The Renewable Energy Potential of Food Crop Wastes in Indonesia

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Received: 07.11.2022 Accepted:17.01.2023

Abstract – One of Indonesia's great potential biomass energy sources is food crop waste. Five food crop commodities with nine types of waste were investigated in the study. This study aimed to determine the physical, chemical, and thermal properties of food crops waste and their potential for utilization as an energy source. Furthermore, the spatial map of the gross energy potential of food crop wastes in 34 provinces in Indonesia is depicted. The results of the research showed a moisture content of the samples in the range of 10.31 wt.% (rice husk) to 13.92 wt.% (peanut stem). The food crop waste containing low ash was corncob. The volatile content in food crop waste was more than 60%, except for rice husk and rice straw. Cassava stem had the highest fixed carbon of 17.12%, while peanut shell had the highest calorific value of 17260 kJ/kg. The food crops waste had sulfur and nitrogen content below 1%. The carbon content of food crops waste ranged from 31.03 to 42.03%, while the hydrogen content was between 5.29 and 6.54%. Rice husk has the lowest hygroscopic nature while corn cob is the opposite. The amount of food crop waste in Indonesia reaches 115.73 million tons per year, with a gross energy potential (GEP) of 1596.12 PJ/year. Rice waste has the greatest GEP, followed by corn, cassava, peanut, and soybean. The GEP of food crops waste was dominant in provinces in Java.

Keywords- Biomass, food crop waste, gross energy potential (GEP), Indonesia, spatial map

1. Introduction

A country's secured energy supply is needed to support development in all sectors. The world's energy demands tend to increase continuously, except for the effects of COVID-19 in the previous two years. In 2022, global primary energy data showed growth of almost 6% compared to 2021, decreasing COVID-19 restrictions around many countries of the world [1]. Indonesia accounted for 2,9% of growth in the primary energy consumption in 2021. The country, which has a population of about 270 million, had an economic growth of 5.44 in the second quarter of 2022 compared to the previous year [2]. Indonesia's large population and high economic growth have also resulted in high energy demand. Transportation is the sector with the highest consumption, followed by the household and industrial sectors.

The increasing energy consumption and environmental problems such as pollution and greenhouse gas emissions are two interrelated issues today. Fulfillment of energy demands must not destroy the environment, and environmental conservation must not be an obstruction to the completion of energy demands. The fact is an opportunity to develop the utility of renewable energy sources, including biomass. Biomass is considered as one of the potential renewable energy resources that is sustainable and environmentally friendly [3], [4].

Indonesia is a Southeast Asian country which located between 6° 04’ 30’’ N latitude and 11° 00’ 36’’ S latitude, and 94° 58’ 21’’ E longitude and 141° 01’ 10’’ E longitude [5]. The country is located in the tropics so that it has high rainfall, high intensity of sunlight, fertile soil, and rich in various types of biodiversity. Indonesia is one of the biggest agricultural countries, with a farming land area of around 62.3 million ha

[6]. Agriculture is an important sector in Indonesia because it is able to absorb the most human resources, which is more than 40 million [2]. The main commodities of food crop agriculture sub-sector are rice, corn, soybeans, peanuts, and cassava. The food crop wastes are roughly divided into two main categories: field and process wastes [7], [8]. Field waste is residue during harvesting, while process waste is residue in the post-harvest processes. Rice straws, corn stalks, soybean stalks, bean stalks, and cassava stems are included as primary waste. Secondary waste includes rice husks, corn cobs, corn husks, and peanut shells. These food crop wastes have a large enough bioenergy potential [9]. Increasing use of renewable energy can be achieved by utilizing agricultural waste. Currently, the utilization of agricultural wastes as a source of energy generation has attracted increasing attention [10].

