M, Saint-André L. 2010. Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. For Ecol Manag 260(8): 1375-1388. DOI: https://doi.org/10.1016/j.foreco.2010.07.040.

Ismail I, Linatoc AC, Mohamed M, Tokiman L. 2015. Documentation of medicinal plants traditionally used by the jakun people of endau-rompin (peta) for treatments of malaria-like symptoms. Jurnal Teknologi 77(31): 63-69.

Jain RK, Singh B. 1999. Fuelwood characteristics of selected indigenous tree species from central India. Bioresour Technol 68: 305-308. DOI: https://doi.org/10.1016/S0960-8524(98)00173-4.

Johansson V, Lehtveer M, Göransson L. 2019. Biomass in the electricity system: A complement to variable renewables or a source of negative emissions? Energy 168: 532-541. DOI: https://doi.org/10.1016/j.energy.2018.11.112.

Karmaker AK, Rahman MM, Hossain MA, Ahmed MR. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. J Clean Prod 244: 118645. DOI: https://doi.org/10.1016/j.jclepro.2019.118645.

Liu Y, Xu Y, Zhang F, Yun J, Shen Z. 2014. The impact of biofuel plantation on biodiversity: a review. Chinese Sci Bull 59(34): 4639-4651. DOI: https://doi.org/10.1007/s11434-014-0639-1.

Lu G, Yan Y, Cornwell S, Whitehouse M, Riley G. 2008. Impact of co-firing coal and biomass on flame characteristics and stability. Fuel 87: 1133-1140. DOI: https://doi.org/10.1016/j.fuel.2007.07.005.

Mäkipää R, Linkosalo T, Komarov A, Mäkelä A. 2015. Mitigation of climate change with biomass harvesting in Norway spruce stands: are harvesting practices carbon neutral? Canadian J For Res 45(2): 217-225. DOI: https://doi.org/10.1139/cjfr-2014-0120.

Mancini M, Rinnan Å. 2021. Near infrared technique as a tool for the rapid assessment of waste wood quality for energy applications. Renew Energy 177: 113-123. DOI: https://doi.org/10.1016/j.renene.2021.05.137.

Mola-Yudego B, Arevalo J, Díaz-Yáñez O, Dimitriou I, Freshwater E, Haapala A, Khanam T, Selkimäki M. 2017. Reviewing wood biomass potentials for energy in Europe: the role of forests and fast-growing plantations. Biofuels 8(4): 401-410. DOI: https://doi.org/10.1080/17597269.2016.1271627.

Moya R, Tenorio C, Oporto G. 2019. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. Energies 12(4): 705. DOI: https://doi.org/10.3390/en12040705.

Mukhdlor A, Haqiqi MT, Tirkaamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation. Advances in Biological Science Research 11: 21-25.

Mutezo G, Mulopo J. 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 137: 110609. DOI: https://doi.org/10.1016/j.rser.2020.110609.

Niemczyk M, Kaliszewski A, Jewiarz M, Wrobel M, Mudryk K. 2018. Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland. Biomass Bioenergy, 111, 46-51. DOI: https://doi.org/10.1016/j.biombioe.2018.02.002.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI: https://doi.org/10.1016/j.energy.2021.119945.

Parikh L, Channiwala SA, Ghosal GK. 2007. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86: 1710-1719. DOI: https://doi.org/10.1016/j.fuel.2006.12.029.

Pérez S, Renedo CJ, Ortiz A, Manána M. 2008. Energy potential of waste from 10 forest species in the North of Spain (Cantabria). Bioresour Technol 99: 6339–6345. DOI: https://doi.org/10.1016/j.biortech.2007.12.014.

Pérez S, Renedo CJ, Ortiz A, Delgado F, Fernández I. 2014. Energy potential of native shrub species in northern Spain. Renew Energy 62: 79-83. DOI: https://doi.org/10.1016/j.renene.2013.06.048.

Pio D, D'Cruz R. 2005. *WWF: Borneo's Lost World: Newly Discovered Species on Borneo*. Jakarta, Indonesia: WWF.

Präger F, Paczkowski S, Sailer G, Derkyi NSA, Pelz S. 2019. Biomass sources for a sustainable energy supply in Ghana–A case study for Sunyani. Renew Sustain Energy Rev 107: 413-424. DOI: https://doi.org/10.1016/j.rser.2019.03.016.

Proto AR, Palma A, Paris E, Papandrea SF, Vincenti B, Carnevale M, Guerriero E, Bonofiglio R, Gallucci F. 2021. Assessment of wood chip combustion and emission behavior of different agricultural biomasses. Fuel 289: 119758. DOI: https://doi.org/10.1016/j.fuel.2020.119758.

Ram M, Child M, Aghahosseini A, Bogdanov D, Lohrmann A, Breyer C. 2018. A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030. J Clean Prod 199: 687-704. DOI: https://doi.org/10.1016/j.jclepro.2018.07.159.

Rempel A, Gupta J. 2020. Conflicting commitments? Examining pension funds, fossil fuel assets and climate policy in the organisation for economic co-operation and development (OECD). Energy Res Soc Sci 69: 101736. DOI: https://doi.org/10.1016/j.erss.2020.101736.

Rincon L, Puri M, Kojakovic A, Maltsoglou I. 2019. The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy policy 130: 69-88. DOI: https://doi.org/10.1016/j.enpol.2019.03.024.

Shao Y, Xu C, Zhu J, Preto F, Wang J, Li H, Badour C. 2011. Ash deposition in co-firing three-fuel blends consisting of woody biomass, peat, and lignite in a pilot-scale fluidized-bed reactor. Energy Fuels 25(7): 2841-2849. DOI: https://doi.org/10.1021/ef2002603.

Simangunsong BCH, Sitanggang VJ, Manurung EGT, Rahmadi A, Moore GA, Aye L, Tambunan AH. 2017. Potential forest biomass resource as feedstock for bioenergy and its economic value in Indonesia. For Policy Econ 81: 10–17. DOI: https://doi.org/10.1016/j.forpol.2017.03.022.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101(11): 3808-3815. DOI: https://doi.org/10.1016/j.biortech.2010.01.021.

Tenorio C, Moya R, Filho MT, Valaert J. 2015. Quality of pellets made from agricultural and forestry crops in Costa Rican tropical climates. Bioresources 10(1): 482-498.

Tursunov O, Abduganiev N. 2020. A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region. Mater Today: Proc 25: 67-71. DOI: https://doi.org/10.1016/j.matpr.2019.11.108.

Vega LY, López L, Valdés CF, Chejne F. 2019. Assessment of energy potential of wood industry wastes through thermochemical conversions. Waste Manag 87: 108-118. DOI: https://doi.org/10.1016/j.wasman.2019.01.048.

Wang Z, Bui Q, Zhang B, Pham TLH. 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci Total Environ 743: 140741. DOI: https://doi.org/10.1016/j.scitotenv.2020.140741.

Yuliansyah, Amirta R. 2016. Physico-chemical properties and energy potency of wood waste biomass from logging activities to generate electricity in East Kalimantan, Indonesia. *AIP Conference Proceeding* 1755.040001-6. DOI: https://doi.org/10.1063/1.4958476.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Helmi AS, Setiawan KA, Setiyono B, Angi EM, Saparwadi, Sari NM, Kusuma IW, Rujehan, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20(8): 2236-2242. DOI: https://doi.org/10.13057/biodiv/d200818.

Rudianto Amirta <rudiantoamirta@gmail.com>

[biodiv] Submission Acknowledgement

1 message

Ahmad Dwi Setyawan <smujo.id@gmail.com> Fri, May 13, 2022 at 8:34 PM
To: Rudianto AMIRTA <rudiantoamirta@gmail.com>

Rudianto AMIRTA:

Thank you for submitting the manuscript, "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks" to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/11174
Username: r_amirta

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ahmad Dwi Setyawan

Biodiversitas Journal of Biological Diversity

Notifications

[biodiv] Editor Decision

2022-05-17 12:23 AM

Rudianto AMIRTA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks".

Our decision is: Revisions Required

Reviewer A:

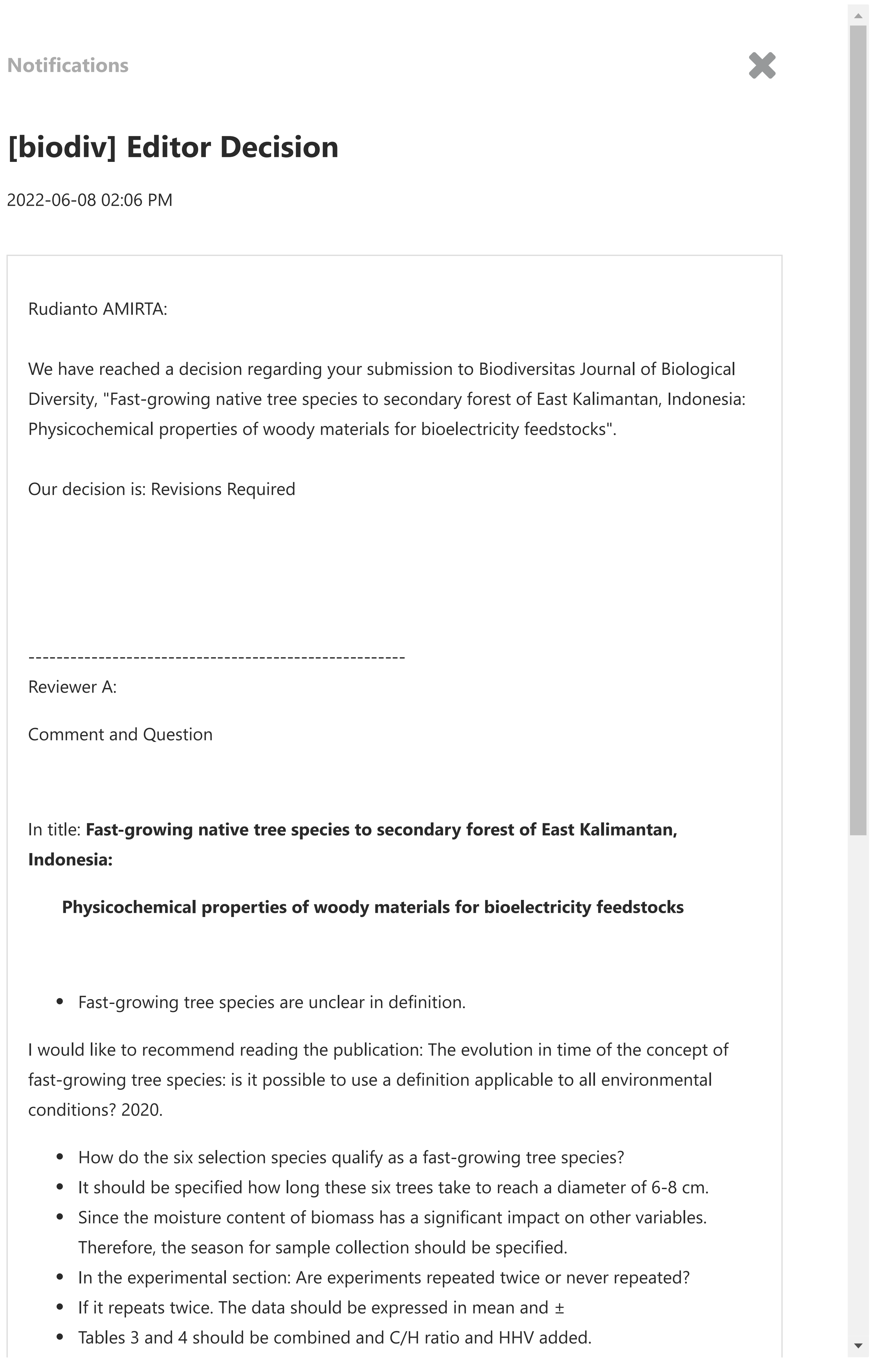
Dear author(s),

Please cite more international recent journals for your references. References list should consist of at least 20 citations which 80% of international scientific journals published in the last 10 years (2012-2022), and a maximum of 10% references from national publication, Also, please follow the guidance for reference writing (https://smujo.id/biodiv/guidance-for-author).

Best regards

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity



Notifications

[biodiv] Editor Decision

2022-06-08 02:06 PM

Rudianto AMIRTA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks".

Our decision is: Revisions Required

Reviewer A:

Comment and Question

In title: **Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia:**

Physicochemical properties of woody materials for bioelectricity feedstocks

- Fast-growing tree species are unclear in definition.

I would like to recommend reading the publication: The evolution in time of the concept of fast-growing tree species: is it possible to use a definition applicable to all environmental conditions? 2020.

- How do the six selection species qualify as a fast-growing tree species?
- It should be specified how long these six trees take to reach a diameter of 6-8 cm.
- Since the moisture content of biomass has a significant impact on other variables. Therefore, the season for sample collection should be specified.
- In the experimental section: Are experiments repeated twice or never repeated?
- If it repeats twice. The data should be expressed in mean and ±
- Tables 3 and 4 should be combined and C/H ratio and HHV added.

Revison # 1 and 2_Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

Participants Edit

Smujo Editors (editors)

Nor Liza (nliza)

Rudianto AMIRTA (r_amirta)

Messages

Note	From
Dear Editors, Attached is our manuscript entitled Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks which have been revised according to suggestions/notes provided by reviewer. For your information, in this manuscript we have cited 53 articles, of which 44 articles (83%) are relatively new (published in the last 10 years). Thank you, Best regards, Rudianto Amirta	r_amirta 2022-06-08 06:29 AM

Add Message

Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

**YULIANSYAH[1], MUHAMMAD TAUFIQ HAQIQI[1], KRISNA ADIB SETIAWAN[1], AGUS SETIAWAN[1],
PRISTIANGGA DWI SAPUTRA[1], HERI SUKMA IQBAL ROMADLON[1], AHMAD MUKHDLOR[1],
RICO RAMADHAN[2], RUDIANTO AMIRTA[1]♥**

[1]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683. ♥email: ramirta@fahutan.unmul.ac.id.
[2]Department of Chemistry, Faculty of Science and Technology, Universitas Airlangga. Jl. Mulyorejo, Surabaya 60115, East Java, Indonesia.

Manuscript received: .... Revision accepted: .... 20xx.

ABSTRACT

The conversion of woody biomass into electricity through a thermochemical process has recently attracted significant attention worldwide to promote green energy production. It provides a low-cost and straightforward operation ~~that is~~ promising for developing rural areas, especially ~~areas~~ with limited transportation access. In East Kalimantan Province, almost all remote areas are surrounded by forests with high tree species diversity, which is the potential to be utilized for sustainable feedstocks in electric power plants. This study pointed out the energy potential produced from woody biomass of selected fast-growing tree species ~~that is~~ native to East Kalimantan secondary tropical forest: *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull. Arg. and *Schima wallichii* (DC). Their wood physicochemical properties were firstly investigated. Furthermore, each species' wood quality for solid energy purposes ~~the wood quality for solid energy purposes from each species~~ was presented as the fuel value index (FVI). The results revealed that the change from ~~green wood~~greenwood into wood chip effectively removed the moisture content~~;~~, thus improving efficiency to achieve higher energy potency. Our findings showed that the highest energy potency was obtained from the wood chip of *S. splendidissima* (3.61 MWh/ton), followed by *S. wallichii* (2.98 MWh/ton). A similar pattern was also found in FVI determination showing that the wood chip of *S. Splendidissima* had the greatest value (8970). Therefore, we observed that the high quality of *S. splendidissima* compared to other selected fast-growing species indicates its high suitability for further large-scale crop plantation to supply wood chips for ~~a biomass-based-electricity~~biomass-based electricity generation.

Keywords: Electricity, ~~fast growing~~fast-growing, native species, secondary forest, woody biomass.

Running title: ~~Fast growing~~Fast-growing tree species native to secondary forest.

INTRODUCTION

The exploitation of fossil fuels has significantly increased the degradation of natural resources and the environment. Its combustion corresponding to ~~generate~~ generating electricity constantly accelerates the global warming potential. According to the report from the International Energy Agency, energy production from fossil fuels sectors is responsible for more than 80% of released carbon dioxide (CO_2) in the atmosphere, or it is estimated to exceed two-thirds of total greenhouse gas (GHC) emission (Ram et al., 2018; Cardoso et al., 2019). Although the Paris Agreement in 2015 implicitly called for shifting away from the domination of fossil fuels, the human population and industrialization are continuously growing, creating a significant challenge on how to mitigate climate change and reduce those harmful GHC effects (Karmaker et al., 2020; Rempel and Gupta, 2020). The United Nations (UN), through the Climate Action Summit in New York in 2019, has set a global plan to achieve net-zero ~~emission~~ emissions by 2050 (Mutezo and Mulopo, 2021). Therefore, many countries have committed to addressing a transition from fossil fuels to renewable energy by implementing a legal policy (Mola-Yudego et al., 2017; Moya et al., 2019; Rincon et al., 2019).

Among all resources, biomass has been considered the most applicated renewable energy globally, with ~~the~~ a proportion of 12.4% of the total energy consumption (Wang et al., 2020). Energy production from biomass is expected to meet global energy demands in the future (Bilgili et al., 2017). It offers various advantages over other renewable sources, such as better energy properties and less CO_2 emission (Liu et al., 2014; Tenorio et al., 2015). Woody biomass harvested from the forest is also one of the promising feedstocks to produce energy. Since almost all remote areas in Indonesia are covered by forests with limited transportation access, the approach to ~~use~~ using its biomass will be adequate to overcome the electricity limitation in those rural areas. Moreover, it will ~~create an improved~~improve economic growth by providing micro or small-scale electricity with a simple and cheaper process. When the wood ~~was~~ is burned during the combustion stage, the CO_2 emission can be easily absorbed by available forest plant species through photosynthesis. Thus, the net cycle of CO_2 is always in balance, and this phenomenon is known as neutral carbon (Mäkipää et al., 2015; Proto et al., 2021). It will potentially lead to a zero-emission power system (Mori et al., 2022). Excellent performance of biomass-based electricity has been reported earlier (González et al., 2015). Furthermore, it has also been successfully developed in many countries in the world, such as in Brazil (Ferreira, 2018), Finland (Majava et al., 2022), Ghana (Präger et al., 2019), India (Narnaware and Panwar, 2022), Japan (Battuvshin et al., 2020), Portugal (da Costa et al., 2020), Spain (Aguado et al., 2022), and United States (Broughel, 2019).

East Kalimantan province was ~~reported as~~ one of Indonesia's most considerable bioenergy potentials ~~the most considerable bioenergy potentials in Indonesia~~ due to its high availability of wood biomass resources from the forest (Simangunsong et al., 2017). The high diversity of biomass plant species distributed in the tropical rain forest of East Kalimantan was also reported as ~~the most essential~~the essential biodiversity value in Indonesia for many endemic species compared to other places on the earth (Pio and D'Cruz, 2005). However, the wood harvested from its forest resources was still dominated by the Dipterocarpaceae family, commonly used for~~Dipterocarpaceae family which was commonly used in the~~ furniture and construction purposes. Although it had promising calorific values, it was considered ~~the~~ a ~~low growing~~low-growing tree species that was not desirable for sustainable energy crops (Yuliansyah et al., 2016). On the other hand, fast-growing tree species planted ~~in~~ on forest ~~plantation~~ plantations, such as *Acacia mangium*, *Anthocephalus cadamba*, *Eucalyptus pellita*, *Gmelina arborea*, and *Paraserianthes falcataria*, are have been reported to possess low heating value (Amirta et al., 2016; Haqiqi et al., 2022). Therefore, finding suitable plant species having high wood calorific value combined with ~~its~~ their fast-growing ability to obtain high biomass yield for energy-electricity production is recently growing (Haqiqi et al., 2018).

The investigation of native species can be an important step ~~to search~~in searching for ~~the~~ suitable plant biomass species to be cultivated as energy crops in some remote areas. In East Kalimantan Province, many local fast-growing species are characterized as non-commercial species, even known as species with high adaptability to grow well in their origin ecosystem. They are mainly found in plant communities at secondary forest succession. Commonly used as firewood by local people, those species still have less attention for further large-scale utilization, especially in ~~for~~ energy production. These species will promise future plantation of short-rotation wood crops to provide sustainable raw materials with ~~the~~ a faster-growing ability. However, further wood physicochemical analysis was necessary to meet ~~the requirements for an ideal energy crop~~an ideal energy crop requirement. ~~Herein, this~~This study reported comparing wood physicochemical properties of selected fast-growing tree species ~~the comparison of wood physicochemical properties of selected fast-growing tree species that are~~ native to~~to~~ the East Kalimantan forest to be used as feedstocks in electricity production.

MATERIALS AND METHODS

Study area

Wood biomass materials and leaf samples from some fast-growing native species were collected at the secondary forest of Mulawarman University Educational Forest (KHDTK Fahutan UNMUL, Samarinda), Samarinda City, East Kalimantan Province, Indonesia (0º25’10” LS – 0º25’10” LS and, 117º14’00” BT-117º14’14” BT - 300 ha).

Biomass plant species

Medium trees with ~~the diameter of 6-8 cm~~ 6-8 cm diameter recognized as native fast-growing species naturally grown on secondary tropical rain ~~forest~~ forests associated ~~in~~ with East Kalimantan were pointed out. Identification through leaf herbarium ~~specimen~~ specimens of each species ~~was~~ was deposited at the Laboratory of Forest Dendrology and Ecology, Faculty of Forestry, Mulawarman University. In this study, six species were identified, namely *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull.Arg. and *Schima wallichii* (DC). They belong to different family groups, including elaeocarpaceae, moraceae, fabaceae, lauraceae, euphorbiaceae and theaceae, respectively. The woody biomass samples were debarked to analyze the dry bark-wood ratio, ~~following~~ then converted~~by converting~~ into wood ~~chip~~ chips before ~~proceeded~~ proceeding to laboratory analysis.

Determination of wood physicochemical properties and energy potency

The total moisture and proximate compositions of wood materials were carried out according to ASTM D 7582-12 method. The lost weight of the samples after reaching the constant weight in a hot air oven at 105ºC was calculated to determine the moisture content. For proximate analysis, the samples were dried and grounded into smaller ~~size~~ sizes (±60 mesh). The measurements consisted of two steps in a furnace. The first step was done by heating from 300-575ºC for 3 hours. The ~~loss of weight~~weight loss was measured and noted as a ~~substance of volatile matter (VM)~~volatile matter (VM) substance. Then, the temperature was increased to reach 950ºC for 2 hours to heat the remaining samples. After cooling down to room temperature, the residual weight was measured in ash content while the lost weight was fixed carbon (FC).

The ultimate compositions of wood biomass including carbon (C), hydrogen (H), and oxygen (O) were estimated based on the following Equation (Parikh et al., 2007):

$$C (\%) = (0.637 \text{ x } FC) + (0.455 \text{ x } VM) \tag{1}$$

$$H (\%) = (0.052 \text{ x } FC) + (0.062 \text{ x } VM) \tag{2}$$

$$O\ (\%) = (0.304 \times FC) + (0.476 \times VM) \quad (3)$$

Measurement of wood density (kg/m^3) was conducted by drying the wood samples at 105ºC following Edwards et al. (2014). The wood calorific value (MJ/kg) was accomplished in a bomb calorimeter according to the standard from EN-ISO 15400:2011, followed~~in accordance with the standard from EN-ISO 15400:2011 following~~ by the calculation of energy-electricity potency according to Francescato et al. (2008). Those measurements were classified into ~~green wood~~greenwood and wood ~~chip~~chips. Furthermore, the fuel value index (FVI) was calculated using the equation as ~~follow~~ follows (Jain and Singh, 1999):

$$FVI = \frac{\text{Calorific value x wood density}}{\text{Ash content x moisture content}} \quad (4)$$

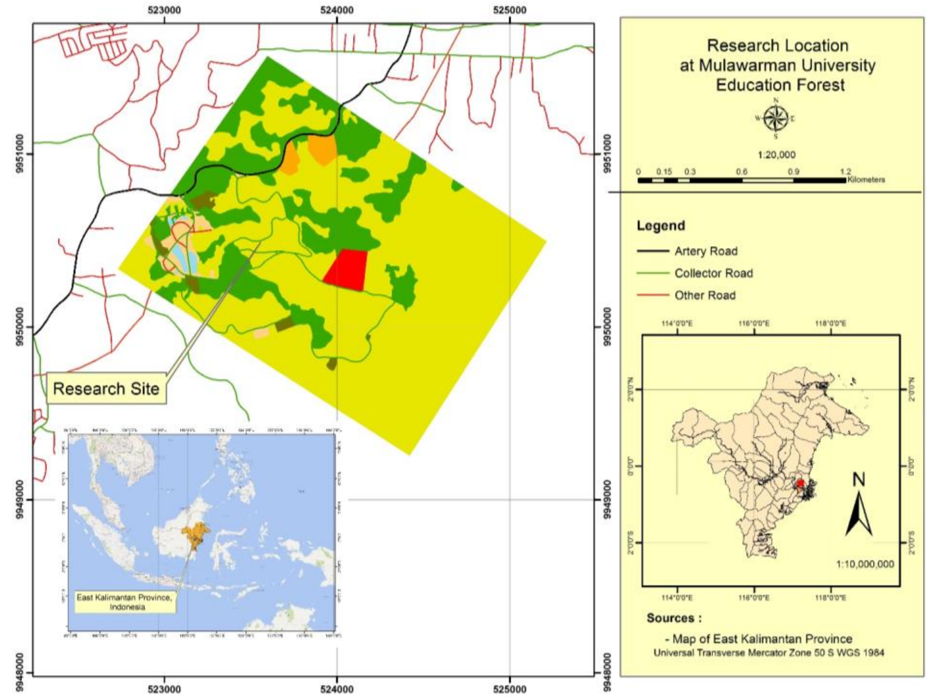
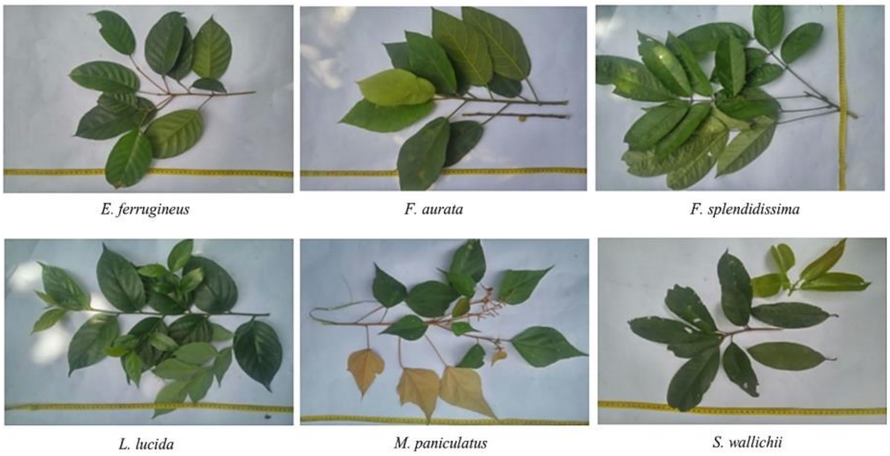


Figure 1. Research location conducted at Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia (0º25’10” LS – 0º25’10” LS and~~,~~ 117º14’00” BT-117º14’14” BT).



E. ferrugineus *F. aurata* *F. splendidissima*

L. lucida *M. paniculatus* *S. wallichii*

Figure 2. Fresh leaf shape ~~varities~~ varieties of some fast-growing native tree species were collected from the secondary forest of Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia.

RESULTS AND DISCUSSION

Plant biomass species

Generally, tropical forest areas provide better environmental conditions~~area provides better environmental condition~~ for plants to produce ~~a~~ sustainable biomass with high ~~yield~~yields. This condition will lead to its potential wide-range application in biomass-based conversion technology, such as electricity generation. However, a previous study demonstrated that forest biomass species with high energy content were commonly produced from ~~low growing~~low-growing species (Amirta et al., 2016). In ~~the~~ large-scale electricity production, utilization of the ~~low growing~~low-growing species in energy feedstocks requires a slow harvest cycle period with a ~~h~~ high-cost operation. Therefore, this study assessed woody materials obtained from selected fast-growing species, including E. ferrugineus, F. aurata, F. splendidissima, L. lucida, M. paniculatus, and S. wallichii ~~in this study, woody materials obtained from selected fast-growing species, including *E. ferrugineus, F. aurata, F. splendidissima, L. lucida, M. paniculatus*, and *S. wallichii were assessed for*~~ *the purpose of energy-electricity feedstock*. Those species are abundant and native to the secondary forest of East Kalimantan, in which the local people traditionally used their wood as firewood for cooking ~~activity~~activities~~.~~. Nevertheless, literature describing those plant species for further industrial application is still rare. The measurement of bark and wood proportion of each species was summarized in Table 1. It was notice~~-~~able that three species, including *E. ferrugineus*, *F. aurata*, and *F. splendidissima*, had the lowest bark-wood ratio (0.7). The highest bark proportion was obtained from *S. wallichiii*, followed by *M. paniculatus*~~,~~ and *L. lucida*, with the value of 12.95%, 11.22%, and 7.80%, respectively. It has been reported earlier that the stem bark of E. ferrugineus was the potential for treating malaria-like symptoms~~stem bark of *E. ferrugineus* was potential for malaria-like symptoms treatment~~ (Ismail et al., 2015~~).~~). On the other hand, *S. wallichii* bark could be utilized as an antimicrobial agent (Dewanjee et al. 2008). Hence, ~~due to these interesting properties, it~~these interesting properties could potentially enhance their application for both energy feedstocks and natural medicine products. Since the stem bark ~~produced~~ produces a high quantity of ash (Pérez et al., 2008), its removal from wood when used for energy production through thermochemical conversion is necessary.

Table 1. Wood and bark ratio of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia.

Plant Species		Bark Proportion (%)	Wood Proportion (%)	Bark-Wood Ratio
Latin name	**Local name**			
E. ferrugineus	Belau	6.37	93.63	0.07
F. aurata	Kayu ara	6.65	93.35	0.07
F. splendidissima	Makumpit	6.70	93.30	0.07
L. lucida	Madang	7.80	92.20	0.08

M. paniculatus	Balik angin	11.22	88.78	0.13
S. wallichii	Puspa	12.95	87.06	0.15
Average		**8.62**	**91.39**	**0.10**

Wood physicochemical properties

Moisture content, density, and chip capacity of woody materials examined from some selected native tree species were summarized in Table 2. It has been previously reported that the percentage of wood moisture content depends on the plant species, season, and ~~condition of storage~~storage condition (Mancini and Rinnan, 2021). In green ~~condition~~conditions, the highest wood moisture content was obtained from *S. wallichii* (59.25%), while the lowest moisture content could be found ~~on~~ in *F. splendidissima* (40.37%). The conversion of the wood into chip form evidently reduced their moisture content. As shown ~~by~~ in Table 2, all wood chips revealed ~~lower percentage of moisture compared to that of the~~a lower moisture percentage than green wood conditions. It was found that the average moisture content of wood chips was 9.58%. It seems that wood chip form could easily evaporate the amount of water. Surprisingly, this situation could also ~~provide benefits to~~be benefited considerably increase the achieved calorific value due to the water loss phenomenon (Figure 3A). According to the measurement of wood density, it was found that the highest wood density was obtained from *F. splendidissima* (750 kg/m^3). The second and third largest were found ~~at~~ in *E. ferrugineus* (580 kg/m^3) and *S. wallichii* (550 kg/m^3) wood, respectively. The average ~~value of wood density~~wood density value from all species used in this study was 510 kg/m^3~~.~~. Meanwhile, their form ~~changes~~ changed into wood ~~chip~~ chips that needed a high ~~capacity of storage~~storage capacity. It was found that the average value of wood ~~chip~~ chips of all species was 201 kg per m^3 of storage area. The high wood density contributed to ~~increase~~ increasing the efficiency of wood chip storage. As ~~could be~~ observed from *F. splendidissima*, its wood chip (300 kg/m^3) was the most efficient storage capacity among all woody materials used. Especially for a ~~the~~ large-scale operation, the high density of wood ~~chip~~ chips potentially ~~contribute~~contributes~~s~~ to ~~produce low energy production cost~~low energy production costs (Bahadori et al., 2014). In contrast, low wood density affects the fast burning of the reactor, high transport costs, and high storage capacity (de Oliveira et al., 2013).

Table 2. Moisture content, wood density, and chip capacity of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia.

Plant Species		**Moisture content (%)**		**Wood density**	**Chip capacity**
Latin name	**Local name**	**~~Green wood~~Greenwood**	**wood Chip**	**(kg/m^3)**	**(kg/m^3)**
E. ferrugineus	Belau	49.77	9.34	580	229
F. aurata	Kayu ara	56.90	9.62	490	193
F. splendidissima	Makumpit	40.37	9.81	760	300
L. lucida	Madang	50.64	9.64	350	138
M. paniculatus	Balik angin	52.85	9.52	330	130
S. wallichii	Puspa	59.25	9.53	550	217
Average		**51.63**	**9.58**	**510**	**201**

Various laboratory tests were carried out for proximate and ultimate analysis~~Proximate and ultimate analysis was carried out by various laboratory tests~~. The proximate analysis includes ash, fixed carbon, and volatile matter (Table 3). These parameters strongly affected the performance of combustion, pyrolysis, and gasification of wood biomass in the thermochemical conversion process (Tursunov and Abduganiev, 2020). Ash content of all woody materials showed less than 5%, which demonstrated their high potency utilized for raw materials of energy production. The low value of ash residue (<5%) ~~resulted~~ resulting from the combustion process has a positive impact ~~to increase~~on increasing the efficiency stage and ~~to avoid~~avoiding damage ~~of~~ to the electricity reactor (Shao et al., 2011). Nimmanterdwong et al. (2021) stated that the ash in biomass is directly related to the mineral and inorganic elements absorbed by plants from the ground via the root cells, while its percentage differently depends~~ed~~ on the soil properties, rocks, chemical treatment, and available metal contents. The volatile matters of all woody materials in this study were in the range of 73.83 – 75.87%, whereas the fixed carbons were in the range of 12.96–14.82%. It has been reported that the heat decomposition of cellulose and hemicellulose in biomass is the ~~sources~~ source of volatile ~~matters~~matter~~, whereas lignin~~. In contrast, lignin is a ~~source of char~~char source due to its richness in carbon atoms (Vega et al., 2019). The ultimate compositions, including C (carbon), H (hydrogen), and O (oxygen), were presented in Table 4. This investigation is ~~very~~ essential to determine the theoretical air-fuel ratio in the thermochemical system and ~~to ~~predict the released pollution (Telmo et al., 2010). The average value of C, H, and O was 42.72%, 5.35%, and 39.70%, respectively. It was clearly observed that all woody materials contained C higher than O, indicating its high suitability used as the energy feedstock since high C content will increase the obtained calorific value. Moreover, the C content, with ~~the ~~a value of more than 40% in this study, was in line with that of the C content of various tropical woods reported earlier (Amirta et al., 2016; Amirta et al., 2019; Yuliansyah et al., 2019; Mukhdlor et al., 2021).

Table 3. Proximate analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia.

Plant Species		Ash Content	Fixed Carbon	Volatile Matter
Latin name	**Local name**	**(%)**	**(%)**	**(%)**
E. ferrugineus	Belau	2.29	14.23	74.14
F. aurata	Kayu ara	2.30	13.53	75.55
F. splendidissima	Makumpit	1.62	13.85	74.72
L. lucida	Madang	1.71	14.82	73.83
M. paniculatus	Balik angin	2.69	13.36	74.43
S. wallichii	Puspa	1.64	12.96	75.87
Average		**2.04**	**13.79**	**74.76**

Table 4. Ultimate analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia.

Plant Species		Carbon	Hydrogen	Oxygen
Latin name	**Local name**	**(%)**	**(%)**	**(%)**
E. ferrugineus	Belau	42.80	5.34	39.62
F. aurata	Kayu ara	42.54	5.33	39.60
F. splendidissima	Makumpit	42.82	5.35	37.78
L. lucida	Madang	43.03	5.35	39.62
M. paniculatus	Balik angin	42.38	5.31	39.49
S. wallichii	Puspa	42.78	5.38	40.05
Average		**42.72**	**5.34**	**39.70**

Wood quality for energy feedstock

The investigation of the fuelwood~~fuel wood~~ quality of native species is presented in Figure 3. The important parameters were calorific value, wood chip conversion value, energy-electricity potency, and fuel value index. According to Figure 3A, the conversion of green wood (original solid form) into wood chip form significantly enhanced the average calorific value up to 0.5-fold. It was calculated that the average calorific value of all examined woods ~~at the ~~in the green form (7.92 MJ/kg) increased to 17.01 MJ/kg at the wood chip condition. We found that those results were in line with decreasing the amount of moisture content on wood samples when converted into wood chips (51.63% to 9.58%) (Table 2). It has ~~been ~~also been reported by Deboni et al. (2020) that lower moisture content is considered one of the factors that significantly influence the increased calorific value of woody biomass as a ~~solid ~~reliable energy ~~sources~~source. The high proportion of moisture content in ~~fuel wood~~fuelwood could result in ~~a ~~delayed ignition and devolatilization (Lu et al., 2008). ~~In this work, although it~~Although this work promised high energy content, the wood chip form consequently required a larger storage area (m^3) per ton of wood chip biomass ~~compared to~~than the ~~green wood~~greenwood form, as ~~could be derived from~~shown in Figure 3B.

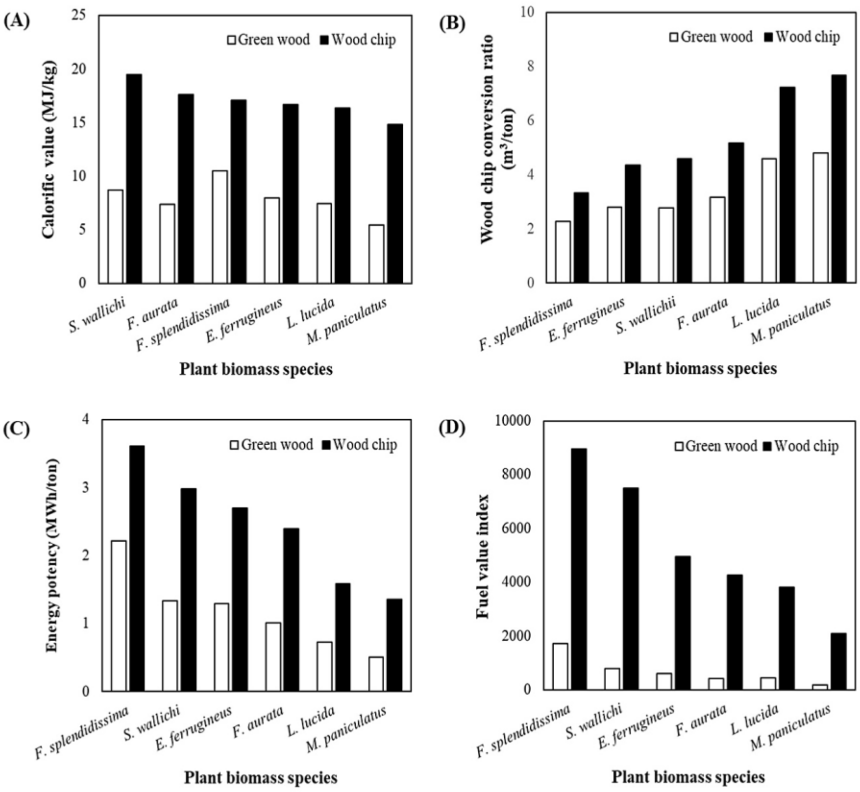


Figure 3. Analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia, for electricity feedstock: Wood calorific value (A), wood chip conversion ratio (B), energy potency (C), and fuel value index (D).

In order to compare the suitability of woody materials from selected native species, further measurement of energy potency in MWh per ton biomass was performed (Figure 3C). The results showed that *F. splendidissima* exhibited the highest energy potency in both ~~green wood~~greenwood (2.21 MWh/ton) and wood chip (3.61 MWh/ton) ~~form~~forms. Although *S. wallichii* and *F. aurata* possessed high calorific ~~value~~ values (Figure 3A), *F. splendidissima* had higher energy-electricity potency than those species due to its high wood density (760 kg/m^3). Interestingly, even though *F. splendidissima* is considered fast-growing species, this species was classified as high wood density (< 600 kg/m^3), whereas *S. wallichii* and *F. aurata* were characterized as ~~middle~~ medium wood density (400 – 600 kg/m^3). Having a similar pattern with calorific value results, the energy potency of all woody materials to generate electricity demonstrated significantly enhanced value after converting into wood ~~chip~~ chips due to the moisture removal. ~~Based on our previous study,~~Our previous study shows fast-growing species in the lowland community forest, such as *Gmelina arborea*, *Anthocephalus cadamba*, *Acacia mangium*, and *Paraserianthes falcataria*, had relatively low energy potency (1.37 – 1.70 MWh/ton) (Amirta et al., 2016). Another study also reported that fast-growing and shrub species found in the tropical swamp-peat forest of Kutai Kartanegara in East Kalimantan generated low energy potency: *Kleinhovia hospita* (1.76 MWh/ton), *Cananga odorata* (1.36 MWh/ton), and *Octomeles sumatrana* (1.17 MWh/ton) (Amirta et al., 2019). However, our findings in this study indicated that fast-growing species native to the secondary forest in East Kalimantan, especially *F. splendidissima*, could produce woody materials with superior energy capacity for electricity production.

The bioenergy potential of each fast-growing native species was represented by Fuel Value Index (FVI) (Figure 3D). The FVI is an essential assessment for screening desirable biomass species for solid fuel (Samal et al., 2021). This measurement was also used by Niemczyk et al. (2018) to rank the quality of 10 poplar cultivars in northern Poland. The FVI was calculated ~~by~~ using combinations of some influencing factors, including ash content, moisture content, calorific value, and wood density. ~~In this study, we~~This study found that wood chips containing low moisture content increased the

FVI result from each wood tested. The average FVI of the wood chip, which had ~~the~~ a value of 5267, was significantly higher than that of the ~~green wood~~greenwood condition, with an average value of 698. The greatest FVI was obtained from *F. splendidissima* (8970), followed by *S. wallichii* and *F. ferrugineus* with the value of 7502 and 4958, respectively. A high FVI value of wood biomass was observed because of low ash content, low moisture content, and high density (Pérez et al., 2014). We concluded that the wood chip revealed lower moisture content compared to the ~~origin~~ original form (green condition), indicating its high suitability to produce sustainable green energy.

Commented [XO1]: value of 5267.. ukuran dalam bentuk apa..MWh/ton atau lainya

Commented [XO2]: the value of 7502 and 4958... ukuran dalam bentuk apa..

Finally, all woody materials obtained from fast-growing native species ~~to~~ in the secondary forest of East Kalimantan were suitable for electricity feedstock due to the low ash content~~secondary forest of East Kalimantan were suitable for electricity feedstock due to the low content of ash~~ and a high proportion of carbon. When each wood biomass was converted into wood chip form, ~~the efficiency of their utilization~~ their efficiency in energy feedstocks (calorific value, storage capacity, energy-electricity potency, and FVI) was gradually increased since this form was able to remove moisture effectively. In contrast, the ~~green wood~~greenwood showed inefficient use since it might take longer ~~longer time~~ to dry; thus, the cost of energy production will also increase. Among all biomass tested, the wood chip of *F. splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency (3.61 MWh/ton) with desired FVI value (8970). Furthermore, the high adaptability in the local ecosystem combined with its high wood density and fast-growing ability will be the promising characteristics that allow *F. splendidissima* to be one of the ideal crops for energy feedstocks in the future. In general, this study successfully demonstrated the physicochemical properties of selected fast-growing native species in the tropical secondary forest in East Kalimantan, Indonesia, to generate electricity in rural communities, especially to develop the economic sector in this province.

ACKNOWLEDGEMENTS

The current study was financially supported by the Project Implementation Unit of Islamic Development Bank – PIU IsDB (Grant No. 402/UN17.45/DL/2021 for Yl, RA, and MTH), and the research funding for lecturers and students from the Faculty of Forestry, Mulawarman University (FY 2022).

REFERENCES

Aguado R, Vera D, Jurado F, Beltrán G. 2022. An integrated gasification plant for electric power generation from wet biomass: toward a sustainable production in the olive oil industry. Biomass Convers Biorefin. DOI:10.1007/s13399-021-02231-0.

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Londong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast-growing wood species for energy production. Nusantara Biosci 8(1): 22-31. DOI:10.13057/nusbiosci/n080106.

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(6): 1516-1523. DOI:10.13057/biodiv/d200605.

Bahadori A, Zahedi G, Zendehboudi S, Jamili A. 2014. Estimation of the effect of biomass moisture content on the direct combustion of sugarcane bagasse in boilers. Int J Sustain Energy 33: 349–356. DOI:10.1080/14786451.2012.748766.

Battuvshin B, Matsuoka Y, Shirasawa H, Toyama K, Hayashi U, Aruga K. 2020. Supply potential and annual availability of timber and forest biomass resources for energy considering inter-prefectural trade in Japan. Land Use Policy 97: 104780. DOI:10.1016/j.landusepol.2020.104780.

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S. 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew Sustain Energy Rev 71: 830-845. DOI:10.1016/j.rser.2016.12.109.

Broughel AE. 2019. Impact of state policies on generating capacity for production of electricity and combined heat and power from forest biomass in the United States. Renew Energy 134: 1163-1172. DOI:10.1016/j.renene.2018.09.058.

Cardoso J, Silva V, Eusébio D. 2019. Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal. J Clean Prod 212: 741-753. DOI:10.1016/j.jclepro.2018.12.054.

da Costa TP, Quinteiro P, Arroja L, Dias AC. 2020. Environmental comparison of forest biomass residues application in Portugal: Electricity, heat, and biofuel. Renew Sustain Energy Rev 134: 110302. DOI:10.1016/j.rser.2020.110302.

de Oliveira JL, da Silva JN, Pereira EG, Filho DO, Carvalho DR. 2013. Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification. Renew Sustain Energy Rev 21: 52–58. DOI:10.1016/j.rser.2012.12.025.

Deboni TL, Simioni FJ, do Rosário JDA, Costa VJ. 2020. Quality of biomass from old wood waste deposits in Southern Brazil. Biomass Bioenergy 143: 105841. DOI:10.1016/j.biombioe.2020.105841.

Dewanjee S, Maiti A, Majumdar R, Majumdar A, Mandal SC. 2008. Evaluation of antimicrobial activity of hydroalcoholic extract *Schima wallichii* bark. Pharmacologyonline 1: 523-528.