It should be noted that agricultural waste is a fully renewable and carbon neutral energy resource [11]. The carbon dioxide released when combusted and utilized does not increase atmospheric carbon dioxide because plants use CO_2 for their previous growth and metabolic processes. Therefore, the exploitation of agricultural waste only leads to a faster displacement of CO_2 into the atmosphere that plants will use again to grow. Restrictions on the use of coal and increasing carbon taxes are factors that support the use of biomass fuels, including agricultural waste. The Indonesian government's policy in the national energy mix by targeting 25% renewable energy by 2025 and 31% in 2050 encourages the use of agricultural waste biomass energy [12]. Restrictions on using coal in power plants promote the search for alternative materials to replace coal while still utilizing existing power plants. The alternative fuel to replace coal is biomass. Several coal-fired power plants in Indonesia have switched to apply co-firing technology or to use 100% biomass.

Energy generated from biomass offers a solution to overcoming the problem of environmental pollution caused by fossil fuels. Several thermochemical (direct combustion, gasification, pyrolysis, torrefaction, hydrothermal), biochemistry (anaerobic digestion), and chemical (transesterification) technologies are used to convert biomass energy into bioenergy [9], [13]–[15].

A geographic Information System (GIS) is a system that is useful for collecting and presenting information related to geography. GIS integrates data, software, hardware, method, and people into a comprehensive technique. GIS combines computer, geography, and remote sensing sciences to collect, manage, evaluate, and visualize geographic data [16]. GIS is widely used for evaluation and assessment in various fields correlated to geography, including assessing the potential of biomass energy. Chakraborty et al. used GIS to develop a spatial information system of biomass potential from crop residues to plan and establish a biofuel/biomass power plant in India [17]. Channi et al. conducted an agricultural waste assessment for optimal power generation in Ludhiana district, Punjab, India [18]. Carlucci et al. used GIS to map the amount of biomass and energy potential of the residue in the Novara district-Northwest Italy [19]. GIS was also used by Anand et al. to assess crop residue potential for power generation potential for energy security in Bangladesh [20].

The focus of the study was to investigate the characterization of the nine types of food crop wastes to assess their suitability as fuel. The study attempted to generate geospatial maps of energy potential from food crop residues over all provinces in Indonesia. The geospatial map is a map that presents information on specific themes and particular interests. The geospatial map refers to the base map made by the Geospatial Information Agency (BIG). The map provides information on the energy potential of food crop waste in 34 provinces in Indonesia. Previous studies mostly depicted energy potential maps in only one region. Nine types of residues from 5 kinds of food crops were used in this study.

2. Materials and Methods

2.1 Food Crop Waste Characterization

The investigation of moisture, fixed carbon, volatile matter, and ash contents in the sample resulted proximate analysis. A muffle furnace (Carbolite AAF 1100) was used to determine volatile matter and ash contents following ASTM 3175 and ASTM 3174, respectively, while moisture content analysis was performed by MFS oven (Carbolite) according to ASTM 3171. The fixed carbon content was calculated by subtracting the moisture, volatile, and ash contents from the total biomass on air-dry basis.

The elemental components (C, H, O, N, S) of the samples were determined by LECO CHN 628 elemental analyzer according to ASTM D5373, while sulfur content was analyzed using LECO S 632 elemental analyzer according to ASTM D4239. Oxygen content was determined by the difference. Heating values (HHV) of the samples was measured using IKA C6000 oxygen bomb calorimeter. The measurement was performed in triplicate to validate.

The hydrophilicity of the samples was evaluated by equilibrium moisture content (EMC). Analysis of hydrophilicity was conducted by putting 2 grams of each dry grinding samples in an airtight container. The relative humidity in the container was controlled of about 75% by a saturated solution of sodium chloride (NaCl) [21]. The moisture absorbed by the sample caused an increase in weight. The increase in weight of the sample was investigated by weighing the sample every 2 hours up to 12 hours. After that, the weighing was done every 12 hours until there was no more increase in weight.