Edwards LE, Newby AF, Gilliam CH, Fain GB, Sibley JL, Murphy, AM. 2014. Evaluation of eastern redcedar substrate in the production of four annual species. J Environ Hortic 32(3): 167-173.

Ferreira LRA, Otto RB, Silva FP, De Souza SNM, De Souza SS, Junior OA. 2018. Review of the energy potential of the residual biomass for the distributed generation in Brazil. Renew Sustain Energy Rev 94: 440-455. DOI:10.1016/j.rser.2018.06.034.

Francescato F, Antonini E, Bergomi LZ. 2008. Wood Fuels Handbook: Production, Quality Requirements, Trading. Legnaro, Italy.

González A, Riba JR, Puig R, Navarro P. 2015. Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. Renew Sustain Energy Rev 43: 143-155. DOI:10.1016/j.rser.2014.11.013.

Haqiqi MT, Yuliansyah, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf. Series: Earth and Environmental Science. DOI:10.1088/1755-1315/144/1/012041.

Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R Yuliansyah, Suwinarti W, Amirta R. 2022. Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency. Biodiversitas 23(5): 2389-2394. DOI:10.13057/biodiv/d230516

Ismail I, Linatoc AC, Mohamed M, Tokiman L. 2015. Documentation of medicinal plants traditionally used by the jakun people of endau-rompin (peta) for treatments of malaria-like symptoms. Jurnal Teknologi 77(31): 63-69.

Jain RK, Singh B. 1999. Fuelwood characteristics of selected indigenous tree species from central India. Bioresour Technol 68: 305-308. DOI: 10.1016/S0960-8524(98)00173-4.

Karmaker AK, Rahman MM, Hossain MA, Ahmed MR. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. J Clean Prod 244: 118645. DOI:10.1016/j.jclepro.2019.118645.

Liu Y, Xu Y, Zhang F, Yun J, Shen Z. 2014. The impact of biofuel plantation on biodiversity: a review. Chinese Sci Bull 59(34): 4639-4651. DOI:10.1007/s11434-014-0639-1.

Lu G, Yan Y, Cornwell S, Whitehouse M, Riley G. 2008. Impact of co-firing coal and biomass on flame characteristics and stability. Fuel 87: 1133-1140. DOI:10.1016/j.fuel.2007.07.005.

Majava A, Vadén T, Toivanen T, Järvensivu P, Lähde V, Eronen JT. 2022. Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target. Energy Strategy Rev 41: 100836. DOI:10.1016/j.esr.2022.100836.

Mäkipää R, Linkosalo T, Komarov A, Mäkelä A. 2015. Mitigation of climate change with biomass harvesting in Norway spruce stands: are harvesting practices carbon neutral? Canadian J For Res 45(2): 217-225. DOI:10.1139/cjfr-2014-0120.

Mancini M, Rinnan Å. 2021. Near infrared technique as a tool for the rapid assessment of waste wood quality for energy applications. Renew Energy 177: 113-123. DOI:10.1016/j.renene.2021.05.137.

Mola-Yudego B, Arevalo J, Díaz-Yáñez O, Dimitriou I, Freshwater E, Haapala A, Khanam T, Selkimäki M. 2017. Reviewing wood biomass potentials for energy in Europe: the role of forests and fast-growing plantations. Biofuels 8(4): 401-410. DOI:10.1080/17597269.2016.1271627.

Mori S, Sumner J, Bouvet J, Simms NJ. 2022. Fireside and steamside performance in biomass power plant. Mater High Temp 39(2): 106-121. DOI:10.1080/09603409.2021.2019657.

Moya R, Tenorio C, Oporto G. 2019. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. Energies 12(4): 705. DOI:10.3390/en12040705.

Mukhdlor A, Haqiqi MT, Tirkaamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation. Advances in Biological Science Research. DOI:10.2991/absr.k.210408.005.

Mutezo G, Mulopo J. 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 137: 110609. DOI:10.1016/j.rser.2020.110609.

Narnaware SL, Panwar NL. 2022. Biomass gasification for climate change mitigation and policy framework in India: A review. Bioresour Technol Rep 17: 100892. DOI:10.1016/j.biteb.2021.100892.

Niemczyk M, Kaliszewski A, Jewiarz M, Wrobel M, Mudryk K. 2018. Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland. Biomass Bioenergy, 111, 46-51. DOI:10.1016/j.biombioe.2018.02.002.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI:10.1016/j.energy.2021.119945.

Parikh L, Channiwala SA, Ghosal GK. 2007. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86: 1710-1719. DOI:10.1016/j.fuel.2006.12.029.

Pérez S, Renedo CJ, Ortiz A, Manána M. 2008. Energy potential of waste from 10 forest species in the North of Spain (Cantabria). Bioresour Technol 99: 6339–6345. DOI:10.1016/j.biortech.2007.12.014.

Pérez S, Renedo CJ, Ortiz A, Delgado F, Fernández I. 2014. Energy potential of native shrub species in northern Spain. Renew Energy 62: 79-83. DOI:10.1016/j.renene.2013.06.048.

Pio D, D'Cruz R. 2005. Borneo's Lost World: Newly Discovered Species on Borneo. WWF, Jakarta.

Präger F, Paczkowski S, Sailer G, Derkyi NSA, Pelz S. 2019. Biomass sources for a sustainable energy supply in Ghana–A case study for Sunyani. Renew Sustain Energy Rev 107: 413-424. DOI:10.1016/j.rser.2019.03.016.

Proto AR, Palma A, Paris E, Papandrea SF, Vincenti B, Carnevale M, Guerriero E, Bonofiglio R, Gallucci F. 2021. Assessment of wood chip combustion and emission behavior of different agricultural biomasses. Fuel 289: 119758. DOI:10.1016/j.fuel.2020.119758.

Ram M, Child M, Aghahosseini A, Bogdanov D, Lohrmann A, Breyer C. 2018. A comparative analysis of electricity generation costs from renewable, fossil fuel, and nuclear sources in G20 countries for the period 2015-2030. J Clean Prod 199: 687-704. DOI:10.1016/j.jclepro.2018.07.159.

Rempel A, Gupta J. 2020. Conflicting commitments? Examining pension funds, fossil fuel assets, and climate policy in the organisation for economic co-operation and development (OECD). Energy Res Soc Sci 69: 101736. DOI:10.1016/j.erss.2020.101736.

Rincon L, Puri M, Kojakovic A, Maltsoglou I. 2019. The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy policy 130: 69-88. DOI:10.1016/j.enpol.2019.03.024.

Samal B, Vanapalli KR, Dubey BK, Bhattacharya J, Chandra S, Medha I. 2021. Influence of process parameters on thermal characteristics of char from co-pyrolysis of eucalyptus biomass and polystyrene: Its prospects as a solid fuel. Energy 232: 121050. DOI:10.1016/j.energy.2021.121050.

Shao Y, Xu C, Zhu J, Preto F, Wang J, Li H, Badour C. 2011. Ash deposition in co-firing three-fuel blends consisting of woody biomass, peat, and lignite in a pilot-scale fluidized-bed reactor. Energy Fuels 25(7): 2841-2849. DOI:10.1021/ef2002603.

Simangunsong BCH, Sitanggang VJ, Manurung EGT, Rahmadi A, Moore GA, Aye L, Tambunan AH. 2017. Potential forest biomass resource as feedstock for bioenergy and its economic value in Indonesia. For Policy Econ 81: 10–17. DOI:10.1016/j.forpol.2017.03.022.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101(11): 3808-3815. DOI:10.1016/j.biortech.2010.01.021.

Tenorio C, Moya R, Filho MT, Valaert J. 2015. Quality of pellets made from agricultural and forestry crops in Costa Rican tropical climates. Bioresources 10(1): 482-498.

Tursunov O, Abduganiev N. 2020. A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region. Mater Today: Proc 25: 67-71. DOI:10.1016/j.matpr.2019.11.108.

Vega LY, López L, Valdés CF, Chejne F. 2019. Assessment of energy potential of wood industry wastes through thermochemical conversions. Waste Manag 87: 108-118. DOI:10.1016/j.wasman.2019.01.048.

Wang Z, Bui Q, Zhang B, Pham TLH. 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci Total Environ 743: 140741. DOI:10.1016/j.scitotenv.2020.140741.

Yuliansyah, Amirta R. 2016. Physico-chemical properties and energy potency of wood waste biomass from logging activities to generate electricity in East Kalimantan, Indonesia. AIP Conference Proceeding. DOI:10.1063/1.4958476.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Helmi AS, Setiawan KA, Setiyono B, Angi EM, Saparwadi, Sari NM, Kusuma IW, Rujehan, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20(8): 2236-2242. DOI:10.13057/biodiv/d200818.

BIODIVERSITAS
Volume 23, Number 7, July 2022
Pages: xxx

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d2307xx

Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

YULIANSYAH[1], MUHAMMAD TAUFIQ HAQIQI[1], KRISNA ADIB SETIAWAN[1], AGUS SETIAWAN[1], PRISTIANGGA DWI SAPUTRA[1], HERI SUKMA IQBAL ROMADLON[1], AHMAD MUKHDLOR[1], RICO RAMADHAN[2], RUDIANTO AMIRTA[1,♥]

[1]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683. ♥email: ramirta@fahutan.unmul.ac.id.
[2]Department of Chemistry, Faculty of Science and Technology, Universitas Airlangga. Jl. Mulyorejo, Surabaya 60115, East Java, Indonesia.

Manuscript received: 13 May 2022. Revision accepted: xxx June 2022.

Abstract. *Yuliansyah. Haqiqi MT, Setiawan KA, Setiawan A, Saputra D, Romadlon HSI, Mukhdlor A, Ramadhan R, Amirta R. 2022. Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks. Biodiversitas 23: xxxx.* The conversion of woody biomass into electricity through a thermochemical process has recently attracted significant attention worldwide to promote green energy production. It provides a low-cost and straightforward operation promising for developing rural areas, especially with limited transportation access. In East Kalimantan Province, almost all remote areas are surrounded by forests with high tree species diversity, which is the potential to be utilized for sustainable feedstocks in electric power plants. This study pointed out the energy potential produced from woody biomass of selected fast-growing tree species native to East Kalimantan secondary tropical forest: *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull. Arg. and *Schima wallichii* (DC). Their wood physicochemical properties were firstly investigated. Furthermore, each species' wood quality for solid energy purposes was presented as the fuel value index (FVI). The results revealed that the change from greenwood into wood chip effectively removed the moisture content, thus improving efficiency to achieve higher energy potency. Our findings showed that the highest energy potency was obtained from the wood chip of *S. splendidissima* (3.61 MWh/ton), followed by *S. wallichii* (2.98 MWh/ton). A similar pattern was also found in FVI determination showing that the wood chip of *S. Splendidissima* had the greatest value (8970). Therefore, we observed that the high quality of *S. splendidissima* compared to other selected fast-growing species indicates its high suitability for further large-scale crop plantation to supply wood chips for biomass-based electricity generation.

Keywords: Electricity, fast-growing, native species, secondary forest, woody biomass.

INTRODUCTION

The exploitation of fossil fuels has significantly increased the degradation of natural resources and the environment. Its combustion corresponding to generating electricity constantly accelerates the global warming potential. According to the report from the International Energy Agency, energy production from fossil fuels sectors is responsible for more than 80% of released carbon dioxide (CO_2) in the atmosphere, or it is estimated to exceed two-thirds of total greenhouse gas (GHC) emission (Ram et al. 2018; Cardoso et al. 2019). Although the Paris Agreement in 2015 implicitly called for shifting away from the domination of fossil fuels, the human population and industrialization are continuously growing, creating a significant challenge on how to mitigate climate change and reduce those harmful GHC effects (Karmaker et al. 2020; Rempel and Gupta 2020). The United Nations (UN), through the Climate Action Summit in New York in 2019, has set a global plan to achieve net-zero emissions by 2050 (Mutezo and Mulopo 2021). Therefore, many countries have committed to addressing a transition from fossil fuels to renewable energy by implementing a legal policy (Mola-Yudego et al. 2017; Moya et al. 2019; Rincon et al. 2019).

Among all resources, biomass has been considered the most applicated renewable energy globally, with a proportion of 12.4% of the total energy consumption (Wang et al. 2020). Energy production from biomass is expected to meet global energy demands in the future (Bilgili et al. 2017). It offers various advantages over other renewable sources, such as better energy properties and less CO_2 emission (Liu et al. 2014; Tenorio et al. 2015). Woody biomass harvested from the forest is also one of the promising feedstocks to produce clean energy because it contains quite low sulphur and nitrogen (Hupa et al. 2017; Lee et al. 2021). Since almost all remote areas in Indonesia are covered by forests with limited transportation access, the approach to using its biomass will be adequate to overcome the electricity limitation in those rural areas. Moreover, it will improve economic growth by providing micro or small-scale electricity with a simple and cheaper process. When the wood is burned during the combustion stage, the CO_2 emission can be easily absorbed by available forest plant species through photosynthesis. The net cycle of CO_2 is always in balance, and this phenomenon is known as neutral carbon (Mäkipää et al. 2015; Proto et al. 2021). It will potentially lead to a zero-emission power system (Mori et al. 2022). Excellent performance of biomass-based electricity has been reported earlier (González et al. 2015). Furthermore, it has also been successfully developed in many countries in the world, such as in Brazil (Ferreira 2018), Finland (Majava et al. 2022), Ghana (Präger et al. 2019), India (Narnaware and Panwar 2022), Japan (Battuvshin et al. 2020), Portugal (da Costa et al. 2020), Spain (Aguado et al. 2022), and United States (Broughel 2019).

East Kalimantan province was one of Indonesia's most considerable bioenergy potentials due to its high availability of wood biomass resources from the forest (Simangunsong et al. 2017). The high diversity of biomass plant species distributed in the tropical rain forest of East Kalimantan was also reported as the essential biodiversity value in Indonesia for many endemic species compared to other places on the earth (Pio and D'Cruz 2005). However, the wood harvested from its forest resources was still dominated by the Dipterocarpaceae family, commonly used for furniture and construction purposes. Although it had promising calorific values, it was considered a low-growing tree species that was not desirable for sustainable energy crops (Yuliansyah et al. 2016). On the other hand, fast-growing tree species planted on forest plantations, such as *Acacia mangium*, *Anthocephalus cadamba*, *Eucalyptus pellita*, *Gmelina arborea*, and *Paraserianthes falcataria*, are have been reported to possess low heating value (Amirta et al. 2016; Haqiqi et al. 2022). Therefore, finding suitable plant species having high wood calorific value combined with their fast-growing ability to obtain high biomass yield for energy-electricity production is recently growing (Haqiqi et al. 2018).

The investigation of native species can be an important step in searching for suitable plant biomass species to be cultivated as energy crops in some remote areas. In East Kalimantan Province, many local fast-growing species are characterized as non-commercial species, even known as species with high adaptability to grow well in their origin ecosystem. They are mainly found in plant communities at secondary forest succession. Commonly used as firewood by local people, those species still have less attention for further large-scale utilization, especially in energy production. These species will promise future plantation of short-rotation wood crops to provide sustainable raw materials with a faster-growing ability. However, further wood physicochemical analysis was necessary to meet an ideal energy crop requirement. This study reported comparing wood physicochemical properties of selected fast-growing tree species native to the East Kalimantan forest to be used as feedstocks in electricity production.

MATERIALS AND METHODS

Study area

Wood biomass materials and leaf samples from some fast-growing native species were collected at the secondary forest of Mulawarman University Educational Forest (KHDTK Fahutan UNMUL, Samarinda), Samarinda City, East Kalimantan Province, Indonesia (0º25'10" LS – 0º25'10" LS and, 117º14'00" BT-117º14'14" BT - 300 ha).

Biomass plant species

Medium trees with 6-8 cm diameter recognized as native fast-growing species naturally grown on secondary tropical rain forests in East Kalimantan were pointed out. Identification through leaf herbarium specimens of each species was deposited at the Laboratory of Forest Dendrology and Ecology, Faculty of Forestry, Mulawarman University. In this study, six species were identified, namely *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull.Arg. and *Schima wallichii* (DC). They belong to different family groups, including elaeocarpaceae, moraceae, fabaceae, lauraceae, euphorbiaceae and theaceae, respectively. All woody biomass samples were collected in September 2021. They were debarked to analyze the dry bark-wood ratio, then converted into wood chips before proceeding to laboratory analysis.

Determination of wood physicochemical properties and energy potency

The total moisture and proximate compositions of wood materials were carried out according to ASTM D 7582-12 method. The lost weight of the samples after reaching the constant weight in a hot air oven at 105ºC was calculated to determine the moisture content. For proximate analysis, the samples were dried and grounded into smaller sizes (±60 mesh). The measurements consisted of two steps in a furnace. The first step was done by heating from 300-575ºC for 3 hours. The weight loss was measured and noted as a volatile matter (VM) substance. Then, the temperature was increased to reach 950ºC for 2 hours to heat the remaining samples. After cooling down to room temperature, the residual weight was measured in ash content while the lost weight was fixed carbon (FC).

The ultimate compositions of wood biomass including carbon (C), hydrogen (H), and oxygen (O) were estimated based on the following Equation (Parikh et al. 2007):

$$C\ (\%) = (0.637 \times FC) + (0.455 \times VM) \quad (1)$$

$$H\ (\%) = (0.052 \times FC) + (0.062 \times VM) \quad (2)$$

$$O\ (\%) = (0.304 \times FC) + (0.476 \times VM) \quad (3)$$

Measurement of wood density (kg/m^3) was conducted by drying the wood samples at 105ºC following Edwards et al. (2014). The wood calorific value (MJ/kg) was accomplished in a bomb calorimeter according to the standard from EN-ISO 15400:2011, followed by the calculation of energy-electricity potency according to Francescato et al. (2008). Those measurements were classified into greenwood and wood chips. Furthermore, the fuel value index (FVI) was calculated using the equation as follows (Jain and Singh 1999):

$$FVI = (\text{Calorific value} \times \text{density}) / (\text{ash} \times \text{moisture}) \quad (4)$$

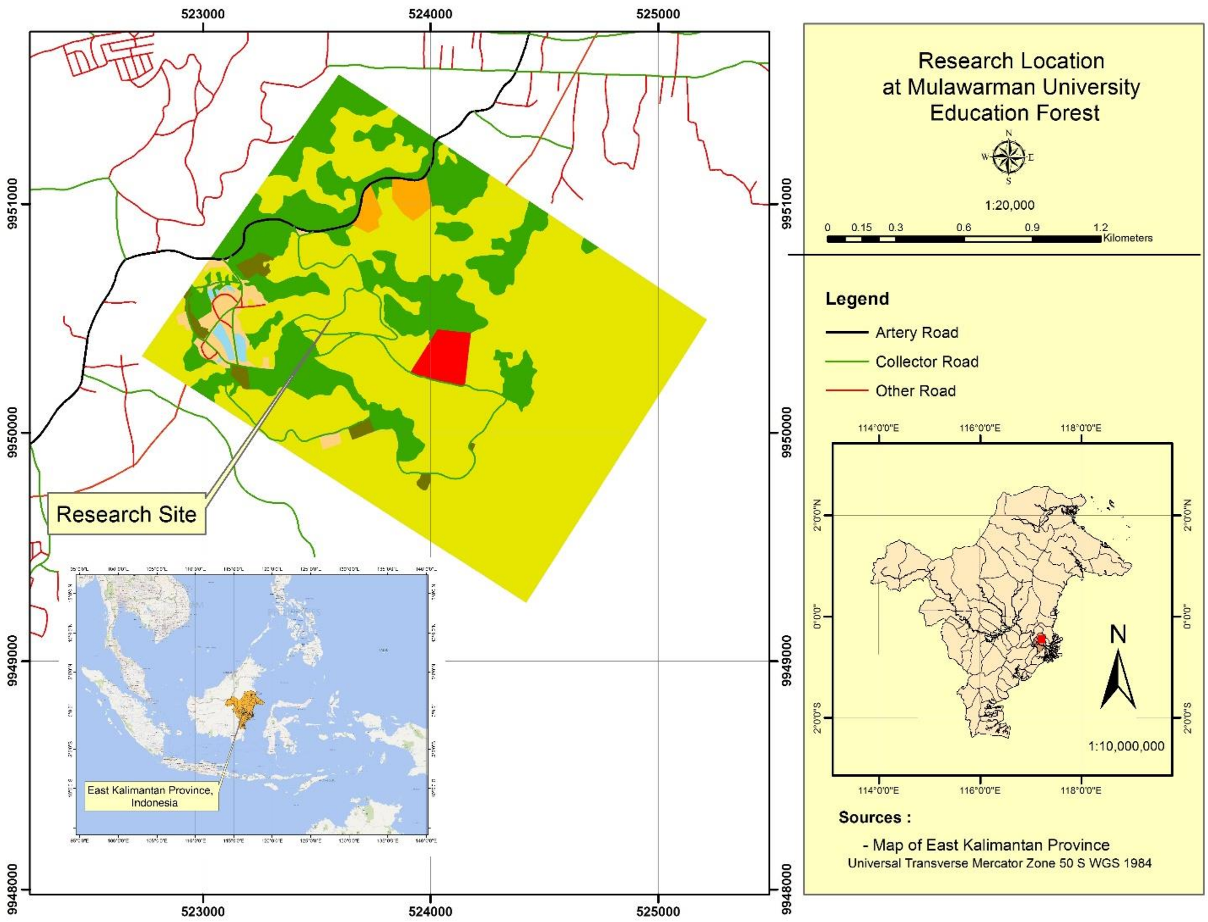


Figure 1. Research location conducted at Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia (0°25’10” LS – 0°25’10” LS and 117°14’00” BT-117°14’14” BT).

E. ferrugineus *F. aurata* *F. splendidissima*

L. lucida *M. paniculatus* *S. wallichii*

Figure 2. Fresh leaf shape varieties of some fast-growing native tree species were collected from the secondary forest of Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia

RESULTS AND DISCUSSION

Plant biomass species

Generally, tropical forest areas provide better environmental conditions for plants to produce sustainable biomass with high yields. This condition will lead to its potential wide-range application in biomass-based conversion technology, such as electricity generation. However, a previous study demonstrated that forest biomass species with high energy content were commonly produced from low-growing species (Amirta et al. 2016). In large-scale electricity production, utilization of the low-growing species in energy feedstocks requires a slow harvest cycle period with a high-cost operation. Therefore, this study assessed woody materials obtained from selected fast-growing species, including *E. ferrugineus*, *F. aurata*, *F. splendidissima*, *L. lucida*, *M. paniculatus*, and *S. wallichii* for the purpose of energy-electricity feedstock. Those species are abundant and native to the secondary forest of East Kalimantan, in which the local people traditionally used their wood as firewood for cooking activities. Nevertheless, literature describing those plant species for further industrial application is still rare. The measurement of bark and wood proportion of each species was summarized in Table 1. It was noticeable that three species, including *E. ferrugineus, F. aurata,* and *F. splendidissima,* had the lowest bark-wood ratio (0.7). The highest bark proportion was obtained from *S. wallichiii*, followed by *M. paniculatus* and *L. lucida,* with the value of 12.95%, 11.22%, and 7.80%, respectively. It has been reported earlier that the stem bark of *E. ferrugineus* was the potential for treating malaria-like symptoms (Ismail et al. 2015). On the other hand, *S. wallichii* bark could be utilized as an antimicrobial agent (Dewanjee et al. 2008). Hence, these interesting properties could potentially enhance their application for both energy feedstocks and natural medicine products. Since the stem bark produces a high quantity of ash (Pérez et al. 2008), its removal from wood when used for energy production through thermochemical conversion is necessary.