2.2 Crop Waste Selection

The study was conducted for all provinces in Indonesia, encompassing food crop wastes. Rice, corn, soybeans, peanuts, and cassava were selected for the food crop commodities in the study. These commodities were chosen because they are the 5 commodity production in Indonesia. Meanwhile, the waste from the 5 commodities selected was rice husks, rice straw, corn cobs, corn husks, corn stalks, soybean stalks, peanut shells, peanut stalks, and cassava stems (Fig. 1). The selection of these wastes was based on the dominant waste of each selected commodity.

Fig. 1. Food crops and wastes selection

2.1 Estimation of crop waste

Production data of food crop commodities is needed to estimate their energy potential. This data was collected from data on the production of rice, corn, peanuts, soybeans, and cassava in 2021 released by Statistics Indonesia. The data included production data in 34 provinces in Indonesia. Map locating all provinces of Indonesia selected as study areas is showed in Fig. 2. Data processing to determine the value of potential energy was obtained by combining production data, waste data and waste calorific value obtained from sample testing.

Agricultural waste was unused by-products obtained from crop cultivation or process after cultivation. The potential of gross agricultural waste can be estimated by knowing two parameters, namely – the production of the crop and their respective waste-to-production ratio (WPR). WPR was calculated using a result of residue and product weighing of the samples. Based on the above parameters, gross agricultural waste was estimated by Eq. 1.

$$GAW = POC*WPR \quad (1)$$

where GAW is gross agricultural waste in tons/year, POC is crop production in tons per year, and WPR is the waste-to-production ratio in %. WPR was determined by dividing crop production by the amount of sample waste. Paddy, corn, peanuts, and soybeans were measured after dried under the sunlight for a week, while cassava was measured on an after-harvested condition. The mass of waste from each sample was also weighed after dried under the sunlight for 6 - 7 days.

2.2 Estimation of the Gross Energy Potential of Crop Wastes

The energy potential of agricultural waste was calculated based on data on the amount of waste and the results of testing the calorific value of each waste.

$$GEP = GAW*CV \quad (2)$$

where GEP is gross energy potential of agricultural waste in ton/year, and CV is heating value of agricultural waste in MJ/kg.

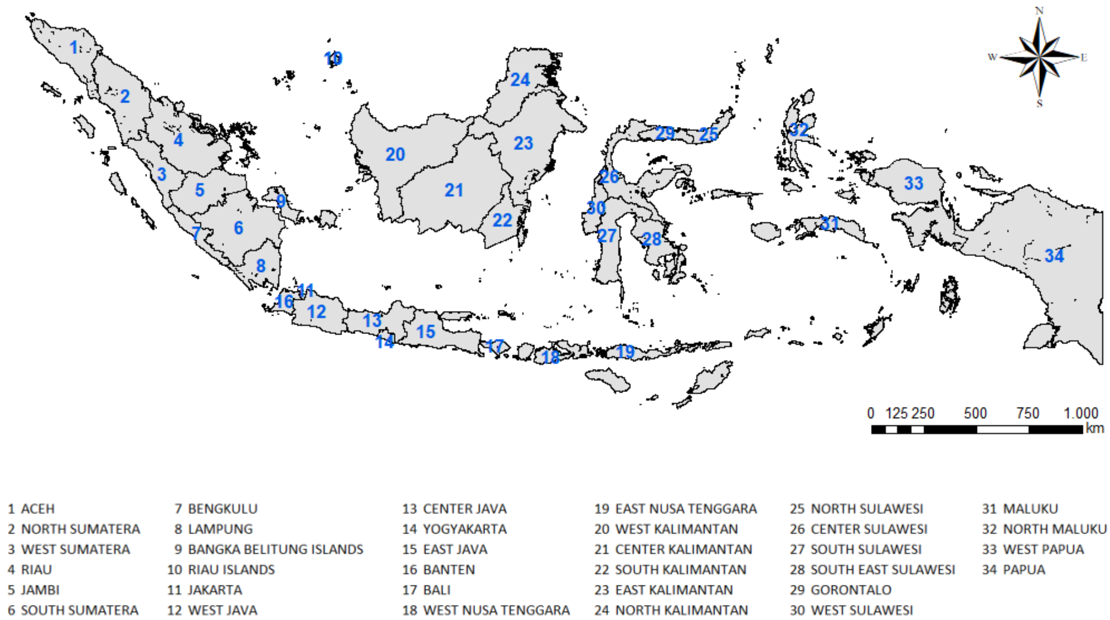

Fig. 2. Map of provinces in Indonesia

3. Results and Discussions

3.1 Characteristics of FoodCcrops Waste

The purpose of food crop waste utilization is to make useless waste more useful while reducing fossil fuel consumption, which negatively impacts the environment. The feasibility of food crop waste utilization as a biofuel needs several considerations, including its physical, chemical, and thermal properties. Important parameters that must be known when utilizing food crop waste as fuel are calorific value, proximate analysis, and ultimate analysis. [22]. The calorific value is the amount of heat contained in each unit weight of fuel, and this heat content will be released during the combustion process [23]. The calorific value data of each food crop waste can be used to assess its potential to be used as fuel. Proximate analysis is useful for knowing the content of the fuel's moisture, volatile matter, fixed carbon, and ash. Ultimate analysis is carried out to determine the composition of the elements C, H, O, N, and S in the material. Proximate and ultimate material analysis is carried out before the material is used as fuel because the results of the analysis can be used to assess the feasibility of the material being used as fuel [24]. The results of the proximate and ultimate analyses can also be used to determine the preparation or pretreatment of material that must be carried out before being utilized as fuel.

The results of the proximate analysis and calorific value test of the samples are presented in Table 1. The data shows that the minimum moisture content is 10.31 wt.% from rice husk, and the maximum is 13.92 wt.% from peanut stem. This condition was after the wastes are dried under the sun. The lower the moisture content in the material, the easier it starts to burn. Moisture content also influences the calorific value of the material. The higher moisture content leads to the lower calorific value [7].

The ash content in food crop waste is different from each other. The investigation showed that some food crops waste (i.e., rice husk, rice straw, and peanut stem) had high ash content. Corn cob had the lowest ash content (1.64%). Meanwhile, rice straw had the highest ash content (22.12%). Solid biofuel with lower ash content had a higher calorific value because ash is an incombustible matter, so it is preferred as fuel [7]. Materials with low ash content are good for use as fuel because they leave a little ash when burning [19].

Solid fuels with a high ash content have disadvantages, among others, reducing reactivity during char combustion due to obstruction of oxygen diffusion into the fuel. Fuels with high ash content need a particular design for handling ash after combustion. High ash content also has a higher tendency to occur fouling and slagging on the heat exchanger surface [25], [26].

Table 1. Proximate analysis and calorific value of selected food crop wastes

Wastes	Moisture (% ar)	Ash (%adb)	VM (%adb)	FC (%adb)	Calorific value (kJ/kg)
Rice husk	10.31	21.12	55.64	12.93	13291
Rice straw	11.2	22.12	53.56	13.12	12854
Corncob	12.74	1.64	68.81	16.81	16612
Corn stalk	10.36	2.98	69.95	16.71	16701
Corn husk	11.74	2.1	71.39	14.77	16350
Peanut shell	12.26	6.06	65.45	16.23	17260
Peanut stem	13.92	12.63	61.72	11.73	13168
Soybean stem	10.76	2.5	70.28	16.46	14612
Cassava stem	10.52	3.87	68.49	17.12	17143

One of the principal characteristics of biomass is high volatile matter content. The high volatile matter content makes biomass more flammable, and the combustion rate is relatively high because most volatile components are easily ignited and burned at relatively low temperatures compared to fixed carbon [27] . Most food crop waste had a volatile content of above 60%. The volatile matter content of food crop waste was between 53.56% (i.e., rice straw) to 71.39% (i.e., corn husk). Before food crop waste is used as a solid fuel, it needs to be treated to reduce volatile content by carbonization or torrefaction [23], [28]. The high volatile content material has good potential as the feedstock for oil fuel production by pyrolysis or syngas production by gasification [29].