Wood physicochemical properties

Moisture content, density, and chip capacity of woody materials examined from some selected native tree species were summarized in Table 2. It has been previously reported that the percentage of wood moisture content depends on the plant species, season, and storage condition (Mancini and Rinnan 2021). In green conditions, the highest wood moisture content was obtained from *S. wallichii* (59.25%), while the lowest moisture content could be found in *F. splendidissima* (40.37%). The conversion of the wood into chip form evidently reduced their moisture content. As shown in Table 2, all wood chips revealed a lower moisture percentage than green wood conditions. It was found that the average moisture content of wood chips was 9.58%. It seems that wood chip form could easily evaporate the amount of water. Surprisingly, this situation could also be benefited considerably increase the achieved calorific value due to the water loss phenomenon (Figure 3A). According to the measurement of wood density, it was found that the highest wood density was obtained from *F. splendidissima* (760 kg/m^3). The second and third largest were found in *E. ferrugineus* (575 kg/m^3) and *S. wallichii* (536 kg/m^3) wood, respectively. The average wood density value from all species used in this study was 507 kg/m^3. Meanwhile, their form changed into wood chips that needed a high storage capacity. It was found that the average value of wood chips of all species was 201 kg per m^3 of storage area. The high wood density contributed to increasing the efficiency of wood chip storage. As observed from *F. splendidissima*, its wood chip (300 kg/m^3) was the most efficient storage capacity among all woody materials used. Especially for a large-scale operation, the high density of wood chips potentially contributes to low energy production costs (Bahadori et al. 2014). In contrast, low wood density affects the fast burning of the reactor, high transport costs, and high storage capacity (de Oliveira et al. 2013).

Table 1. Wood and bark ratio of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant Species		**Bark Proportion (%)**	**Wood Proportion (%)**	**Bark-Wood Ratio**
Latin name	**Local name**			
E. ferrugineus	Belau	6.37 ± 0.59	93.63 ± 0.59	0.07 ± 0.01
F. aurata	Kayu ara	6.65 ± 0.25	93.35 ± 0.25	0.07 ± 0.00
F. splendidissima	Makumpit	6.70 ± 0.93	93.30 ± 0.93	0.07 ± 0.01
L. lucida	Madang	7.80 ± 0.55	92.20 ± 0.55	0.08 ± 0.01
M. paniculatus	Balik angin	11.22 ± 0.45	88.78 ± 0.45	0.13 ± 0.01
S. wallichii	Puspa	12.95 ± 0.68	87.06 ± 0.68	0.15 ± 0.01
Average		**8.62 ± 2.79**	**91.39 ± 2.79**	**0.10 ± 0.10**

Table 2. Moisture content, wood density, and chip capacity of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant Species		**Moisture content (%)**		**Wood density**	**Chip capacity**
Latin name	**Local name**	**Greenwood**	**wood Chip**	**(kg/m^3)**	**(kg/m^3)**
E. ferrugineus	Belau	49.77 ± 1.59	9.34 ± 0.03	575 ± 25.78	227± 10.18
F. aurata	Kayu ara	56.90 ± 0.63	9.62 ± 0.03	487 ± 23.19	192 ± 9.15
F. splendidissima	Makumpit	40.37 ± 0.19	9.81 ± 0.01	760 ± 22.69	300 ± 8.94
L. lucida	Madang	50.64 ± 1.05	9.64 ± 0.05	354 ± 14.86	140 ± 5.86
M. paniculatus	Balik angin	52.85 ± 0.28	9.52 ± 0.03	331 ± 11.21	131 ± 4.42
S. wallichii	Puspa	59.25 ± 1.83	9.53 ± 0.01	536 ± 18.99	211 ± 7.49
Average		**51.63 ± 6.61**	**9.58 ± 0.15**	**507 ± 157.7**	**200 ± 62.6**

Table 3. Proximate and ultimate analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant species	**Ash (%)**	**Fixed carbon (%)**	**Volatile matter (%)**	**Carbon (%)**	**Hydrogen (%)**	**Oxygen (%)**	**H/C ratio**
E. ferrugineus	2.29 ± 0.03	14.23 ± 0.18	74.14 ± 0.14	42.80 ± 0.18	5.34 ± 0.01	39.62 ± 0.12	0.12 ± 0.00
F. aurata	2.30 ± 0.02	13.53 ± 0.16	75.55 ± 0.17	42.54 ± 0.17	5.33 ± 0.01	39.60 ± 0.13	0.13 ± 0.00
F. splendidissima	1.62 ± 0.04	13.85 ± 0.13	74.72 ± 0.13	42.82 ± 0.14	5.35 ± 0.02	37.78 ± 0.10	0.12 ± 0.00
L. lucida	1.71 ± 0.02	14.82 ± 0.21	73.83 ± 0.21	43.03 ± 0.04	5.35 ± 0.01	39.62 ± 0.04	0.12 ± 0.00
M. paniculatus	2.69 ± 0.01	13.36 ± 0.10	74.43 ± 0.16	42.38 ± 0.13	5.31 ± 0.01	39.49 ± 0.10	0.13 ± 0.00
S. wallichii	1.64 ± 0.05	12.96 ± 0.16	75.87 ± 0.09	42.78 ± 0.14	5.38 ± 0.01	40.05 ± 0.09	0.13 ± 0.00
Average	**2.04 ± 0.44**	**13.79 ± 0.66**	**74.76 ± 0.80**	**42.72 ± 0.44**	**5.34 ± 0.66**	**39.70 ± 0.80**	**0.13 ± 0.00**

Various laboratory tests were carried out for proximate and ultimate analysis. The proximate analysis includes ash, fixed carbon, and volatile matter (Table 3). These parameters strongly affected the performance of combustion, pyrolysis, and gasification of wood biomass in the thermochemical conversion process (Tursunov and Abduganiev 2020). Ash content of all woody materials showed less than 5%, which demonstrated their high potency utilized for raw materials of energy production. The low value of ash residue (<5%) resulting from the combustion process has a positive impact on increasing the efficiency stage and avoiding damage to the electricity reactor (Shao et al. 2011). Nimmanterdwong et al. (2021) stated that the ash in biomass is directly related to the mineral and inorganic elements absorbed by plants from the ground via the root cells, while its percentage differently depends on the soil properties, rocks, chemical treatment, and available metal contents. The volatile matters of all woody materials in this study were in the range of 73.83 – 75.87%, whereas the fixed carbons were in the range of 12.96–14.82%. It has been reported that the heat decomposition of cellulose and hemicellulose in biomass is the source of volatile matter. In contrast, lignin is a char source due to its richness in carbon atoms (Vega et al. 2019). The ultimate compositions, including C (carbon), H (hydrogen), and O (oxygen), were presented in Table 3. This investigation is essential to determine the theoretical air-fuel ratio in the thermochemical system and predict the released pollution (Telmo et al. 2010). The average value of C, H, and O was 42.72%, 5.35%, and 39.70%, respectively. It was clearly observed that all woody materials contained C higher than O, indicating its high suitability used as the energy feedstock since high C content will increase the obtained calorific value. Moreover, the C content, with a value of more than 40% in this study, was in line with that of the C content of various tropical woods (Amirta et al. 2016; Amirta et al. 2019; Yuliansyah et al. 2019; Mukhdlor et al. 2021). Ratio of H/C was also assessed since higher value could contribute to improve energy efficiency and decrease released emission during combustion (Gopalakrishnan et al. 2019). The average of H/C ratio of the six-plant studied was 0.13. This value was comparable with sawdust previously reported by Garcia et al. (2012). More importantly, these findings demonstrated that all fast-growing species selected in this study possessed better H/C ratio than those of other tropical fast-growing woody species, such as *Bridelia tomentosa*, *Fagraea racemosa*, *Piper aduncum*, *Trema orientalis*, and *Vernonia arborea* (Amirta et al. 2016).

Wood quality for energy feedstock

The investigation of the fuelwood quality of native species is presented in Figure 3. The important parameters were calorific value, wood chip conversion value, energy-electricity potency, and fuel value index. According to Figure 3A, the conversion of green wood (original solid form) into wood chip form significantly enhanced the average calorific value up to 0.5-fold. It was calculated that the average calorific value of all examined woods in the green form (7.92 MJ/kg) increased to 17.01 MJ/kg at the wood chip condition. We found that those results were in line with decreasing the amount of moisture content on wood samples when converted into wood chips (51.63% to 9.58%) (Table 2). It has also been reported by Deboni et al. (2020) that lower moisture content is considered one of the factors that significantly influence the increased calorific value of woody biomass as a reliable energy source. The high proportion of moisture content in fuelwood could result in delayed ignition and devolatilization (Lu et al. 2008). Although this work promised high energy content, the wood chip form consequently required a larger storage

area (m^3) per ton of wood chip biomass than the greenwood form, as shown in Figure 3B.

In order to compare the suitability of woody materials from selected native species, further measurement of energy potency in MWh per ton biomass was performed (Figure 3C). The results showed that *F. splendidissima* exhibited the highest energy potency in both greenwood (2.21 MWh/ton) and wood chip (3.61 MWh/ton) forms. Although *S. wallichii* and *F. aurata* possessed high calorific values (Figure 3A), *F. splendidissima* had higher energy-electricity potency than those species due to its high wood density (760 kg/m^3). Interestingly, even though *F. splendidissima* is considered fast-growing species, this species was classified as high wood density (< 600 kg/m^3), whereas *S. wallichii* and *F. aurata* were characterized as medium wood density (400 – 600 kg/m^3). Having a similar pattern with calorific value results, the energy potency of all woody materials to generate electricity demonstrated significantly enhanced value after converting into wood chips due to the moisture removal. Our previous study shows fast-growing species in the lowland community forest, such as *Gmelina arborea*, *Anthocephalus cadamba*, *Acacia mangium*, and *Paraserianthes falcataria,* had relatively low energy potency (1.37 – 1.70 MWh/ton) (Amirta et al. 2016). Another study also reported that fast-growing and shrub species found in the tropical swamp-peat forest of Kutai Kartanegara in East Kalimantan generated low energy potency: *Kleinhovia hospita* (1.76 MWh/ton), *Cananga odorata* (1.36 MWh/ton), and *Octomeles sumatrana* (1.17 MWh/ton) (Amirta et al. 2019). However, our findings in this study indicated that fast-growing species native to the secondary forest in East Kalimantan, especially *F. splendidissima*, could produce woody materials with superior energy capacity for electricity production.

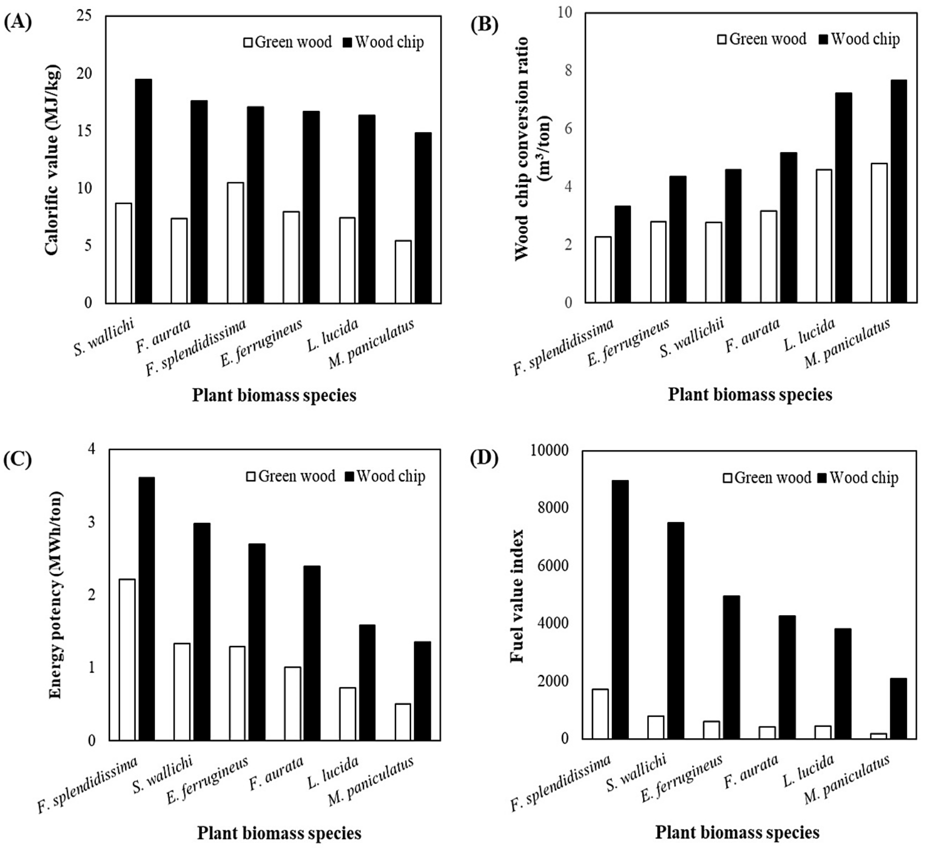


Figure 3. Analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia, for electricity feedstock: Wood calorific value (A), wood chip conversion ratio (B), energy potency (C), and fuel value index (D)

The bioenergy potential of each fast-growing native species was represented by Fuel Value Index (FVI) (Figure 3D). The FVI is an essential assessment for screening desirable biomass species for solid fuel (Samal et al. 2021). This measurement was also used by Niemczyk et al. (2018) to rank the quality of 10 poplar cultivars in northern Poland. The FVI was calculated using combinations of some influencing factors, including ash content, moisture content, calorific value, and wood density. This study found that wood chips containing low moisture content increased the FVI result from each wood tested. The average FVI of the wood chip, which had a value of 5267, was significantly higher than that of the greenwood condition, with an average value of 698. The greatest FVI was obtained from *F. splendidissima* (8970), followed by *S. wallichii* and *F. ferrugineus* with the value of 7502 and 4958, respectively. A high FVI value of wood biomass was observed because of low ash content, low moisture content, and high density (Pérez et al. 2014). We concluded that the wood chip revealed lower moisture content compared to the original form (green condition), indicating its high suitability to produce sustainable green energy.

Finally, all woody materials obtained from fast-growing native species in the secondary forest of East Kalimantan were suitable for electricity feedstock due to the low ash content and a high proportion of carbon. When each wood biomass was converted into wood chip form, their efficiency in energy feedstocks (calorific value, storage capacity, energy-electricity potency, and FVI) was gradually increased since this form was able to remove moisture effectively. In contrast, the greenwood showed inefficient use since it might take longer to dry; thus, the cost of energy production will also increase. Among all biomass tested, the wood chip of *F. splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency (3.61 MWh/ton) with desired FVI value (8970). Furthermore, the high adaptability in the local ecosystem combined with its high wood density and fast-growing ability will be the promising characteristics that allow *F. splendidissima* to be one of the ideal crops for energy feedstocks in the future. In general, this study successfully demonstrated the physicochemical properties of selected fast-growing native species in the tropical secondary forest in East Kalimantan, Indonesia, to generate electricity in rural communities, especially to develop the economic sector in this province.

ACKNOWLEDGEMENTS

The current study was financially supported by the Project Implementation Unit of Islamic Development Bank – PIU IsDB (Grant No. 402/UN17.45/DL/2021 for Yl, RA, and MTH), and the research funding for lecturers and students from the Faculty of Forestry, Mulawarman University (For Yl 2022)

REFERENCES

Aguado R, Vera D, Jurado F, Beltrán G. 2022. An integrated gasification plant for electric power generation from wet biomass: toward a sustainable production in the olive oil industry. Biomass Convers Biorefin. DOI: 10.1007/s13399-021-02231-0.

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Londong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast-growing wood species for energy production. Nusantara Biosci 8 (1): 22-31. DOI:10.13057/nusbiosci/n080106.

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 (6): 1516-1523. DOI: 10.13057/biodiv/d200605.

Bahadori A, Zahedi G, Zendehboudi S, Jamili A. 2014. Estimation of the effect of biomass moisture content on the direct combustion of sugarcane bagasse in boilers. Int J Sustain Energy 33: 349–356. DOI:10.1080/14786451.2012.748766.

Battuvshin B, Matsuoka Y, Shirasawa H, Toyama K, Hayashi U, Aruga K. 2020. Supply potential and annual availability of timber and forest biomass resources for energy considering inter-prefectural trade in Japan. Land Use Policy 97: 104780. DOI:10.1016/j.landusepol.2020.104780.

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S. 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew Sustain Energy Rev 71: 830-845. DOI: 10.1016/j.rser.2016.12.109.

Broughel AE. 2019. Impact of state policies on generating capacity for production of electricity and combined heat and power from forest biomass in the United States. Renew Energy 134: 1163-1172. DOI: 10.1016/j.renene.2018.09.058.

Cardoso J, Silva V, Eusébio D. 2019. Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal. J Clean Prod 212: 741-753. DOI:10.1016/j.jclepro.2018.12.054.

da Costa TP, Quinteiro P, Arroja L, Dias AC. 2020. Environmental comparison of forest biomass residues application in Portugal: Electricity, heat, and biofuel. Renew Sustain Energy Rev 134: 110302. DOI:10.1016/j.rser.2020.110302.

de Oliveira JL, da Silva JN, Pereira EG, Filho DO, Carvalho DR. 2013. Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification. Renew Sustain Energy Rev 21: 52–58. DOI:10.1016/j.rser.2012.12.025.

Deboni TL, Simioni FJ, do Rosário JDA, Costa VJ. 2020. Quality of biomass from old wood waste deposits in Southern Brazil. Biomass Bioenergy 143: 105841. DOI:10.1016/j.biombioe.2020.105841.

Dewanjee S, Maiti A, Majumdar R, Majumdar A, Mandal SC. 2008. Evaluation of antimicrobial activity of hydroalcoholic extract *Schima wallichii* bark. Pharmacologyonline 1: 523-528.

Edwards LE, Newby AF, Gilliam CH, Fain GB, Sibley JL, Murphy, AM. 2014. Evaluation of eastern redcedar substrate in the production of four annual species. J Environ Hortic 32 (3): 167-173.

Ferreira LRA, Otto RB, Silva FP, De Souza SNM, De Souza SS, Junior OA. 2018. Review of the energy potential of the residual biomass for the distributed generation in Brazil. Renew Sustain Energy Rev 94: 440-455. DOI:10.1016/j.rser.2018.06.034.

Francescato F, Antonini E, Bergomi LZ. 2008. Wood Fuels Handbook: Production, Quality Requirements, Trading. Legnaro, Italy.

García R, Pizarro C, Lavín AG, Bueno J.L. 2012. Characterization of Spanish biomass wastes for energy use. Bioresour Technol 103(1): 249-258. DOI: 10.1016/j.biortech.2011.10.004.

González A, Riba JR, Puig R, Navarro P. 2015. Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. Renew Sustain Energy Rev 43: 143-155. DOI:10.1016/j.rser.2014.11.013.

Gopalakrishnan B, Khanna N, Das D. 2019. Dark-fermentative biohydrogen production. In: Biohydrogen. Elsevier. DOI: 10.1016/B978-0-444-64203-5.00004-6.

Haqiqi MT, Yuliansyah, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf. Series: Earth and Environmental Science. DOI: 10.1088/1755-1315/144/1/012041.

Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R Yuliansyah, Suwinarti W, Amirta R. 2022. Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency. Biodiversitas 23 (5): 2389-2394. DOI: 10.13057/biodiv/d230516

Hupa M, Karlström O, Vainio E. 2017. Biomass combustion technology development–It is all about chemical details. Proc Combust Inst 36(1): 113-134. DOI: 10.1016/j.proci.2016.06.152.

Ismail I, Linatoc AC, Mohamed M, Tokiman L. 2015. Documentation of medicinal plants traditionally used by the jakun people of endau-rompin (peta) for treatments of malaria-like symptoms. Jurnal Teknologi 77 (31): 63-69.

Jain RK, Singh B. 1999. Fuelwood characteristics of selected indigenous tree species from central India. Bioresour Technol 68: 305-308. DOI: 10.1016/S0960-8524(98)00173-4.

Karmaker AK, Rahman MM, Hossain MA, Ahmed MR. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. J Clean Prod 244: 118645. DOI: 10.1016/j.jclepro.2019.118645.

Lee BH, Sh L, Lee DG, Jeon CH. 2021. Effect of torrefaction and ashless process on combustion and NOx emission behaviors of woody and herbaceous biomass. Biomass Bioenerg 151: 106133. DOI: 10.1016/j.biombioe.2021.106133.

Liu Y, Xu Y, Zhang F, Yun J, Shen Z. 2014. The impact of biofuel plantation on biodiversity: a review. Chinese Sci Bull 59 (34): 4639-4651. DOI: 10.1007/s11434-014-0639-1.

Lu G, Yan Y, Cornwell S, Whitehouse M, Riley G. 2008. Impact of co-firing coal and biomass on flame characteristics and stability. Fuel 87: 1133-1140. DOI:10.1016/j.fuel.2007.07.005.

Majava A, Vadén T, Toivanen T, Järvensivu P, Lähde V, Eronen JT. 2022. Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target. Energy Strategy Rev 41: 100836. DOI:10.1016/j.esr.2022.100836.

Mäkipää R, Linkosalo T, Komarov A, Mäkelä A. 2015. Mitigation of climate change with biomass harvesting in Norway spruce stands: are harvesting practices carbon neutral? Canadian J For Res 45 (2): 217-225. DOI:10.1139/cjfr-2014-0120.

Mancini M, Rinnan Å. 2021. Near infrared technique as a tool for the rapid assessment of waste wood quality for energy applications. Renew Energy 177: 113-123. DOI: 10.1016/j.renene.2021.05.137.

Mola-Yudego B, Arevalo J, Díaz-Yáñez O, Dimitriou I, Freshwater E, Haapala A, Khanam T, Selkimäki M. 2017. Reviewing wood biomass potentials for energy in Europe: the role of forests and fast-growing plantations. Biofuels 8 (4): 401-410. DOI: 10.1080/17597269.2016.1271627.

Mori S, Sumner J, Bouvet J, Simms NJ. 2022. Fireside and steamside performance in biomass power plant. Mater High Temp 39 (2): 106-121. DOI:10.1080/09603409.2021.2019657.

Moya R, Tenorio C, Oporto G. 2019. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. Energies 12(4): 705. DOI:10.3390/en12040705.

Mukhdlor A, Haqiqi MT, Tirkaamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation. Advances in Biological Science Research. DOI: 10.2991/absr.k.210408.005.

Mutezo G, Mulopo J. 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 137: 110609. DOI: 10.1016/j.rser.2020.110609.

Narnaware SL, Panwar NL. 2022. Biomass gasification for climate change mitigation and policy framework in India: A review. Bioresour Technol Rep 17: 100892. DOI:10.1016/j.biteb.2021.100892.

Niemczyk M, Kaliszewski A, Jewiarz M, Wrobel M, Mudryk K. 2018. Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland. Biomass Bioenergy, 111: 46-51. DOI: 10.1016/j.biombioe.2018.02.002.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI: 10.1016/j.energy.2021.119945.

Parikh L, Channiwala SA, Ghosal GK. 2007. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86: 1710-1719. DOI:10.1016/j.fuel.2006.12.029.