Another important component of biomass is fixed carbon. Fixed carbon is the main component in biomass that produces energy during the combustion process. This component also has a slower combustion rate compared to the volatile matter. According to the results, the cassava stem contained the highest fixed carbon compared to the other samples. Meanwhile, the lowest fixed carbon was identified in the peanut stem. Fixed carbon is the component in biomass that has the most influence on the calorific value of the fuel. It can be seen from the results of the proximate analysis that the higher the fixed carbon, the higher the calorific value. For instance, the highest fixed carbon was 17.12% wt.% from cassava stem with a calorific value of 17.143 kJ/kg, while the lowest was 11.73 wt.% from peanut stem with a calorific value of 13.168 kJ/kg. Evidently, the fixed carbon content of cassava stem is not much different than that of some wood such as pine (17,8%) [30], rubberwood (16,6%) [31], Sakura (17,4%) and Nara (17.0%) [32]. Increasing the fixed carbon content while reducing the volatile content can be carried out by the pretreatment of the material [33].

In the study, the calorific value of food crop waste was between 12854 kJ/kg to 17260 kJ/kg. Based on the results of the calorific value investigation, peanut shells, cassava stalks, corn stalks, corn cobs, and corn husks have the potential to be used as fuel because their calorific value is higher than others. Peanut shell had the highest calorific value, 17260 kJ/kg. Materials with a lower calorific value still have the potential to be used as fuel but require more quantities.

The ultimate analysis is an analytical method to determine the content of chemical elements that compose biomass. Table 2 presents the composition of C (carbon), H (hydrogen), O (oxygen), N (nitrogen), and S (sulfur) of the samples. Information on the constituent elements of biomass is very important because it influences the combustion process and exhaust gas emissions [34]. Food crop waste, like biomass in general, has low Sulfur and Nitrogen content (mostly below 1%), except for nitrogen content in peanut stems (1.36%). The property is an advantage of biomass as a fuel. The low content of Sulfur and Nitrogen makes the flue gas from biomass combustion relatively free from NOx and SOx, which are dangerous gases [35].

Carbon and hydrogen contents in biomass affect the energy content because they produce energy during combustion. Food crop waste contained carbon between 31.03% (rice straw) to 42.03% (cassava stems), while the hydrogen content was between 5.29% (rice straw) to 6.54% (corn husks). The oxygen content in the biomass plays a role in a higher combustion rate with a lower temperature [36]. Food crop waste contained oxygen between 39.85% (rice husk) to 50.7% (corn husk).

Tabel 2. Ultimate analysis of selected food crop waste

Wastes	S (% ar)	C (%adb)	H (%adb)	N (%adb)	O (%adb)
Rice husk	0.1	32.92	5.51	0.5	39.85
Rice straw	0.12	31.03	5.29	0.62	40.82
Corncob	0.088	41.49	6.5	0.33	49.95
Corn stalk	0.08	42.52	6.37	0.41	47.63
Corn husk	0.084	40.29	6.54	0.29	50.7
Peanut shell	0.12	41.58	6.28	0.86	45.1
Peanut stem	0.22	35.21	6.13	1.36	44.45
Soybean stem	0.09	41.95	6.42	0.61	48.43
Cassava stem	0.15	42.03	6.48	0.69	46.78

Biomass that has been dried can absorb moisture again when stored in open air so that the moisture content increases. Increasing the moisture content in the biomass reduces the heating value, makes easier to biodegrade, and increases transportation and handling costs [37]. Comparison of hygroscopicity between various food crop wastes can be seen in Fig. 3.

Based on the data obtained in this study, the rate of moisture absorption of food crop waste was quite high in the first 6 hours, and as the hour getting longer, the ability to absorb moisture decreased. The sample did not absorb any more moisture after 48 hours, which indicated that the moisture content in the material was saturated. The hydrophilicity of food crop waste varied. Rice husk had the lowest hygroscopicity, while corn cob was the opposite. Corn cob absorbed moisture as much as 15.3%, while rice husk only absorbed 10.7% from the initial weight. The easier a material absorbs moisture when put in open air, the higher the increasing moisture content is. The hygroscopic is a negative characteristic of food crop waste that must be addressed.