Pérez S, Renedo CJ, Ortiz A, Manána M. 2008. Energy potential of waste from 10 forest species in the North of Spain (Cantabria). Bioresour Technol 99: 6339–6345. DOI: 10.1016/j.biortech.2007.12.014.

Pérez S, Renedo CJ, Ortiz A, Delgado F, Fernández I. 2014. Energy potential of native shrub species in northern Spain. Renew Energy 62: 79-83. DOI: 10.1016/j.renene.2013.06.048.

Pio D, D'Cruz R. 2005. Borneo's Lost World: Newly Discovered Species on Borneo. WWF, Jakarta.

Präger F, Paczkowski S, Sailer G, Derkyi NSA, Pelz S. 2019. Biomass sources for a sustainable energy supply in Ghana–A case study for Sunyani. Renew Sustain Energy Rev 107: 413-424. DOI: 10.1016/j.rser.2019.03.016.

Proto AR, Palma A, Paris E, Papandrea SF, Vincenti B, Carnevale M, Guerriero E, Bonofiglio R, Gallucci F. 2021. Assessment of wood chip combustion and emission behavior of different agricultural biomasses. Fuel 289: 119758. DOI:10.1016/j.fuel.2020.119758.

Ram M, Child M, Aghahosseini A, Bogdanov D, Lohrmann A, Breyer C. 2018. A comparative analysis of electricity generation costs from renewable, fossil fuel, and nuclear sources in G20 countries for the period 2015-2030. J Clean Prod 199: 687-704. DOI:10.1016/j.jclepro.2018.07.159.

Rempel A, Gupta J. 2020. Conflicting commitments? Examining pension funds, fossil fuel assets, and climate policy in the organisation for economic co-operation and development (OECD). Energy Res Soc Sci 69: 101736. DOI: 10.1016/j.erss.2020.101736.

Rincon L, Puri M, Kojakovic A, Maltsoglou I. 2019. The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy policy 130: 69-88. DOI: 10.1016/j.enpol.2019.03.024.

Samal B, Vanapalli KR, Dubey BK, Bhattacharya J, Chandra S, Medha I. 2021. Influence of process parameters on thermal characteristics of char from co-pyrolysis of eucalyptus biomass and polystyrene: Its prospects as a solid fuel. Energy 232: 121050. DOI:10.1016/j.energy.2021.121050.

Shao Y, Xu C, Zhu J, Preto F, Wang J, Li H, Badour C. 2011. Ash deposition in co-firing three-fuel blends consisting of woody biomass, peat, and lignite in a pilot-scale fluidized-bed reactor. Energy Fuels 25 (7): 2841-2849. DOI:10.1021/ef2002603.

Simangunsong BCH, Sitanggang VJ, Manurung EGT, Rahmadi A, Moore GA, Aye L, Tambunan AH. 2017. Potential forest biomass resource as feedstock for bioenergy and its economic value in Indonesia. For Policy Econ 81: 10–17. DOI:10.1016/j.forpol.2017.03.022.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101 (11): 3808-3815. DOI:10.1016/j.biortech.2010.01.021.

Tenorio C, Moya R, Filho MT, Valaert J. 2015. Quality of pellets made from agricultural and forestry crops in Costa Rican tropical climates. Bioresources 10 (1): 482-498.

Tursunov O, Abduganiev N. 2020. A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region. Mater Today: Proc 25: 67-71. DOI: 10.1016/j.matpr.2019.11.108.

Vega LY, López L, Valdés CF, Chejne F. 2019. Assessment of energy potential of wood industry wastes through thermochemical conversions. Waste Manag 87: 108-118. DOI: 10.1016/j.wasman.2019.01.048.

Wang Z, Bui Q, Zhang B, Pham TLH. 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci Total Environ 743: 140741. DOI:10.1016/j.scitotenv.2020.140741.

Yuliansyah, Amirta R. 2016. Physico-chemical properties and energy potency of wood waste biomass from logging activities to generate electricity in East Kalimantan, Indonesia. AIP Conference Proceeding. DOI:10.1063/1.4958476.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Helmi AS, Setiawan KA, Setiyono B, Angi EM, Saparwadi, Sari NM, Kusuma IW, Rujehan, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20 (8): 2236-2242. DOI:10.13057/biodiv/d200818.

Notifications

[biodiv] Editor Decision

2022-06-27 02:35 PM

YULIANSYAH YULIANSYAH, MUHAMMAD TAUFIQ HAQIQI, KRISNA ADIB SETIAWAN, AGUS SETIAWAN, PRISTIANGGA DWI SAPUTRA, HERI SUKMA IQBAL ROMADLON, AHMAD MUKHDLOR, RICO RAMADHAN, RUDIANTO AMIRTA:

The editing of your submission, "Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks," is complete. We are now sending it to production.

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/11174

Biodiversitas Journal of Biological Diversity

BIODIVERSITAS
Volume 23, Number 7, July 2022
Pages: xxx

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d2307xx

Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

YULIANSYAH[1], MUHAMMAD TAUFIQ HAQIQI[1], KRISNA ADIB SETIAWAN[1], AGUS SETIAWAN[1], PRISTIANGGA DWI SAPUTRA[1], HERI SUKMA IQBAL ROMADLON[1], AHMAD MUKHDLOR[1], RICO RAMADHAN[2], RUDIANTO AMIRTA[1,♥]

[1]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683. ♥email: ramirta@fahutan.unmul.ac.id.
[2]Department of Chemistry, Faculty of Science and Technology, Universitas Airlangga. Jl. Mulyorejo, Surabaya 60115, East Java, Indonesia.

Manuscript received: 13 May 2022. Revision accepted: xxx June 2022.

Abstract. *Yuliansyah. Haqiqi MT, Setiawan KA, Setiawan A, Saputra D, Romadlon HSI, Mukhdlor A, Ramadhan R, Amirta R. 2022. Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks. Biodiversitas 23: xxxx.* The conversion of woody biomass into electricity through a thermochemical process has recently attracted significant attention worldwide to promote green energy production. It provides a low-cost and straightforward operation promising for developing rural areas, especially with limited transportation access. In East Kalimantan Province, almost all remote areas are surrounded by forests with high tree species diversity, which is the potential to be utilized for sustainable feedstocks in electric power plants. This study pointed out the energy potential produced from woody biomass of selected fast-growing tree species native to East Kalimantan secondary tropical forest: *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull. Arg. and *Schima wallichii* (DC). Their wood physicochemical properties were firstly investigated. Furthermore, each species' wood quality for solid energy purposes was presented as the fuel value index (FVI). The results revealed that the change from greenwood into wood chip effectively removed the moisture content, thus improving efficiency to achieve higher energy potency. Our findings showed that the highest energy potency was obtained from the wood chip of *S. splendidissima* (3.61 MWh/ton), followed by *S. wallichii* (2.98 MWh/ton). A similar pattern was also found in FVI determination showing that the wood chip of *S. Splendidissima* had the greatest value (8970). Therefore, we observed that the high quality of *S. splendidissima* compared to other selected fast-growing species indicates its high suitability for further large-scale crop plantation to supply wood chips for biomass-based electricity generation.

Keywords: Electricity, fast-growing, native species, secondary forest, woody biomass.

INTRODUCTION

The exploitation of fossil fuels has significantly increased the degradation of natural resources and the environment. Its combustion corresponding to generating electricity constantly accelerates the global warming potential. According to the report from the International Energy Agency, energy production from fossil fuels sectors is responsible for more than 80% of released carbon dioxide (CO_2) in the atmosphere, or it is estimated to exceed two-thirds of total greenhouse gas (GHC) emission (Ram et al. 2018; Cardoso et al. 2019). Although the Paris Agreement in 2015 implicitly called for shifting away from the domination of fossil fuels, the human population and industrialization are continuously growing, creating a significant challenge on how to mitigate climate change and reduce those harmful GHC effects (Karmaker et al. 2020; Rempel and Gupta 2020). The United Nations (UN), through the Climate Action Summit in New York in 2019, has set a global plan to achieve net-zero emissions by 2050 (Mutezo and Mulopo 2021). Therefore, many countries have committed to addressing a transition from fossil fuels to renewable energy by implementing a legal policy (Mola-Yudego et al. 2017; Moya et al. 2019; Rincon et al. 2019).

Among all resources, biomass has been considered the most applicated renewable energy globally, with a proportion of 12.4% of the total energy consumption (Wang et al. 2020). Energy production from biomass is expected to meet global energy demands in the future (Bilgili et al. 2017). It offers various advantages over other renewable sources, such as better energy properties and less CO_2 emission (Liu et al. 2014; Tenorio et al. 2015). Woody biomass harvested from the forest is also one of the promising feedstocks to produce clean energy because it contains quite low sulphur and nitrogen (Hupa et al. 2017; Lee et al. 2021). Since almost all remote areas in Indonesia are covered by forests with limited transportation access, the approach to using its biomass will be adequate to overcome the electricity limitation in those rural areas. Moreover, it will improve economic growth by providing micro or small-scale electricity with a simple and cheaper process. When the wood is burned during the combustion stage, the CO_2 emission can be easily absorbed by available forest plant species through photosynthesis. The net cycle of CO_2 is always in balance, and this phenomenon is known as neutral carbon (Mäkipää et al. 2015; Proto et al. 2021). It will potentially lead to a zero-emission power system (Mori et al. 2022). Excellent performance of biomass-based electricity has been reported earlier (González et al. 2015). Furthermore, it has also been successfully developed in many countries in the world, such as in Brazil (Ferreira 2018), Finland (Majava et al. 2022), Ghana (Präger et al. 2019), India (Narnaware and Panwar 2022), Japan (Battuvshin et al. 2020), Portugal (da Costa et al. 2020), Spain (Aguado et al. 2022), and United States (Broughel 2019).

East Kalimantan province was one of Indonesia's most considerable bioenergy potentials due to its high availability of wood biomass resources from the forest (Simangunsong et al. 2017). The high diversity of biomass plant species distributed in the tropical rain forest of East Kalimantan was also reported as the essential biodiversity value in Indonesia for many endemic species compared to other places on the earth (Pio and D'Cruz 2005). However, the wood harvested from its forest resources was still dominated by the Dipterocarpaceae family, commonly used for furniture and construction purposes. Although it had promising calorific values, it was considered a low-growing tree species that was not desirable for sustainable energy crops (Yuliansyah et al. 2016). On the other hand, fast-growing tree species planted on forest plantations, such as *Acacia mangium*, *Anthocephalus cadamba*, *Eucalyptus pellita*, *Gmelina arborea*, and *Paraserianthes falcataria*, are have been reported to possess low heating value (Amirta et al. 2016; Haqiqi et al. 2022). Therefore, finding suitable plant species having high wood calorific value combined with their fast-growing ability to obtain high biomass yield for energy-electricity production is recently growing (Haqiqi et al. 2018).

The investigation of native species can be an important step in searching for suitable plant biomass species to be cultivated as energy crops in some remote areas. In East Kalimantan Province, many local fast-growing species are characterized as non-commercial species, even known as species with high adaptability to grow well in their origin ecosystem. They are mainly found in plant communities at secondary forest succession. Commonly used as firewood by local people, those species still have less attention for further large-scale utilization, especially in energy production. These species will promise future plantation of short-rotation wood crops to provide sustainable raw materials with a faster-growing ability. However, further wood physicochemical analysis was necessary to meet an ideal energy crop requirement. This study reported comparing wood physicochemical properties of selected fast-growing tree species native to the East Kalimantan forest to be used as feedstocks in electricity production.

MATERIALS AND METHODS

Study area

Wood biomass materials and leaf samples from some fast-growing native species were collected at the secondary forest of Mulawarman University Educational Forest (KHDTK Fahutan UNMUL, Samarinda), Samarinda City, East Kalimantan Province, Indonesia (0º25'10" LS – 0º25'10" LS and, 117º14'00" BT-117º14'14" BT - 300 ha).

Biomass plant species

Medium trees with 6-8 cm diameter recognized as native fast-growing species naturally grown on secondary tropical rain forests in East Kalimantan were pointed out. Identification through leaf herbarium specimens of each species was deposited at the Laboratory of Forest Dendrology and Ecology, Faculty of Forestry, Mulawarman University. In this study, six species were identified, namely *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull.Arg. and *Schima wallichii* (DC). They belong to different family groups, including elaeocarpaceae, moraceae, fabaceae, lauraceae, euphorbiaceae and theaceae, respectively. All woody biomass samples were collected in September 2021. They were debarked to analyze the dry bark-wood ratio, then converted into wood chips before proceeding to laboratory analysis.

Determination of wood physicochemical properties and energy potency

The total moisture and proximate compositions of wood materials were carried out according to ASTM D 7582-12 method. The lost weight of the samples after reaching the constant weight in a hot air oven at 105ºC was calculated to determine the moisture content. For proximate analysis, the samples were dried and grounded into smaller sizes (±60 mesh). The measurements consisted of two steps in a furnace. The first step was done by heating from 300-575ºC for 3 hours. The weight loss was measured and noted as a volatile matter (VM) substance. Then, the temperature was increased to reach 950ºC for 2 hours to heat the remaining samples. After cooling down to room temperature, the residual weight was measured in ash content while the lost weight was fixed carbon (FC).

The ultimate compositions of wood biomass including carbon (C), hydrogen (H), and oxygen (O) were estimated based on the following Equation (Parikh et al. 2007):

$$C\ (\%) = (0.637 \times FC) + (0.455 \times VM) \qquad (1)$$

$$H\ (\%) = (0.052 \times FC) + (0.062 \times VM) \qquad (2)$$

$$O\ (\%) = (0.304 \times FC) + (0.476 \times VM) \qquad (3)$$

Measurement of wood density (kg/m^3) was conducted by drying the wood samples at 105ºC following Edwards et al. (2014). The wood calorific value (MJ/kg) was accomplished in a bomb calorimeter according to the standard from EN-ISO 15400:2011, followed by the calculation of energy-electricity potency according to Francescato et al. (2008). Those measurements were classified into greenwood and wood chips. Furthermore, the fuel value index (FVI) was calculated using the equation as follows (Jain and Singh 1999):

$$FVI = (\text{Calorific value} \times \text{density}) / (\text{ash} \times \text{moisture}) \qquad (4)$$

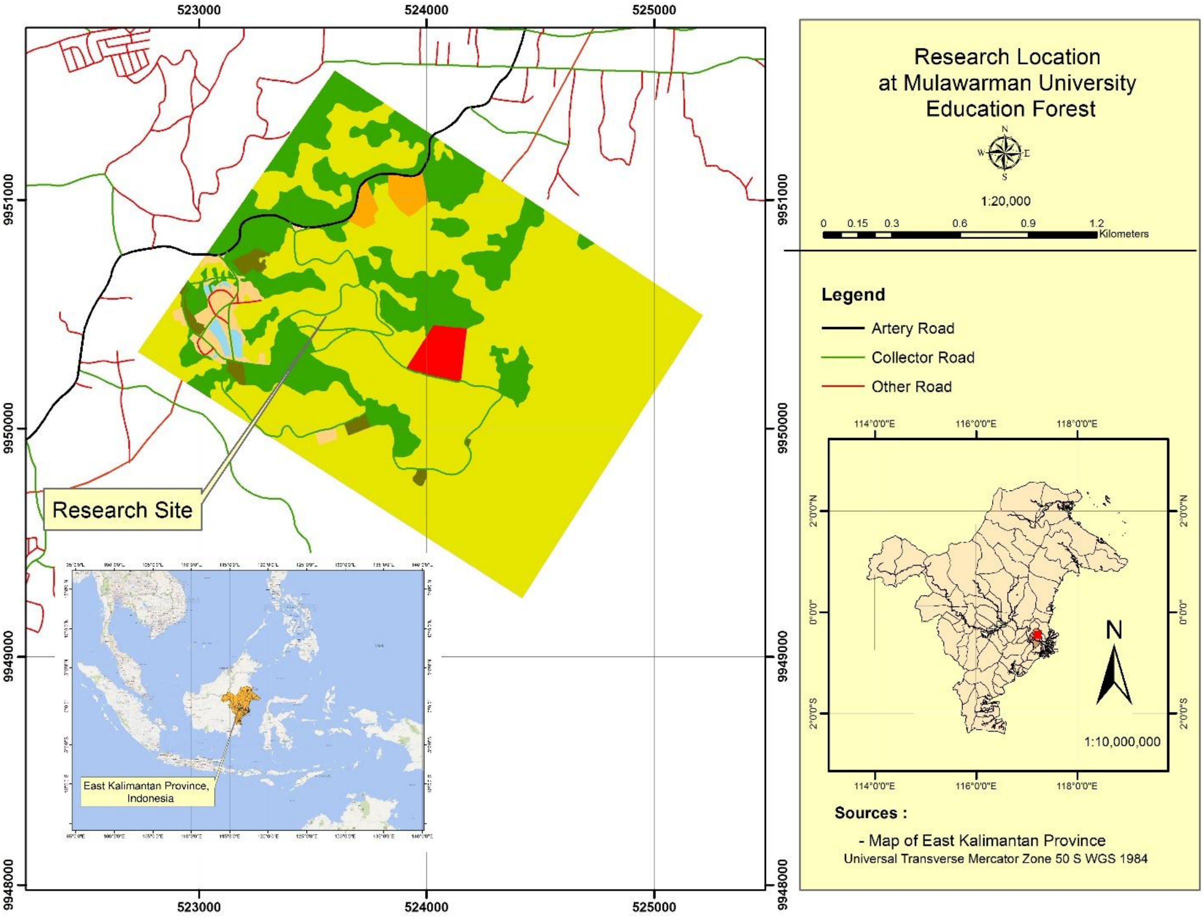


Figure 1. Research location conducted at Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia (0°25’10” LS – 0°25’10” LS and 117°14’00” BT-117°14’14” BT).

E. ferrugineus *F. aurata* *F. splendidissima*

L. lucida *M. paniculatus* *S. wallichii*

Figure 2. Fresh leaf shape varieties of some fast-growing native tree species were collected from the secondary forest of Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia

RESULTS AND DISCUSSION

Plant biomass species

Generally, tropical forest areas provide better environmental conditions for plants to produce sustainable biomass with high yields. This condition will lead to its potential wide-range application in biomass-based conversion technology, such as electricity generation. However, a previous study demonstrated that forest biomass species with high energy content were commonly produced from low-growing species (Amirta et al. 2016). In large-scale electricity production, utilization of the low-growing species in energy feedstocks requires a slow harvest cycle period with a high-cost operation. Therefore, this study assessed woody materials obtained from selected fast-growing species, including *E. ferrugineus*, *F. aurata*, *F. splendidissima*, *L. lucida*, *M. paniculatus*, and *S. wallichii* for the purpose of energy-electricity feedstock. Those species are abundant and native to the secondary forest of East Kalimantan, in which the local people traditionally used their wood as firewood for cooking activities. Nevertheless, literature describing those plant species for further industrial application is still rare. The measurement of bark and wood proportion of each species was summarized in Table 1. It was noticeable that three species, including *E. ferrugineus, F. aurata,* and *F. splendidissima,* had the lowest bark-wood ratio (0.7). The highest bark proportion was obtained from *S. wallichiii*, followed by *M. paniculatus* and *L. lucida,* with the value of 12.95%, 11.22%, and 7.80%, respectively. It has been reported earlier that the stem bark of *E. ferrugineus* was the potential for treating malaria-like symptoms (Ismail et al. 2015). On the other hand, *S. wallichii* bark could be utilized as an antimicrobial agent (Dewanjee et al. 2008). Hence, these interesting properties could potentially enhance their application for both energy feedstocks and natural medicine products. Since the stem bark produces a high quantity of ash (Pérez et al. 2008), its removal from wood when used for energy production through thermochemical conversion is necessary.

Wood physicochemical properties

Moisture content, density, and chip capacity of woody materials examined from some selected native tree species were summarized in Table 2. It has been previously reported that the percentage of wood moisture content depends on the plant species, season, and storage condition (Mancini and Rinnan 2021). In green conditions, the highest wood moisture content was obtained from *S. wallichii* (59.25%), while the lowest moisture content could be found in *F. splendidissima* (40.37%). The conversion of the wood into chip form evidently reduced their moisture content. As shown in Table 2, all wood chips revealed a lower moisture percentage than green wood conditions. It was found that the average moisture content of wood chips was 9.58%. It seems that wood chip form could easily evaporate the amount of water. Surprisingly, this situation could also be benefited considerably increase the achieved calorific value due to the water loss phenomenon (Figure 3A). According to the measurement of wood density, it was found that the highest wood density was obtained from *F. splendidissima* (760 kg/m^3). The second and third largest were found in *E. ferrugineus* (575 kg/m^3) and *S. wallichii* (536 kg/m^3) wood, respectively. The average wood density value from all species used in this study was 507 kg/m^3. Meanwhile, their form changed into wood chips that needed a high storage capacity. It was found that the average value of wood chips of all species was 201 kg per m^3 of storage area. The high wood density contributed to increasing the efficiency of wood chip storage. As observed from *F. splendidissima*, its wood chip (300 kg/m^3) was the most efficient storage capacity among all woody materials used. Especially for a large-scale operation, the high density of wood chips potentially contributes to low energy production costs (Bahadori et al. 2014). In contrast, low wood density affects the fast burning of the reactor, high transport costs, and high storage capacity (de Oliveira et al. 2013).

Table 1. Wood and bark ratio of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant Species		**Bark Proportion (%)**	**Wood Proportion (%)**	**Bark-Wood Ratio**
Latin name	**Local name**			
E. ferrugineus	Belau	6.37 ± 0.59	93.63 ± 0.59	0.07 ± 0.01
F. aurata	Kayu ara	6.65 ± 0.25	93.35 ± 0.25	0.07 ± 0.00
F. splendidissima	Makumpit	6.70 ± 0.93	93.30 ± 0.93	0.07 ± 0.01
L. lucida	Madang	7.80 ± 0.55	92.20 ± 0.55	0.08 ± 0.01
M. paniculatus	Balik angin	11.22 ± 0.45	88.78 ± 0.45	0.13 ± 0.01
S. wallichii	Puspa	12.95 ± 0.68	87.06 ± 0.68	0.15 ± 0.01
Average		**8.62 ± 2.79**	**91.39 ± 2.79**	**0.10 ± 0.10**

Table 2. Moisture content, wood density, and chip capacity of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant Species		**Moisture content (%)**		**Wood density**	**Chip capacity**
Latin name	**Local name**	**Greenwood**	**wood Chip**	**(kg/m^3)**	**(kg/m^3)**
E. ferrugineus	Belau	49.77 ± 1.59	9.34 ± 0.03	575 ± 25.78	227± 10.18
F. aurata	Kayu ara	56.90 ± 0.63	9.62 ± 0.03	487 ± 23.19	192 ± 9.15
F. splendidissima	Makumpit	40.37 ± 0.19	9.81 ± 0.01	760 ± 22.69	300 ± 8.94
L. lucida	Madang	50.64 ± 1.05	9.64 ± 0.05	354 ± 14.86	140 ± 5.86
M. paniculatus	Balik angin	52.85 ± 0.28	9.52 ± 0.03	331 ± 11.21	131 ± 4.42
S. wallichii	Puspa	59.25 ± 1.83	9.53 ± 0.01	536 ± 18.99	211 ± 7.49
Average		**51.63 ± 6.61**	**9.58 ± 0.15**	**507 ± 157.7**	**200 ± 62.6**

Table 3. Proximate and ultimate analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant species	**Ash (%)**	**Fixed carbon (%)**	**Volatile matter (%)**	**Carbon (%)**	**Hydrogen (%)**	**Oxygen (%)**	**H/C ratio**
E. ferrugineus	2.29 ± 0.03	14.23 ± 0.18	74.14 ± 0.14	42.80 ± 0.18	5.34 ± 0.01	39.62 ± 0.12	0.12 ± 0.00
F. aurata	2.30 ± 0.02	13.53 ± 0.16	75.55 ± 0.17	42.54 ± 0.17	5.33 ± 0.01	39.60 ± 0.13	0.13 ± 0.00
F. splendidissima	1.62 ± 0.04	13.85 ± 0.13	74.72 ± 0.13	42.82 ± 0.14	5.35 ± 0.02	37.78 ± 0.10	0.12 ± 0.00
L. lucida	1.71 ± 0.02	14.82 ± 0.21	73.83 ± 0.21	43.03 ± 0.04	5.35 ± 0.01	39.62 ± 0.04	0.12 ± 0.00
M. paniculatus	2.69 ± 0.01	13.36 ± 0.10	74.43 ± 0.16	42.38 ± 0.13	5.31 ± 0.01	39.49 ± 0.10	0.13 ± 0.00
S. wallichii	1.64 ± 0.05	12.96 ± 0.16	75.87 ± 0.09	42.78 ± 0.14	5.38 ± 0.01	40.05 ± 0.09	0.13 ± 0.00
Average	**2.04 ± 0.44**	**13.79 ± 0.66**	**74.76 ± 0.80**	**42.72 ± 0.44**	**5.34 ± 0.66**	**39.70 ± 0.80**	**0.13 ± 0.00**

Various laboratory tests were carried out for proximate and ultimate analysis. The proximate analysis includes ash, fixed carbon, and volatile matter (Table 3). These parameters strongly affected the performance of combustion, pyrolysis, and gasification of wood biomass in the thermochemical conversion process (Tursunov and Abduganiev 2020). Ash content of all woody materials showed less than 5%, which demonstrated their high potency utilized for raw materials of energy production. The low value of ash residue (<5%) resulting from the combustion process has a positive impact on increasing the efficiency stage and avoiding damage to the electricity reactor (Shao et al. 2011). Nimmanterdwong et al. (2021) stated that the ash in biomass is directly related to the mineral and inorganic elements absorbed by plants from the ground via the root cells, while its percentage differently depends on the soil properties, rocks, chemical treatment, and available metal contents. The volatile matters of all woody materials in this study were in the range of 73.83 – 75.87%, whereas the fixed carbons were in the range of 12.96–14.82%. It has been reported that the heat decomposition of cellulose and hemicellulose in biomass is the source of volatile matter. In contrast, lignin is a char source due to its richness in carbon atoms (Vega et al. 2019). The ultimate compositions, including C (carbon), H (hydrogen), and O (oxygen), were presented in Table 3. This investigation is essential to determine the theoretical air-fuel ratio in the thermochemical system and predict the released pollution (Telmo et al. 2010). The average value of C, H, and O was 42.72%, 5.35%, and 39.70%, respectively. It was clearly observed that all woody materials contained C higher than O, indicating its high suitability used as the energy feedstock since high C content will increase the obtained calorific value. Moreover, the C content, with a value of more than 40% in this study, was in line with that of the C content of various tropical woods (Amirta et al. 2016; Amirta et al. 2019; Yuliansyah et al. 2019; Mukhdlor et al. 2021). Ratio of H/C was also assessed since higher value could contribute to improve energy efficiency and decrease released emission during combustion (Gopalakrishnan et al. 2019). The average of H/C ratio of the six-plant studied was 0.13. This value was comparable with sawdust previously reported by Garcia et al. (2012). More importantly, these findings demonstrated that all fast-growing species selected in this study possessed better H/C ratio than those of other tropical fast-growing woody species, such as *Bridelia tomentosa*, *Fagraea racemosa*, *Piper aduncum*, *Trema orientalis*, and *Vernonia arborea* (Amirta et al. 2016).

Wood quality for energy feedstock

The investigation of the fuelwood quality of native species is presented in Figure 3. The important parameters were calorific value, wood chip conversion value, energy-electricity potency, and fuel value index. According to Figure 3A, the conversion of green wood (original solid form) into wood chip form significantly enhanced the average calorific value up to 0.5-fold. It was calculated that the average calorific value of all examined woods in the green form (7.92 MJ/kg) increased to 17.01 MJ/kg at the wood chip condition. We found that those results were in line with decreasing the amount of moisture content on wood samples when converted into wood chips (51.63% to 9.58%) (Table 2). It has also been reported by Deboni et al. (2020) that lower moisture content is considered one of the factors that significantly influence the increased calorific value of woody biomass as a reliable energy source. The high proportion of moisture content in fuelwood could result in delayed ignition and devolatilization (Lu et al. 2008). Although this work promised high energy content, the wood chip form consequently required a larger storage

area (m^3) per ton of wood chip biomass than the greenwood form, as shown in Figure 3B.

In order to compare the suitability of woody materials from selected native species, further measurement of energy potency in MWh per ton biomass was performed (Figure 3C). The results showed that *F. splendidissima* exhibited the highest energy potency in both greenwood (2.21 MWh/ton) and wood chip (3.61 MWh/ton) forms. Although *S. wallichii* and *F. aurata* possessed high calorific values (Figure 3A), *F. splendidissima* had higher energy-electricity potency than those species due to its high wood density (760 kg/m^3). Interestingly, even though *F. splendidissima* is considered fast-growing species, this species was classified as high wood density (< 600 kg/m^3), whereas *S. wallichii* and *F. aurata* were characterized as medium wood density (400 – 600 kg/m^3). Having a similar pattern with calorific value results, the energy potency of all woody materials to generate electricity demonstrated significantly enhanced value after converting into wood chips due to the moisture removal. Our previous study shows fast-growing species in the lowland community forest, such as *Gmelina arborea*, *Anthocephalus cadamba*, *Acacia mangium*, and *Paraserianthes falcataria,* had relatively low energy potency (1.37 – 1.70 MWh/ton) (Amirta et al. 2016). Another study also reported that fast-growing and shrub species found in the tropical swamp-peat forest of Kutai Kartanegara in East Kalimantan generated low energy potency: *Kleinhovia hospita* (1.76 MWh/ton), *Cananga odorata* (1.36 MWh/ton), and *Octomeles sumatrana* (1.17 MWh/ton) (Amirta et al. 2019). However, our findings in this study indicated that fast-growing species native to the secondary forest in East Kalimantan, especially *F. splendidissima*, could produce woody materials with superior energy capacity for electricity production.

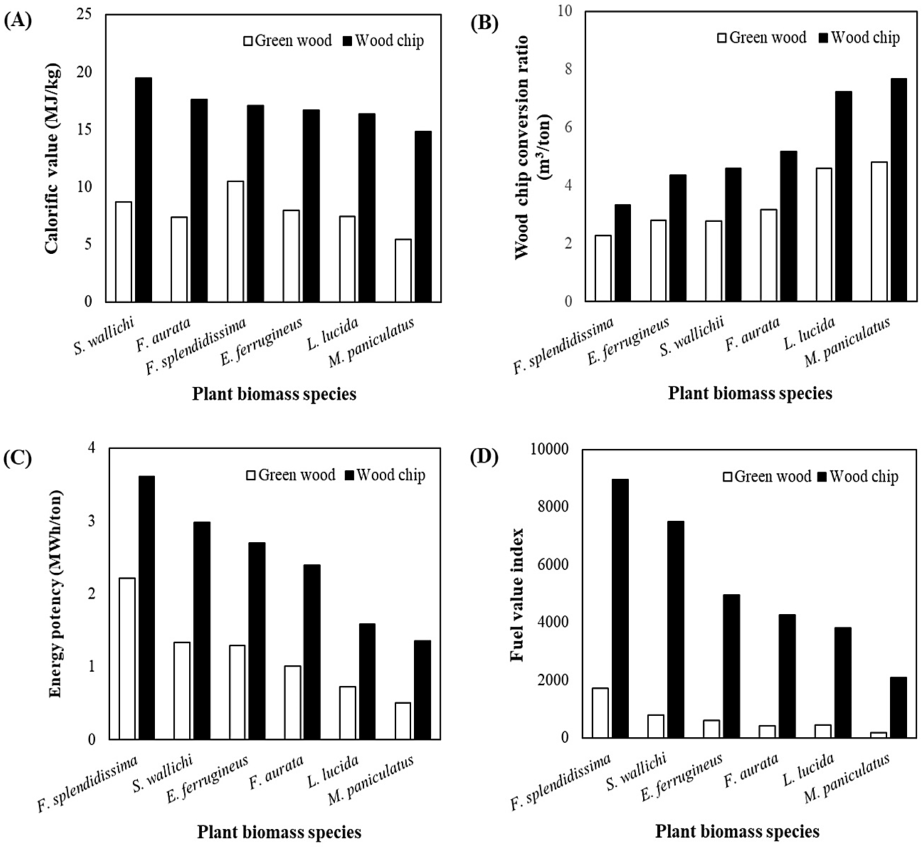


Figure 3. Analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia, for electricity feedstock: Wood calorific value (A), wood chip conversion ratio (B), energy potency (C), and fuel value index (D)

The bioenergy potential of each fast-growing native species was represented by Fuel Value Index (FVI) (Figure 3D). The FVI is an essential assessment for screening desirable biomass species for solid fuel (Samal et al. 2021). This measurement was also used by Niemczyk et al. (2018) to rank the quality of 10 poplar cultivars in northern Poland. The FVI was calculated using combinations of some influencing factors, including ash content, moisture content, calorific value, and wood density. This study found that wood chips containing low moisture content increased the FVI result from each wood tested. The average FVI of the wood chip, which had a value of 5267, was significantly higher than that of the greenwood condition, with an average value of 698. The greatest FVI was obtained from *F. splendidissima* (8970), followed by *S. wallichii* and *F. ferrugineus* with the value of 7502 and 4958, respectively. A high FVI value of wood biomass was observed because of low ash content, low moisture content, and high density (Pérez et al. 2014). We concluded that the wood chip revealed lower moisture content compared to the original form (green condition), indicating its high suitability to produce sustainable green energy.

Finally, all woody materials obtained from fast-growing native species in the secondary forest of East Kalimantan were suitable for electricity feedstock due to the low ash content and a high proportion of carbon. When each wood biomass was converted into wood chip form, their efficiency in energy feedstocks (calorific value, storage capacity, energy-electricity potency, and FVI) was gradually increased since this form was able to remove moisture effectively. In contrast, the greenwood showed inefficient use since it might take longer to dry; thus, the cost of energy production will also increase. Among all biomass tested, the wood chip of *F. splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency (3.61 MWh/ton) with desired FVI value (8970). Furthermore, the high adaptability in the local ecosystem combined with its high wood density and fast-growing ability will be the promising characteristics that allow *F. splendidissima* to be one of the ideal crops for energy feedstocks in the future. In general, this study successfully demonstrated the physicochemical properties of selected fast-growing native species in the tropical secondary forest in East Kalimantan, Indonesia, to generate electricity in rural communities, especially to develop the economic sector in this province.

ACKNOWLEDGEMENTS

The current study was financially supported by the Project Implementation Unit of Islamic Development Bank – PIU IsDB (Grant No. 402/UN17.45/DL/2021 for Yl, RA, and MTH), and the research funding for lecturers and students from the Faculty of Forestry, Mulawarman University (For Yl 2022)

REFERENCES

Aguado R, Vera D, Jurado F, Beltrán G. 2022. An integrated gasification plant for electric power generation from wet biomass: toward a sustainable production in the olive oil industry. Biomass Convers Biorefin. DOI: 10.1007/s13399-021-02231-0.

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Londong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast-growing wood species for energy production. Nusantara Biosci 8 (1): 22-31. DOI:10.13057/nusbiosci/n080106.

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 (6): 1516-1523. DOI: 10.13057/biodiv/d200605.

Bahadori A, Zahedi G, Zendehboudi S, Jamili A. 2014. Estimation of the effect of biomass moisture content on the direct combustion of sugarcane bagasse in boilers. Int J Sustain Energy 33: 349–356. DOI:10.1080/14786451.2012.748766.

Battuvshin B, Matsuoka Y, Shirasawa H, Toyama K, Hayashi U, Aruga K. 2020. Supply potential and annual availability of timber and forest biomass resources for energy considering inter-prefectural trade in Japan. Land Use Policy 97: 104780. DOI:10.1016/j.landusepol.2020.104780.

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S. 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew Sustain Energy Rev 71: 830-845. DOI: 10.1016/j.rser.2016.12.109.

Broughel AE. 2019. Impact of state policies on generating capacity for production of electricity and combined heat and power from forest biomass in the United States. Renew Energy 134: 1163-1172. DOI: 10.1016/j.renene.2018.09.058.

Cardoso J, Silva V, Eusébio D. 2019. Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal. J Clean Prod 212: 741-753. DOI:10.1016/j.jclepro.2018.12.054.

da Costa TP, Quinteiro P, Arroja L, Dias AC. 2020. Environmental comparison of forest biomass residues application in Portugal: Electricity, heat, and biofuel. Renew Sustain Energy Rev 134: 110302. DOI:10.1016/j.rser.2020.110302.

de Oliveira JL, da Silva JN, Pereira EG, Filho DO, Carvalho DR. 2013. Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification. Renew Sustain Energy Rev 21: 52–58. DOI:10.1016/j.rser.2012.12.025.

Deboni TL, Simioni FJ, do Rosário JDA, Costa VJ. 2020. Quality of biomass from old wood waste deposits in Southern Brazil. Biomass Bioenergy 143: 105841. DOI:10.1016/j.biombioe.2020.105841.

Dewanjee S, Maiti A, Majumdar R, Majumdar A, Mandal SC. 2008. Evaluation of antimicrobial activity of hydroalcoholic extract *Schima wallichii* bark. Pharmacologyonline 1: 523-528.

Edwards LE, Newby AF, Gilliam CH, Fain GB, Sibley JL, Murphy, AM. 2014. Evaluation of eastern redcedar substrate in the production of four annual species. J Environ Hortic 32 (3): 167-173.

Ferreira LRA, Otto RB, Silva FP, De Souza SNM, De Souza SS, Junior OA. 2018. Review of the energy potential of the residual biomass for the distributed generation in Brazil. Renew Sustain Energy Rev 94: 440-455. DOI:10.1016/j.rser.2018.06.034.

Francescato F, Antonini E, Bergomi LZ. 2008. Wood Fuels Handbook: Production, Quality Requirements, Trading. Legnaro, Italy.

García R, Pizarro C, Lavín AG, Bueno J.L. 2012. Characterization of Spanish biomass wastes for energy use. Bioresour Technol 103(1): 249-258. DOI: 10.1016/j.biortech.2011.10.004.

González A, Riba JR, Puig R, Navarro P. 2015. Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. Renew Sustain Energy Rev 43: 143-155. DOI:10.1016/j.rser.2014.11.013.

Gopalakrishnan B, Khanna N, Das D. 2019. Dark-fermentative biohydrogen production. In: Biohydrogen. Elsevier. DOI: 10.1016/B978-0-444-64203-5.00004-6.

Haqiqi MT, Yuliansyah, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf. Series: Earth and Environmental Science. DOI: 10.1088/1755-1315/144/1/012041.

Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R Yuliansyah, Suwinarti W, Amirta R. 2022. Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency. Biodiversitas 23 (5): 2389-2394. DOI: 10.13057/biodiv/d230516

Hupa M, Karlström O, Vainio E. 2017. Biomass combustion technology development–It is all about chemical details. Proc Combust Inst 36(1): 113-134. DOI: 10.1016/j.proci.2016.06.152.

Ismail I, Linatoc AC, Mohamed M, Tokiman L. 2015. Documentation of medicinal plants traditionally used by the jakun people of endau-rompin (peta) for treatments of malaria-like symptoms. Jurnal Teknologi 77 (31): 63-69.

Jain RK, Singh B. 1999. Fuelwood characteristics of selected indigenous tree species from central India. Bioresour Technol 68: 305-308. DOI: 10.1016/S0960-8524(98)00173-4.

Karmaker AK, Rahman MM, Hossain MA, Ahmed MR. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. J Clean Prod 244: 118645. DOI: 10.1016/j.jclepro.2019.118645.

Lee BH, Sh L, Lee DG, Jeon CH. 2021. Effect of torrefaction and ashless process on combustion and NOx emission behaviors of woody and herbaceous biomass. Biomass Bioenerg 151: 106133. DOI: 10.1016/j.biombioe.2021.106133.

Liu Y, Xu Y, Zhang F, Yun J, Shen Z. 2014. The impact of biofuel plantation on biodiversity: a review. Chinese Sci Bull 59 (34): 4639-4651. DOI: 10.1007/s11434-014-0639-1.

Lu G, Yan Y, Cornwell S, Whitehouse M, Riley G. 2008. Impact of co-firing coal and biomass on flame characteristics and stability. Fuel 87: 1133-1140. DOI:10.1016/j.fuel.2007.07.005.

Majava A, Vadén T, Toivanen T, Järvensivu P, Lähde V, Eronen JT. 2022. Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target. Energy Strategy Rev 41: 100836. DOI:10.1016/j.esr.2022.100836.

Mäkipää R, Linkosalo T, Komarov A, Mäkelä A. 2015. Mitigation of climate change with biomass harvesting in Norway spruce stands: are harvesting practices carbon neutral? Canadian J For Res 45 (2): 217-225. DOI:10.1139/cjfr-2014-0120.

Mancini M, Rinnan Å. 2021. Near infrared technique as a tool for the rapid assessment of waste wood quality for energy applications. Renew Energy 177: 113-123. DOI: 10.1016/j.renene.2021.05.137.

Mola-Yudego B, Arevalo J, Díaz-Yáñez O, Dimitriou I, Freshwater E, Haapala A, Khanam T, Selkimäki M. 2017. Reviewing wood biomass potentials for energy in Europe: the role of forests and fast-growing plantations. Biofuels 8 (4): 401-410. DOI: 10.1080/17597269.2016.1271627.

Mori S, Sumner J, Bouvet J, Simms NJ. 2022. Fireside and steamside performance in biomass power plant. Mater High Temp 39 (2): 106-121. DOI:10.1080/09603409.2021.2019657.

Moya R, Tenorio C, Oporto G. 2019. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. Energies 12(4): 705. DOI:10.3390/en12040705.

Mukhdlor A, Haqiqi MT, Tirkaamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation. Advances in Biological Science Research. DOI: 10.2991/absr.k.210408.005.

Mutezo G, Mulopo J. 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 137: 110609. DOI: 10.1016/j.rser.2020.110609.

Narnaware SL, Panwar NL. 2022. Biomass gasification for climate change mitigation and policy framework in India: A review. Bioresour Technol Rep 17: 100892. DOI:10.1016/j.biteb.2021.100892.

Niemczyk M, Kaliszewski A, Jewiarz M, Wrobel M, Mudryk K. 2018. Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland. Biomass Bioenergy, 111: 46-51. DOI: 10.1016/j.biombioe.2018.02.002.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI: 10.1016/j.energy.2021.119945.

Parikh L, Channiwala SA, Ghosal GK. 2007. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86: 1710-1719. DOI:10.1016/j.fuel.2006.12.029.

Pérez S, Renedo CJ, Ortiz A, Manána M. 2008. Energy potential of waste from 10 forest species in the North of Spain (Cantabria). Bioresour Technol 99: 6339–6345. DOI: 10.1016/j.biortech.2007.12.014.

Pérez S, Renedo CJ, Ortiz A, Delgado F, Fernández I. 2014. Energy potential of native shrub species in northern Spain. Renew Energy 62: 79-83. DOI: 10.1016/j.renene.2013.06.048.

Pio D, D'Cruz R. 2005. Borneo's Lost World: Newly Discovered Species on Borneo. WWF, Jakarta.

Präger F, Paczkowski S, Sailer G, Derkyi NSA, Pelz S. 2019. Biomass sources for a sustainable energy supply in Ghana–A case study for Sunyani. Renew Sustain Energy Rev 107: 413-424. DOI: 10.1016/j.rser.2019.03.016.

Proto AR, Palma A, Paris E, Papandrea SF, Vincenti B, Carnevale M, Guerriero E, Bonofiglio R, Gallucci F. 2021. Assessment of wood chip combustion and emission behavior of different agricultural biomasses. Fuel 289: 119758. DOI:10.1016/j.fuel.2020.119758.

Ram M, Child M, Aghahosseini A, Bogdanov D, Lohrmann A, Breyer C. 2018. A comparative analysis of electricity generation costs from renewable, fossil fuel, and nuclear sources in G20 countries for the period 2015-2030. J Clean Prod 199: 687-704. DOI:10.1016/j.jclepro.2018.07.159.

Rempel A, Gupta J. 2020. Conflicting commitments? Examining pension funds, fossil fuel assets, and climate policy in the organisation for economic co-operation and development (OECD). Energy Res Soc Sci 69: 101736. DOI: 10.1016/j.erss.2020.101736.

Rincon L, Puri M, Kojakovic A, Maltsoglou I. 2019. The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy policy 130: 69-88. DOI: 10.1016/j.enpol.2019.03.024.

Samal B, Vanapalli KR, Dubey BK, Bhattacharya J, Chandra S, Medha I. 2021. Influence of process parameters on thermal characteristics of char from co-pyrolysis of eucalyptus biomass and polystyrene: Its prospects as a solid fuel. Energy 232: 121050. DOI:10.1016/j.energy.2021.121050.

Shao Y, Xu C, Zhu J, Preto F, Wang J, Li H, Badour C. 2011. Ash deposition in co-firing three-fuel blends consisting of woody biomass, peat, and lignite in a pilot-scale fluidized-bed reactor. Energy Fuels 25 (7): 2841-2849. DOI:10.1021/ef2002603.

Simangunsong BCH, Sitanggang VJ, Manurung EGT, Rahmadi A, Moore GA, Aye L, Tambunan AH. 2017. Potential forest biomass resource as feedstock for bioenergy and its economic value in Indonesia. For Policy Econ 81: 10–17. DOI:10.1016/j.forpol.2017.03.022.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101 (11): 3808-3815. DOI:10.1016/j.biortech.2010.01.021.

Tenorio C, Moya R, Filho MT, Valaert J. 2015. Quality of pellets made from agricultural and forestry crops in Costa Rican tropical climates. Bioresources 10 (1): 482-498.

Tursunov O, Abduganiev N. 2020. A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region. Mater Today: Proc 25: 67-71. DOI: 10.1016/j.matpr.2019.11.108.

Vega LY, López L, Valdés CF, Chejne F. 2019. Assessment of energy potential of wood industry wastes through thermochemical conversions. Waste Manag 87: 108-118. DOI: 10.1016/j.wasman.2019.01.048.

Wang Z, Bui Q, Zhang B, Pham TLH. 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci Total Environ 743: 140741. DOI:10.1016/j.scitotenv.2020.140741.

Yuliansyah, Amirta R. 2016. Physico-chemical properties and energy potency of wood waste biomass from logging activities to generate electricity in East Kalimantan, Indonesia. AIP Conference Proceeding. DOI:10.1063/1.4958476.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Helmi AS, Setiawan KA, Setiyono B, Angi EM, Saparwadi, Sari NM, Kusuma IW, Rujehan, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20 (8): 2236-2242. DOI:10.13057/biodiv/d200818.

Biodiversitas & Nusantara Biosci.