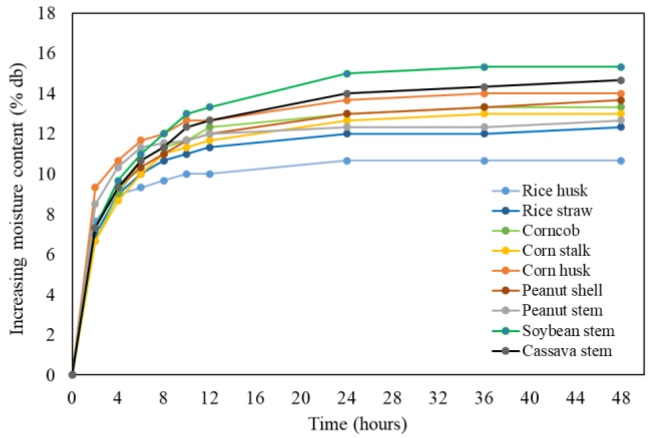

Fig. 3. Hygroscopicity of food crops waste

3.2 *Address the Heterogenous Characteristics of Food Crop Wastes*

The main challenge in utilizing food crop waste as an energy generator is the heterogeneous characteristics. The results of the study indicated that the crop food wastes had ash, volatile, and fixed carbon contents between 2.1 - 22.12 wt.%, 53.56 - 71.39 wt.%, and 11.73 - 17.12 wt.%, respectively. Calorific values of the samples were in the range of 12854 - 17260 kJ/kg. Mutual utilization of food crop waste can be done by first grouping it based on almost the same characteristics. For example, food crop waste can be grouped into 3 groups based on its ash content, namely low ash content (corncob, corn stalk, corn husk, soybean stem, and cassava stem), medium ash content (peanut shell, peanut stem), and high ash. content (rice husk, rice straw). An alternative solution to overcome the gap characteristics of food crop waste utilized for energy generation is to convert it into syngas with gasification technology

The characteristics of food crop waste are also a problem when it is used direcly as a source of energy. The high moisture content causes the biomass needs to be dried before use. However, if it is not used immediately after drying, the moisture content of the biomass will increase again due to its hygroscopic nature [37]. The fibrous nature of the biomass makes it difficult to crush and grind it [38], [39]. The high volatile content makes the biomass burn at a relatively high combustion rate. Biomass also has problems in transportation and storage because of its low energy density. Biomass also cannot be stored for too long because it will be decomposed by small insects and microbes when stored for too long. One of the technologies that can be applied to overcome these problems is torrefaction and densification.

3.3 Main Food Crops in Indonesia

Rice is the main staple food of the majority of the Indonesian population. Rice is the main food crop widely cultivated in Indonesia, with a total harvest area of 10,411,801.22 ha and production reaching 54,415,294.22 tons. The provinces that produce the highest average annual rice are East Java, Central Java, and West Java, i.e., 9,789,587.67 tons, 9,618,656.81 tons, and 9,113,573.08 tons, respectively. Rice plants' waste is straw, rice bran, straw, and husk. Dry straw is produced as much as 149.8% of the milled dry grain production. In the grain milling process, 60.5% of rice, 10.8% of husks, and 28.7% of rice bran are produced. The husk is usually burned to produce heat in bricks or tiles production processes. While some of the straw is used as animal feed, and some is piled or burned in the fields.

Corn is widely used as a feedstock for animal feed. Corn crops are mostly cultivated on dry land and rainfed rice fields. The three provinces that produce the highest average annual rice are East Java, Central Java, and Lampung, with 6,604,888 tons, 3,693,276 tons, and 2,349,502 tons, respectively. In the corn harvesting process, it produces leaf and stems waste, while in the post-harvest process, it produces corn cobs and husks. Upper leaves are widely used for ruminant animal feeds. Corn waste that has not been utilized is corn stalks, cobs, and husks, which are only piled up or burned. The percentages of corn stalk, corn cob, and husk wastes were 40.56%, 18.75, and 11.5%, respectively.