Society for Indonesian Biodiversity
Jl. Ir. Sutami 36 A Surakarta 57126
Tel./Fax. 0271-663375, email: unsjournals@gmail.com
http://biodiversitas.mipa.uns.ac.id/
http://biosains.mipa.uns.ac.id/nusbioscience.htm

INVOICE

for AUTHOR

DATE	17/06/2022
	4032
CUSTOMER ID	4032
DUE DATE	24/06/2022

BILL TO

RUDIANTO AMIRTA
Faculty of Forestry, Universitas Mulawarman.
Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683.
email: ramirta@fahutan.unmul.ac.id.

Title:

Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

DESCRIPTION	TAXED	AMOUNT (IDR)
Payment for manuscript publication		4,500,000.00
Payment for English improvement		1,000,000.00
Cost reduction for manuscript presented in the SIB Meeting		-

Subtotal	5,500,000.00
Taxable	-
Tax rate	0.000%
Tax due	-
Other	-
TOTAL IDR	**5,500,000.00**

OTHER COMMENTS

1. Currency exchange: USD 1 = IDR 14,000
2. Total bill: IDR 5.500.000,-
3. Transfer to BNI (BNINIDJA), Acc. no. 0356986994 (Dewi Nur Pratiwi)¤
4. Send the proof of payment to finance@smujo.id
and a carbon copy (CC) to unsjournals@gmail.com

If you have any questions about this invoice, please contact
Dewi NP. HP **+62-812-9165-0588**, email: dewinp11@gmail.com
Terimakasih atas partisipasi anda

BILLING

✖

Participants

Rudianto AMIRTA (r_amirta)

DEWI NUR PRATIWI (dewinurpratiwi)

Messages

Note	From
Dear Author(s), Kindly find attached an invoice for the publication of your manuscript 🗋 dewinurpratiwi, 4032.RUDIANTO AMIRTA.pdf	dewinurpratiwi 2022-06-17 09:51 AM

Add Message

Payment of my manuscript

✖

Participants

Edit

Rudianto AMIRTA (r_amirta)

DEWI NUR PRATIWI (dewinurpratiwi)

Messages

Note	From
Dear editor, Attached I send proof of payment transfer for the manuscript entitled "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks". Thank you Best regards, Rudianto Amirt r_amirta, Payment_Rudianto Amirta.jpg	r_amirta 2022-06-18 03:36 AM

Add Message

BIODIVERSITAS
Volume 23, Number 7, July 2022
Pages: 3379-3386

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230709

Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks

YULIANSYAH[1], MUHAMMAD TAUFIQ HAQIQI[1], KRISNA ADIB SETIAWAN[1], AGUS SETIAWAN[1], PRISTIANGGA DWI SAPUTRA[1], HERI SUKMA IQBAL ROMADLON[1], AHMAD MUKHDLOR[1], RICO RAMADHAN[2], RUDIANTO AMIRTA[1,♥]

[1]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gn. Kelua, Samarinda 75123, East Kalimantan, Indonesia.
Tel./Fax.: +62-541-748683. ♥email: ramirta@fahutan.unmul.ac.id
[2]Department of Chemistry, Faculty of Science and Technology, Universitas Airlangga. Jl. Dr. Ir. Soekarno, Mulyorejo, Surabaya 60115, East Java, Indonesia

Manuscript received: 13 May 2022. Revision accepted: 17 June 2022.

Abstract. *Yuliansyah. Haqiqi MT, Setiawan KA, Setiawan A, Saputra PD, Romadlon HSI, Mukhdlor A, Ramadhan R, Amirta R. 2022. Fast-growing native tree species to the secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks. Biodiversitas 23: 3379-3386.* The conversion of woody biomass into electricity through a thermochemical process has recently attracted significant attention worldwide to promote green energy production. It provides a low-cost and straightforward operation promising for developing rural areas, especially with limited transportation access. In East Kalimantan Province, almost all remote areas are surrounded by forests with high tree species diversity, which is the potential to be utilized for sustainable feedstocks in electric power plants. This study pointed out the energy potential produced from woody biomass of selected fast-growing tree species native to East Kalimantan secondary tropical forest: *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull. Arg. and *Schima wallichii* (DC). Their wood physicochemical properties were firstly investigated. Furthermore, each species' wood quality for solid energy purposes was presented as the fuel value index (FVI). The results revealed that the change from greenwood into wood chip effectively removed the moisture content, thus improving efficiency to achieve higher energy potency. Our findings showed that the highest energy potency was obtained from the wood chip of *F. splendidissima* (3.61 MWh/ton), followed by *S. wallichii* (2.98 MWh/ton). A similar pattern was also found in FVI determination showing that the wood chip of *S. Splendidissima* had the greatest value (8970). Therefore, we observed that the high quality of *S. splendidissima* compared to other selected fast-growing species indicates its high suitability for further large-scale crop plantation to supply wood chips for biomass-based electricity generation.

Keywords: Electricity, fast-growing, native species, secondary forest, woody biomass

INTRODUCTION

The exploitation of fossil fuels has significantly increased the degradation of natural resources and the environment. Its combustion corresponding to generating electricity constantly accelerates the global warming potential. According to the report from the International Energy Agency, energy production from fossil fuels sectors is responsible for more than 80% of released carbon dioxide (CO_2) in the atmosphere, or it is estimated to exceed two-thirds of total greenhouse gas (GHC) emission (Ram et al. 2018; Cardoso et al. 2019). Although the Paris Agreement in 2015 implicitly called for shifting away from the domination of fossil fuels, the human population and industrialization are continuously growing, creating a significant challenge on how to mitigate climate change and reduce those harmful GHC effects (Karmaker et al. 2020; Rempel and Gupta 2020). The United Nations (UN), through the Climate Action Summit in New York in 2019, has set a global plan to achieve net-zero emissions by 2050 (Mutezo and Mulopo 2021). Therefore, many countries have committed to addressing a transition from fossil fuels to renewable energy by implementing a legal policy (Mola-Yudego et al. 2017; Moya et al. 2019; Rincon et al. 2019).

The usage of renewable energy has gained a lot of attention (Nugraha et al. 2020). Among all resources, biomass has been considered the most applicated renewable energy globally, with a proportion of 12.4% of the total energy consumption (Wang et al. 2020). Energy production from biomass is expected to meet global energy demands in the future (Bilgili et al. 2017). It offers various advantages over other renewable sources, such as better energy properties and less CO_2 emission (Liu et al. 2014; Tenorio et al. 2015). Woody biomass harvested from the forest is also one of the promising feedstocks to produce clean energy because it contains quite low sulfur and nitrogen (Hupa et al. 2017; Lee et al. 2021). Since almost all remote areas in Indonesia are covered by forests with limited transportation access, the approach to using its biomass will be adequate to overcome the electricity limitation in those rural areas. Moreover, it will improve economic growth by providing micro or small-scale electricity with a simple and cheaper process. When the wood is burned during the combustion stage, the CO_2 emission can be easily absorbed by available forest plant species through photosynthesis. The net cycle of CO_2 is always in balance, and this phenomenon is known as neutral carbon (Mäkipää et al. 2015; Proto et al. 2021). It will potentially lead to a zero-emission power system (Mori et al. 2022). Excellent performance of biomass-based electricity has been reported earlier (González et al. 2015). Furthermore, it has also been successfully developed in many countries in the world, such as in Brazil (Ferreira 2018), Finland (Majava et al. 2022), Ghana (Präger et al. 2019), India (Narnaware and Panwar 2022), Japan (Battuvshin et al. 2020), Portugal (da Costa et al. 2020), Spain (Aguado et al. 2022), and United States (Broughel 2019).

East Kalimantan province was one of Indonesia's most considerable bioenergy potentials due to its high availability of wood biomass resources from the forest (Simangunsong et al. 2017). The high diversity of biomass plant species distributed in the tropical rain forest of East Kalimantan was also reported as the essential biodiversity value in Indonesia for many endemic species compared to other places on the earth (Pio and D'Cruz 2005). However, the wood harvested from its forest resources was still dominated by the Dipterocarpaceae family, commonly used for furniture and construction purposes. Although it had promising calorific values, it was considered a low-growing tree species that was not desirable for sustainable energy crops (Yuliansyah et al. 2016). On the other hand, fast-growing tree species planted on forest plantations, such as *Acacia mangium*, *Anthocephalus cadamba*, *Eucalyptus pellita*, *Gmelina arborea*, and *Paraserianthes falcataria*, are have been reported to possess low heating value (Amirta et al. 2016; Haqiqi et al. 2022). Therefore, finding suitable plant species having high wood calorific value combined with their fast-growing ability to obtain high biomass yield for energy-electricity production is recently growing (Haqiqi et al. 2018).

The investigation of native species can be an important step in searching for suitable plant biomass species to be cultivated as energy crops in some remote areas. In East Kalimantan Province, many local fast-growing species are characterized as non-commercial species, even known as species with high adaptability to grow well in their origin ecosystem. They are mainly found in plant communities at secondary forest succession. Commonly used as firewood by local people, those species still have less attention for further large-scale utilization, especially in energy production. These species will promise future plantation of short-rotation wood crops to provide sustainable raw materials with a faster-growing ability. However, further wood physicochemical analysis was necessary to meet an ideal energy crop requirement. This study reported comparing wood physicochemical properties of selected fast-growing tree species native to the East Kalimantan forest to be used as feedstocks in electricity production.

MATERIALS AND METHODS

Study area

Wood biomass materials and leaf samples from some fast-growing native species were collected at the secondary forest of Mulawarman University Educational Forest (KHDTK Fahutan UNMUL, Samarinda), Samarinda City, East Kalimantan Province, Indonesia (0°25'10"S-0°25'10" S and, 117°14'00"E-117°14'14"E, 300 ha).

Biomass plant species

Medium trees with 6-8 cm diameter recognized as native fast-growing species naturally grown on secondary tropical rain forests in East Kalimantan were pointed out. Identification through leaf herbarium specimens of each species was deposited at the Laboratory of Forest Dendrology and Ecology, Faculty of Forestry, Mulawarman University, Samarinda, Indonesia. In this study, six species were identified, namely *Elaeocarpus ferrugineus* (Jacq.) Steud., *Ficus aurata* (Miq.) Miq., *Fordia splendidissima* (Blume ex Miq.) Buijsen, *Lindera lucida* (Blume) Boerl., *Mallotus paniculatus* (Lam.) Mull.Arg. and *Schima wallichii* (DC). They belong to different family groups, including Elaeocarpaceae, Moraceae, Fabaceae, Lauraceae, Euphorbiaceae and Theaceae, respectively. All woody biomass samples were collected in September 2021. They were debarked to analyze the dry bark-wood ratio, then converted into wood chips before proceeding to laboratory analysis.

Determination of wood physicochemical properties and energy potency

The total moisture and proximate compositions of wood materials were carried out according to ASTM D 7582-12 method. The lost weight of the samples after reaching the constant weight in a hot air oven at 105ºC was calculated to determine the moisture content. For proximate analysis, the samples were dried and grounded into smaller sizes (±60 mesh). The measurements consisted of two steps in a furnace. The first step was done by heating from 300-575ºC for 3 hours. The weight loss was measured and noted as a volatile matter (VM) substance. Then, the temperature was increased to reach 950ºC for 2 hours to heat the remaining samples. After cooling down to room temperature, the residual weight was measured in ash content while the lost weight was fixed carbon (FC).

The ultimate compositions of wood biomass including carbon (C), hydrogen (H), and oxygen (O) were estimated based on the following Equation (Parikh et al. 2007):

$$C\ (\%) = (0.637 \times FC) + (0.455 \times VM) \quad (1)$$

$$H\ (\%) = (0.052 \times FC) + (0.062 \times VM) \quad (2)$$

$$O\ (\%) = (0.304 \times FC) + (0.476 \times VM) \quad (3)$$

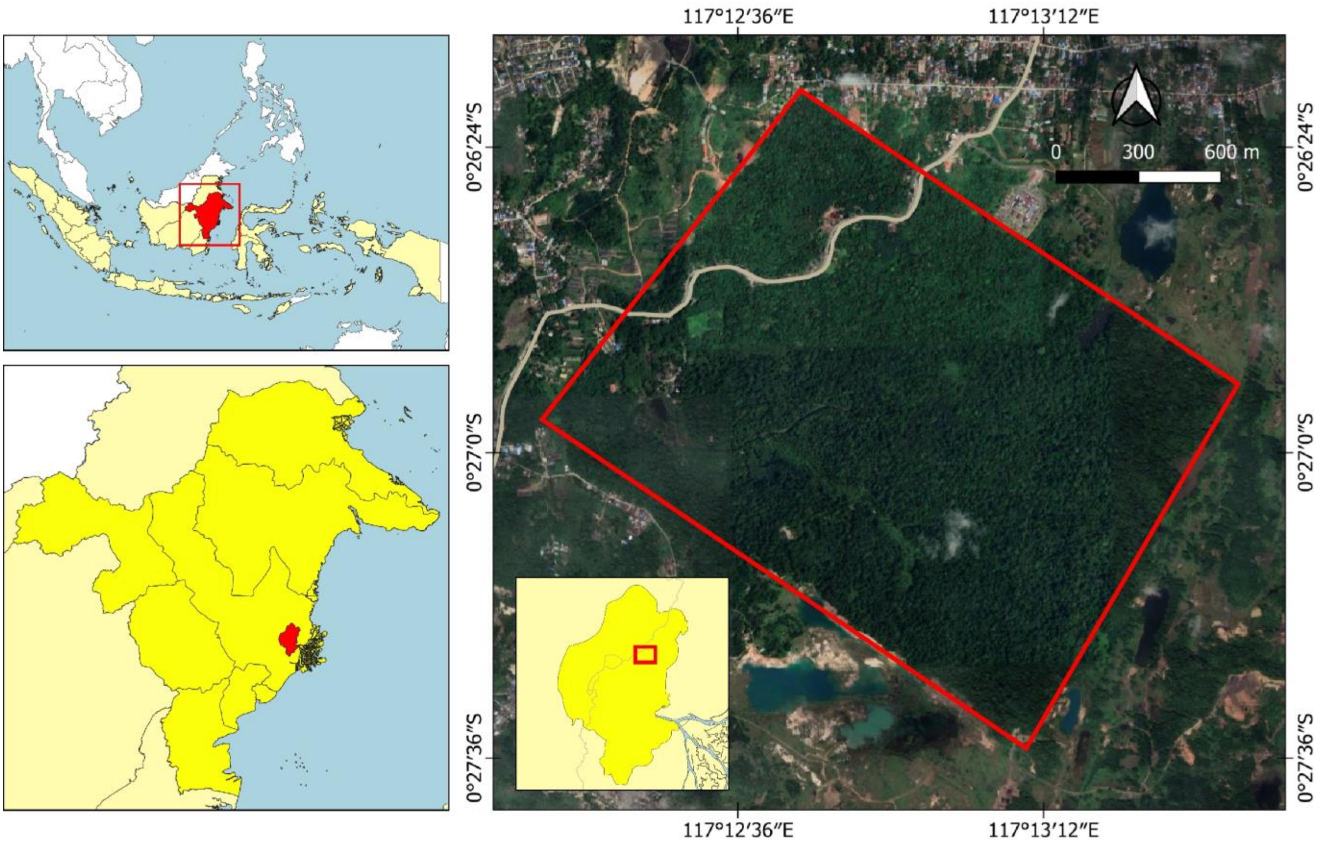


Figure 1. Research location conducted at Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia (0°25’10” LS - 0°25’10” LS and 117°14’00” BT-117°14’14” BT).

E. ferrugineus *F. aurata* *F. splendidissima*

L. lucida *M. paniculatus* *S. wallichii*

Figure 2. Fresh leaf shape varieties of some fast-growing native tree species were collected from the secondary forest of Mulawarman University educational forest, Samarinda City, East Kalimantan Province, Indonesia

Measurement of wood density (kg/m^3) was conducted by drying the wood samples at 105ºC following Edwards et al. (2014). The wood calorific value (MJ/kg) was accomplished in a bomb calorimeter according to the standard from EN-ISO 15400:2011, followed by the calculation of energy-electricity potency according to Francescato et al. (2008). Those measurements were classified into greenwood and wood chips. Furthermore, the fuel value index (FVI) was calculated using the equation as follows (Jain and Singh 1999):

$$\text{FVI} = (\text{Calorific value x density}) / (\text{ash x moisture}) \quad (4)$$

RESULTS AND DISCUSSION

Plant biomass species

Generally, tropical forest areas provide better environmental conditions for plants to produce sustainable biomass with high yields. This condition will lead to its potential wide-range application in biomass-based conversion technology, such as electricity generation. However, a previous study demonstrated that forest biomass species with high energy content were commonly produced from low-growing species (Amirta et al. 2016). In large-scale electricity production, utilization of the low-growing species in energy feedstocks requires a slow harvest cycle period with a high-cost operation. Therefore, this study assessed woody materials obtained from selected fast-growing species, including *E. ferrugineus*, *F. aurata*, *F. splendidissima*, *L. lucida*, *M. paniculatus*, and *S. wallichii* for the purpose of energy-electricity feedstock. Those species are abundant and native to the secondary forest of East Kalimantan, in which the local people traditionally used their wood as firewood for cooking activities. Nevertheless, literature describing those plant species for further industrial application is still rare. The measurement of bark and wood proportion of each species was summarized in Table 1. It was noticeable that three species, including *E. ferrugineus, F. aurata,* and *F. splendidissima,* had the lowest bark-wood ratio (0.7). The highest bark proportion was obtained from *S. wallichiii*, followed by *M. paniculatus* and *L. lucida,* with the value of 12.95%, 11.22%, and 7.80%, respectively. It has been reported earlier that the stem bark of *E. ferrugineus* was the potential for treating malaria-like symptoms (Ismail et al. 2015). On the other hand, *S. wallichii* bark could be utilized as an antimicrobial agent (Dewanjee et al. 2008). Hence, these interesting properties could potentially enhance their application for both energy feedstocks and natural medicine products. Since the stem bark produces a high quantity of ash (Pérez et al. 2008), its removal from wood when used for energy production through thermochemical conversion is necessary.

Wood physicochemical properties

Moisture content, density, and chip capacity of woody materials examined from some selected native tree species were summarized in Table 2. It has been previously reported that the percentage of wood moisture content depends on the plant species, season, and storage condition (Mancini and Rinnan 2021). In green conditions, the highest wood moisture content was obtained from *S. wallichii* (59.25%), while the lowest moisture content could be found in *F. splendidissima* (40.37%). The conversion of the wood into chip form evidently reduced their moisture content. As shown in Table 2, all wood chips revealed a lower moisture percentage than green wood conditions. It was found that the average moisture content of wood chips was 9.58%. It seems that wood chip form could easily evaporate the amount of water. Surprisingly, this situation could also be benefited considerably increase the achieved calorific value due to the water loss phenomenon (Figure 3A). According to the measurement of wood density, it was found that the highest wood density was obtained from *F. splendidissima* (760 kg/m^3). The second and third largest were found in *E. ferrugineus* (575 kg/m^3) and *S. wallichii* (536 kg/m^3) wood, respectively. The average wood density value from all species used in this study was 507 kg/m^3. Meanwhile, their form changed into wood chips that needed a high storage capacity. It was found that the average value of wood chips of all species was 201 kg per m^3 of storage area. The high wood density contributed to increasing the efficiency of wood chip storage. As observed from *F. splendidissima,* its wood chip (300 kg/m^3) was the most efficient storage capacity among all woody materials used. Especially for a large-scale operation, the high density of wood chips potentially contributes to low energy production costs (Bahadori et al. 2014). In contrast, low wood density affects the fast burning of the reactor, high transport costs, and high storage capacity (de Oliveira et al. 2013).

Table 1. Wood and bark ratio of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant species		Bark proportion (%)	Wood proportion (%)	Bark-wood ratio
Latin name	**Local name**			
E. ferrugineus	Belau	6.37 ± 0.59	93.63 ± 0.59	0.07 ± 0.01
F. aurata	Kayu ara	6.65 ± 0.25	93.35 ± 0.25	0.07 ± 0.00
F. splendidissima	Makumpit	6.70 ± 0.93	93.30 ± 0.93	0.07 ± 0.01
L. lucida	Madang	7.80 ± 0.55	92.20 ± 0.55	0.08 ± 0.01
M. paniculatus	Balik angin	11.22 ± 0.45	88.78 ± 0.45	0.13 ± 0.01
S. wallichii	Puspa	12.95 ± 0.68	87.06 ± 0.68	0.15 ± 0.01
Average		8.62 ± 2.79	91.39 ± 2.79	0.10 ± 0.10

Table 2. Moisture content, wood density, and chip capacity of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant species		**Moisture content (%)**		**Wood density**	**Chip capacity**
Latin name	**Local name**	**Greenwood**	**wood Chip**	**(kg/m^3)**	**(kg/m^3)**
E. ferrugineus	Belau	49.77 ± 1.59	9.34 ± 0.03	575 ± 25.78	227± 10.18
F. aurata	Kayu ara	56.90 ± 0.63	9.62 ± 0.03	487 ± 23.19	192 ± 9.15
F. splendidissima	Makumpit	40.37 ± 0.19	9.81 ± 0.01	760 ± 22.69	300 ± 8.94
L. lucida	Madang	50.64 ± 1.05	9.64 ± 0.05	354 ± 14.86	140 ± 5.86
M. paniculatus	Balik angin	52.85 ± 0.28	9.52 ± 0.03	331 ± 11.21	131 ± 4.42
S. wallichii	Puspa	59.25 ± 1.83	9.53 ± 0.01	536 ± 18.99	211 ± 7.49
Average		51.63 ± 6.61	9.58 ± 0.15	507 ± 157.7	200 ± 62.6

Table 3. Proximate and ultimate analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia

Plant species	**Ash (%)**	**Fixed carbon (%)**	**Volatile matter (%)**	**Carbon (%)**	**Hydrogen (%)**	**Oxygen (%)**	**H/C ratio**
E. ferrugineus	2.29 ± 0.03	14.23 ± 0.18	74.14 ± 0.14	42.80 ± 0.18	5.34 ± 0.01	39.62 ± 0.12	0.12 ± 0.00
F. aurata	2.30 ± 0.02	13.53 ± 0.16	75.55 ± 0.17	42.54 ± 0.17	5.33 ± 0.01	39.60 ± 0.13	0.13 ± 0.00
F. splendidissima	1.62 ± 0.04	13.85 ± 0.13	74.72 ± 0.13	42.82 ± 0.14	5.35 ± 0.02	37.78 ± 0.10	0.12 ± 0.00
L. lucida	1.71 ± 0.02	14.82 ± 0.21	73.83 ± 0.21	43.03 ± 0.04	5.35 ± 0.01	39.62 ± 0.04	0.12 ± 0.00
M. paniculatus	2.69 ± 0.01	13.36 ± 0.10	74.43 ± 0.16	42.38 ± 0.13	5.31 ± 0.01	39.49 ± 0.10	0.13 ± 0.00
S. wallichii	1.64 ± 0.05	12.96 ± 0.16	75.87 ± 0.09	42.78 ± 0.14	5.38 ± 0.01	40.05 ± 0.09	0.13 ± 0.00
Average	2.04 ± 0.44	13.79 ± 0.66	74.76 ± 0.80	42.72 ± 0.44	5.34 ± 0.66	39.70 ± 0.80	0.13 ± 0.00

Various laboratory tests were carried out for proximate and ultimate analysis. The proximate analysis includes ash, fixed carbon, and volatile matter (Table 3). These parameters strongly affected the performance of combustion, pyrolysis, and gasification of wood biomass in the thermochemical conversion process (Tursunov and Abduganiev 2020). Ash content of all woody materials showed less than 5%, which demonstrated their high potency utilized for raw materials of energy production. The low value of ash residue (<5%) resulting from the combustion process has a positive impact on increasing the efficiency stage and avoiding damage to the electricity reactor (Shao et al. 2011). Nimmanterdwong et al. (2021) stated that the ash in biomass is directly related to the mineral and inorganic elements absorbed by plants from the ground via the root cells, while its percentage differently depends on the soil properties, rocks, chemical treatment, and available metal contents. The volatile matters of all woody materials in this study were in the range of 73.83 - 75.87%, whereas the fixed carbons were in the range of 12.96 - 14.82%. It has been reported that the heat decomposition of cellulose and hemicellulose in biomass is the source of volatile matter. In contrast, lignin is a char source due to its richness in carbon atoms (Vega et al. 2019). The ultimate compositions, including C (carbon), H (hydrogen), and O (oxygen), were presented in Table 3. This investigation is essential to determine the theoretical air-fuel ratio in the thermochemical system and predict the released pollution (Telmo et al. 2010). The average value of C, H, and O was 42.72%, 5.35%, and 39.70%, respectively. It was clearly observed that all woody materials contained C higher than O, indicating its high suitability used as the energy feedstock since high C content will increase the obtained calorific value. Moreover, the C content, with a value of more than 40% in this study, was in line with that of the C content of various tropical woods (Amirta et al. 2016; Amirta et al. 2019; Yuliansyah et al. 2019; Mukhdlor et al. 2021). Ratio of H/C was also assessed since a higher value could contribute to improving energy efficiency and decreasing released emissions during combustion (Gopalakrishnan et al. 2019). The average H/C ratio of the six-plant studied was 0.13. This value was comparable with sawdust previously reported by García et al. (2012). More importantly, these findings demonstrated that all fast-growing species selected in this study possessed better H/C ratio than those of other tropical fast-growing woody species, such as *Bridelia tomentosa*, *Fagraea racemosa*, *Piper aduncum*, *Trema orientalis,* and *Vernonia arborea* (Amirta et al. 2016).

Wood quality for energy feedstock

The investigation of the fuelwood quality of native species is presented in Figure 3. The important parameters were calorific value, wood chip conversion value, energy-electricity potency, and fuel value index. According to Figure 3A, the conversion of green wood (original solid form) into wood chip form significantly enhanced the average calorific value up to 0.5-fold. It was calculated that the average calorific value of all examined woods in the green form (7.92 MJ/kg) increased to 17.01 MJ/kg at the wood chip condition. We found that those results were in line with decreasing the amount of moisture content on wood samples when converted into wood chips (51.63% to 9.58%) (Table 2). It has also been reported by Deboni et al. (2020) that lower moisture content is considered one of the factors that significantly influence the increased calorific value of woody biomass as a reliable energy source. The high proportion of moisture content in fuelwood could result in delayed ignition and devolatilization (Lu et al. 2008). Although this work promised high energy content, the wood chip form consequently required a larger storage

area (m^3) per ton of wood chip biomass than the greenwood form, as shown in Figure 3B.

In order to compare the suitability of woody materials from selected native species, further measurement of energy potency in MWh per ton biomass was performed (Figure 3C). The results showed that *F. splendidissima* exhibited the highest energy potency in both greenwood (2.21 MWh/ton) and wood chip (3.61 MWh/ton) forms. Although *S. wallichii* and *F. aurata* possessed high calorific values (Figure 3A), *F. splendidissima* had higher energy-electricity potency than those species due to its high wood density (760 kg/m^3). Interestingly, even though *F. splendidissima* is considered fast-growing species, this species was classified as high wood density (< 600 kg/m^3), whereas *S. wallichii* and *F. aurata* were characterized as medium wood density (400 - 600 kg/m^3). Having a similar pattern with calorific value results, the energy potency of all woody materials to generate electricity demonstrated significantly enhanced value after converting into wood chips due to the moisture removal. Our previous study shows fast-growing species in the lowland community forest, such as *Gmelina arborea*, *Anthocephalus cadamba*, *Acacia mangium*, and *Paraserianthes falcataria*, had relatively low energy potency (1.37 - 1.70 MWh/ton) (Amirta et al. 2016). Another study also reported that fast-growing and shrub species found in the tropical swamp-peat forest of Kutai Kartanegara in East Kalimantan generated low energy potency: *Kleinhovia hospita* (1.76 MWh/ton), *Cananga odorata* (1.36 MWh/ton), and *Octomeles sumatrana* (1.17 MWh/ton) (Amirta et al. 2019). However, our findings in this study indicated that fast-growing species native to the secondary forest in East Kalimantan, especially *F. splendidissima*, could produce woody materials with superior energy capacity for electricity production.

The bioenergy potential of each fast-growing native species was represented by Fuel Value Index (FVI) (Figure 3D). The FVI is an essential assessment for screening desirable biomass species for solid fuel (Samal et al. 2021). This measurement was also used by Niemczyk et al. (2018) to rank the quality of 10 poplar cultivars in northern Poland. The FVI was calculated using combinations of some influencing factors, including ash content, moisture content, calorific value, and wood density. This study found that wood chips containing low moisture content increased the FVI result from each wood tested. The average FVI of the wood chip, which had a value of 5267, was significantly higher than that of the greenwood condition, with an average value of 698. The greatest FVI was obtained from *F. splendidissima* (8970), followed by *S. wallichii* and *F. ferrugineus* with the value of 7502 and 4958, respectively. A high FVI value of wood biomass was observed because of low ash content, low moisture content, and high density (Pérez et al. 2014). We concluded that the wood chip revealed lower moisture content compared to the original form (green condition), indicating its high suitability to produce sustainable green energy.

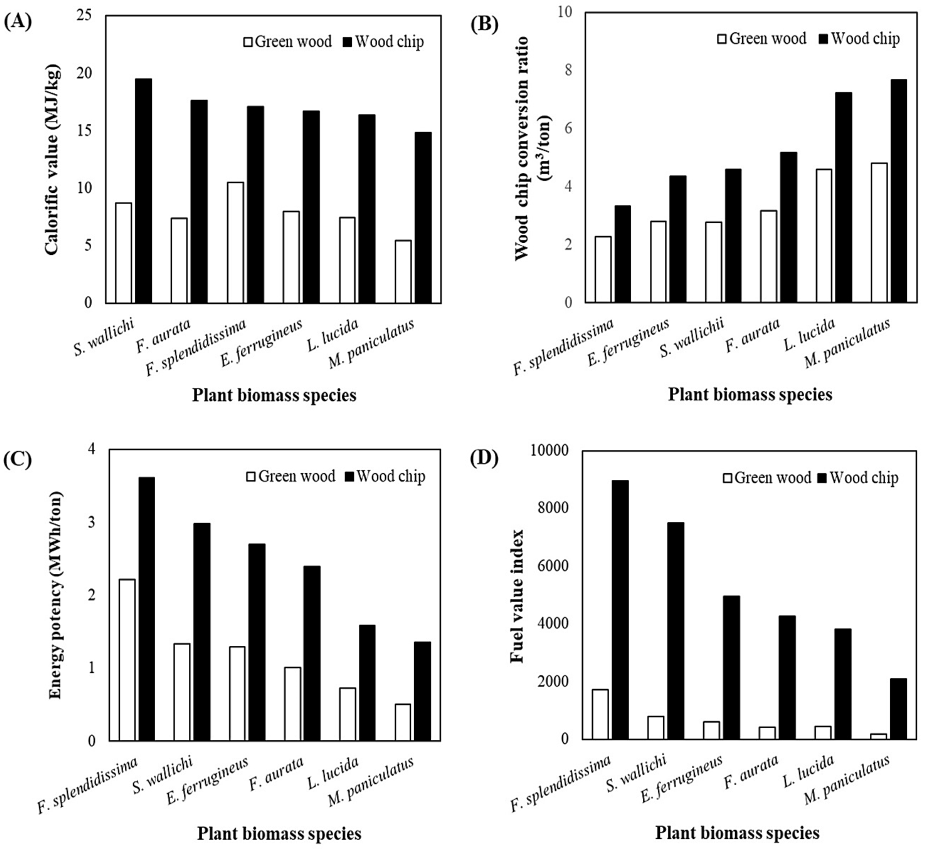


Figure 3. Analysis of some fast-growing tree species native to the secondary forest of East Kalimantan, Indonesia, for electricity feedstock: Wood calorific value (A), wood chip conversion ratio (B), energy potency (C), and fuel value index (D)

Finally, all woody materials obtained from fast-growing native species in the secondary forest of East Kalimantan were suitable for electricity feedstock due to the low ash content and a high proportion of carbon. When each wood biomass was converted into wood chip form, their efficiency in energy feedstocks (calorific value, storage capacity, energy-electricity potency, and FVI) was gradually increased since this form was able to remove moisture effectively. In contrast, the greenwood showed inefficient use since it might take longer to dry; thus, the cost of energy production will also increase. Among all biomass tested, the wood chip of *F. splendidissima* exhibited the most appropriate properties for electricity feedstock due to its high energy potency (3.61 MWh/ton) with desired FVI value (8970). Furthermore, the high adaptability in the local ecosystem combined with its high wood density and fast-growing ability will be the promising characteristics that allow *F. splendidissima* to be one of the ideal crops for energy feedstocks in the future. In general, this study successfully demonstrated the physicochemical properties of selected fast-growing native species in the tropical secondary forest in East Kalimantan, Indonesia, to generate electricity in rural communities, especially to develop the economic sector in this province.

ACKNOWLEDGEMENTS

The current study was financially supported by the Project Implementation Unit of Islamic Development Bank - PIU IsDB (Grant No. 402/UN17.45/DL/2021 for Yl, RA, and MTH), and the research funding for lecturers and students from the Faculty of Forestry, Mulawarman University (For Yl 2022)

REFERENCES

Aguado R, Vera D, Jurado F, Beltrán G. 2022. An integrated gasification plant for electric power generation from wet biomass: toward a sustainable production in the olive oil industry. Biomass Convers Biorefin. DOI: 10.1007/s13399-021-02231-0.

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 (6): 1516-1523. DOI: 10.13057/biodiv/d200605.

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Londong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast-growing wood species for energy production. Nusantara Biosci 8 (1): 22-31. DOI:10.13057/nusbiosci/n080106.

Bahadori A, Zahedi G, Zendehboudi S, Jamili A. 2014. Estimation of the effect of biomass moisture content on the direct combustion of sugarcane bagasse in boilers. Intl J Sustain Energy 33: 349-356. DOI:10.1080/14786451.2012.748766.

Battuvshin B, Matsuoka Y, Shirasawa H, Toyama K, Hayashi U, Aruga K. 2020. Supply potential and annual availability of timber and forest biomass resources for energy considering inter-prefectural trade in Japan. Land Use Policy 97: 104780. DOI:10.1016/j.landusepol.2020.104780.

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S. 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew Sustain Energy Rev 71: 830-845. DOI: 10.1016/j.rser.2016.12.109.

Broughel AE. 2019. Impact of state policies on generating capacity for production of electricity and combined heat and power from forest biomass in the United States. Renew Energy 134: 1163-1172. DOI: 10.1016/j.renene.2018.09.058.

Cardoso J, Silva V, Eusébio D. 2019. Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal. J Clean Prod 212: 741-753. DOI: 10.1016/j.jclepro.2018.12.054.

da Costa TP, Quinteiro P, Arroja L, Dias AC. 2020. Environmental comparison of forest biomass residues application in Portugal: Electricity, heat, and biofuel. Renew Sustain Energy Rev 134: 110302. DOI:10.1016/j.rser.2020.110302.

de Oliveira JL, da Silva JN, Pereira EG, Filho DO, Carvalho DR. 2013. Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification. Renew Sustain Energy Rev 21: 52-58. DOI:10.1016/j.rser.2012.12.025.

Deboni TL, Simioni FJ, do Rosário JDA, Costa VJ. 2020. Quality of biomass from old wood waste deposits in Southern Brazil. Biomass Bioenergy 143: 105841. DOI: 10.1016/j.biombioe.2020.105841.

Dewanjee S, Maiti A, Majumdar R, Majumdar A, Mandal SC. 2008. Evaluation of antimicrobial activity of hydroalcoholic extract *Schima wallichii* bark. Pharmacologyonline 1: 523-528.

Edwards LE, Newby AF, Gilliam CH, Fain GB, Sibley JL, Murphy, AM. 2014. Evaluation of eastern redcedar substrate in the production of four annual species. J Environ Hortic 32 (3): 167-173.

Ferreira LRA, Otto RB, Silva FP, De Souza SNM, De Souza SS, Junior OA. 2018. Review of the energy potential of the residual biomass for the distributed generation in Brazil. Renew Sustain Energy Rev 94: 440-455. DOI: 10.1016/j.rser.2018.06.034.

Francescato F, Antonini E, Bergomi LZ. 2008. Wood Fuels Handbook: Production, Quality Requirements, Trading. Legnaro, Italy.

García R, Pizarro C, Lavín AG, Bueno JL. 2012. Characterization of Spanish biomass wastes for energy use. Bioresour Technol 103 (1): 249-258. DOI: 10.1016/j.biortech.2011.10.004.

González A, Riba JR, Puig R, Navarro P. 2015. Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. Renew Sustain Energy Rev 43: 143-155. DOI:10.1016/j.rser.2014.11.013.

Gopalakrishnan B, Khanna N, Das D. 2019. Dark-fermentative biohydrogen production. In: Biohydrogen. Elsevier. DOI: 10.1016/B978-0-444-64203-5.00004-6.

Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R Yuliansyah, Suwinarti W, Amirta R. 2022. Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency. Biodiversitas 23 (5): 2389-2394. DOI: 10.13057/biodiv/d230516

Haqiqi MT, Yuliansyah, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf Ser: Earth Environ Sci. DOI: 10.1088/1755-1315/144/1/012041.

Hupa M, Karlström O, Vainio E. 2017. Biomass combustion technology development-It is all about chemical details. Proc Combust Inst 36 (1): 113-134. DOI: 10.1016/j.proci.2016.06.152.

Ismail I, Linatoc AC, Mohamed M, Tokiman L. 2015. Documentation of medicinal plants traditionally used by the jakun people of endau-rompin (peta) for treatments of malaria-like symptoms. Jurnal Teknologi 77 (31): 63-69. [Indonesian]

Jain RK, Singh B. 1999. Fuelwood characteristics of selected indigenous tree species from central India. Bioresour Technol 68: 305-308. DOI: 10.1016/S0960-8524(98)00173-4.

Karmaker AK, Rahman MM, Hossain MA, Ahmed MR. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. J Clean Prod 244: 118645. DOI: 10.1016/j.jclepro.2019.118645.

Lee BH, Sh L, Lee DG, Jeon CH. 2021. Effect of torrefaction and ashless process on combustion and NOx emission behaviors of woody and herbaceous biomass. Biomass Bioenerg 151: 106133. DOI: 10.1016/j.biombioe.2021.106133.

Liu Y, Xu Y, Zhang F, Yun J, Shen Z. 2014. The impact of biofuel plantation on biodiversity: a review. Chinese Sci Bull 59 (34): 4639-4651. DOI: 10.1007/s11434-014-0639-1.

Lu G, Yan Y, Cornwell S, Whitehouse M, Riley G. 2008. Impact of co-firing coal and biomass on flame characteristics and stability. Fuel 87: 1133-1140. DOI: 10.1016/j.fuel.2007.07.005.

Majava A, Vadén T, Toivanen T, Järvensivu P, Lähde V, Eronen JT. 2022. Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target. Energy Strategy Rev 41: 100836. DOI: 10.1016/j.esr.2022.100836.

Mäkipää R, Linkosalo T, Komarov A, Mäkelä A. 2015. Mitigation of climate change with biomass harvesting in Norway spruce stands: are harvesting practices carbon neutral? Canadian J For Res 45 (2): 217-225. DOI:10.1139/cjfr-2014-0120.

Mancini M, Rinnan Å. 2021. Near infrared technique as a tool for the rapid assessment of waste wood quality for energy applications. Renew Energy 177: 113-123. DOI: 10.1016/j.renene.2021.05.137.

Mola-Yudego B, Arevalo J, Díaz-Yáñez O, Dimitriou I, Freshwater E, Haapala A, Khanam T, Selkimäki M. 2017. Reviewing wood biomass potentials for energy in Europe: the role of forests and fast-growing plantations. Biofuels 8 (4): 401-410. DOI: 10.1080/17597269.2016.1271627.

Mori S, Sumner J, Bouvet J, Simms NJ. 2022. Fireside and steamside performance in biomass power plant. Mater High Temp 39 (2): 106-121. DOI:10.1080/09603409.2021.2019657.

Moya R, Tenorio C, Oporto G. 2019. Short rotation wood crops in Latin American: A review on status and potential uses as biofuel. Energies 12 (4): 705. DOI:10.3390/en12040705.

Mukhdlor A, Haqiqi MT, Tirkaamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation. Adv Biol Sci Res. DOI: 10.2991/absr.k.210408.005.

Mutezo G, Mulopo J. 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 137: 110609. DOI: 10.1016/j.rser.2020.110609.

Narnaware SL, Panwar NL. 2022. Biomass gasification for climate change mitigation and policy framework in India: A review. Bioresour Technol Rep 17: 100892. DOI:10.1016/j.biteb.2021.100892.

Niemczyk M, Kaliszewski A, Jewiarz M, Wrobel M, Mudryk K. 2018. Productivity and biomass characteristics of selected poplar (*Populus* spp.) cultivars under the climatic conditions of northern Poland. Biomass Bioenergy, 111: 46-51. DOI: 10.1016/j.biombioe.2018.02.002.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI: 10.1016/j.energy.2021.119945.

Nugraha HW, Djajakirana G, Anwar S, Santosa DA. 2020. Producing renewable electricenergy through a microbial fuel cell in the rice field. Biodiversitas 21 (9): 4139-4146. DOI: 10.13057/biodiv/d210927.

Parikh L, Channiwala SA, Ghosal GK. 2007. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86: 1710-1719. DOI:10.1016/j.fuel.2006.12.029.

Pérez S, Renedo CJ, Ortiz A, Delgado F, Fernández I. 2014. Energy potential of native shrub species in northern Spain. Renew Energy 62: 79-83. DOI: 10.1016/j.renene.2013.06.048.

Pérez S, Renedo CJ, Ortiz A, Manána M. 2008. Energy potential of waste from 10 forest species in the North of Spain (Cantabria). Bioresour Technol 99: 6339-6345. DOI: 10.1016/j.biortech.2007.12.014.

Pio D, D'Cruz R. 2005. Borneo's Lost World: Newly Discovered Species on Borneo. WWF, Jakarta.

Präger F, Paczkowski S, Sailer G, Derkyi NSA, Pelz S. 2019. Biomass sources for a sustainable energy supply in Ghana-A case study for Sunyani. Renew Sustain Energy Rev 107: 413-424. DOI: 10.1016/j.rser.2019.03.016.

Proto AR, Palma A, Paris E, Papandrea SF, Vincenti B, Carnevale M, Guerriero E, Bonofiglio R, Gallucci F. 2021. Assessment of wood chip combustion and emission behavior of different agricultural biomasses. Fuel 289: 119758. DOI:10.1016/j.fuel.2020.119758.

Ram M, Child M, Aghahosseini A, Bogdanov D, Lohrmann A, Breyer C. 2018. A comparative analysis of electricity generation costs from renewable, fossil fuel, and nuclear sources in G20 countries for the period 2015-2030. J Clean Prod 199: 687-704. DOI: 10.1016/j.jclepro.2018.07.159.

Rempel A, Gupta J. 2020. Conflicting commitments? Examining pension funds, fossil fuel assets, and climate policy in the organisation for economic co-operation and development (OECD). Energy Res Soc Sci 69: 101736. DOI: 10.1016/j.erss.2020.101736.

Rincon L, Puri M, Kojakovic A, Maltsoglou I. 2019. The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy Pol 130: 69-88. DOI: 10.1016/j.enpol.2019.03.024.

Samal B, Vanapalli KR, Dubey BK, Bhattacharya J, Chandra S, Medha I. 2021. Influence of process parameters on thermal characteristics of char from co-pyrolysis of eucalyptus biomass and polystyrene: Its prospects as a solid fuel. Energy 232: 121050. DOI:10.1016/j.energy.2021.121050.

Shao Y, Xu C, Zhu J, Preto F, Wang J, Li H, Badour C. 2011. Ash deposition in co-firing three-fuel blends consisting of woody biomass, peat, and lignite in a pilot-scale fluidized-bed reactor. Energy Fuels 25 (7): 2841-2849. DOI: 10.1021/ef2002603.

Simangunsong BCH, Sitanggang VJ, Manurung EGT, Rahmadi A, Moore GA, Aye L, Tambunan AH. 2017. Potential forest biomass resource as feedstock for bioenergy and its economic value in Indonesia. For Policy Econ 81: 10-17. DOI: 10.1016/j.forpol.2017.03.022.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101 (11): 3808-3815. DOI:10.1016/j.biortech.2010.01.021.

Tenorio C, Moya R, Filho MT, Valaert J. 2015. Quality of pellets made from agricultural and forestry crops in Costa Rican tropical climates. Bioresources 10 (1): 482-498.

Tursunov O, Abduganiev N. 2020. A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region. Mater Today: Proc 25: 67-71. DOI: 10.1016/j.matpr.2019.11.108.

Vega LY, López L, Valdés CF, Chejne F. 2019. Assessment of energy potential of wood industry wastes through thermochemical conversions. Waste Manag 87: 108-118. DOI: 10.1016/j.wasman.2019.01.048.

Wang Z, Bui Q, Zhang B, Pham TLH. 2020. Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. Sci Total Environ 743: 140741. DOI:10.1016/j.scitotenv.2020.140741.

Yuliansyah, Amirta R. 2016. Physico-chemical properties and energy potency of wood waste biomass from logging activities to generate electricity in East Kalimantan, Indonesia. AIP Conference Proceeding. DOI: 10.1063/1.4958476.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Helmi AS, Setiawan KA, Setiyono B, Angi EM, Saparwadi, Sari NM, Kusuma IW, Rujehan, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20 (8): 2236-2242. DOI: 10.13057/biodiv/d200818.

Payment of my manuscript

Participants

Edit

Rudianto AMIRTA (r_amirta)

DEWI NUR PRATIWI (dewinurpratiwi)

Messages

Note	From
Dear editor, Attached I send proof of payment transfer for the manuscript entitled "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks". Thank you Best regards, Rudianto Amirt r_amirta, Payment_Rudianto Amirta.jpg	r_amirta 2022-06-18 03:36 AM

Add Message

Payment of my manuscript

Participants Edit

Rudianto AMIRTA (r_amirta)

DEWI NUR PRATIWI (dewinurpratiwi)

Messages

Note	From
Dear editor, Attached I send proof of payment transfer for the manuscript entitled "Fast-growing native tree species to secondary forest of East Kalimantan, Indonesia: Physicochemical properties of woody materials for bioelectricity feedstocks". Thank you Best regards, Rudianto Amirt r_amirta, Payment_Rudianto Amirta.jpg	r_amirta 2022-06-18 03:36 AM

Add Message