Soybean is an important commodity in Indonesia after rice and corn. The total soybean production was 982,598 tons in a land area of around 680 ha. East Java is the province that produces the most soybean. Soybean stems are one of the waste products from soybean plants which are surplus material from soybean cultivation activities and are often thrown away or burned. Soybean stem waste is almost twice than soybean produced.

Peanuts are widely needed as food ingredients, so farmers in Indonesia widely cultivate this commodity. The largest peanut producers are East Java and the Special Region of Yogyakarta. Peanut is a food crop that has the potential to produce waste at harvest and post-harvest. When harvesting, peanut generate waste in the form of stems and leaves; in post-harvest, it produces waste in the form of peanut shells. Fresh peanut stems and leaves are widely used as animal feeds. The peanut shell is usually just piled up or just burned. The dried stems and leaves produced from the rest of the peanut harvest are around 119%, while the peanut shell is 46.5%.

Cassava is a food-crop commodity that is widely cultivated throughout Indonesia. The largest cassava producers include the provinces of Lampung, Central Java, and East Java. In Indonesia, cassava can be processed into various types of Indonesian specialties. When harvesting, cassava leaves waste in the form of stems, and during processing, it produces waste in the form of peel. With an average annual yield of 5.5 million tons/year, cassava stem waste has the potential to be used as solid fuel because its characteristics are like wood. Cassava stem waste is about 28% of the cassava yield. A small part of cassava stems is used as fuel, but some are just piled on the edge of the field.

3.4 Energy Potential of Food Crops Waste

The amount of waste of an agricultural commodity in an area is influenced by the productivity and area of land planted with the commodity. Based on the data collection results on production and waste from samples of rice, corn, soybeans, peanuts, and cassava, the percentage of waste and the estimated amount of waste are obtained, as shown in Table 3.

Table 3. The energy potential of food crop wastes

Commodities	Wastes	Waste to production ratio (%)	Amount of waste (million ton/year)	Gross energy potential (PJ/year)
Rice	Rice husk	10.80	5.87	78.11
	Rice straw	149.80	81.51	1047.78
Corn	Corncob	18.70	5.62	93.37
	Corn stalk	40.56	12.19	203.59
	Corn husk	11.50	3.45	56.51
Peanut	Peanut shell	46.50	0.24	4.11
	Peanut stem	119.20	0.61	8.04
Soybean	Soybean stem	84.30	0.83	12.10
Cassava	Cassava stem	27.90	5.39	92.51

The amount of waste was determined based on the sampling of each commodity. Each commodity produced a different percentage of waste. The food crop waste taken as a sample in the research was the dominant waste from each commodity. Overall, the amount of food crop waste in Indonesia is 115.73 million tons per year.

Based on the estimated amount of waste, the commodity that produces the most waste is rice, with husks as much as 5.87 million tons per year and straw as much as 81.51 million tons per year. The next is corn which produces waste in the form of cobs, stalks, and husks, with a total amount of 21.27 million tons per year. While cassava had the most waste from stems, with a total amount of 5,39 million tons per year. Soybean and peanut wastes are less than 1 million tons per year.

Based on the investigation, the thermal properties of each food crop waste did not have the same calorific value. The calorific value influenced the GEP of each waste. As shown in Table 3, the GEP of rice waste is the largest, followed by corn, cassava, peanut, and soybean wastes. From the data, Indonesia has a remarkably large GEP of biomass. From rice waste only, GEP is 1125.89 PJ/year. While GEP of corn, cassava, peanut, and soybean wastes are 353.47 PJ/year, 92.51 PJ/year, 12,15 PJ/year, and 12.10 PJ/year. Overall, the GEP of the five food crop commodities is 1596.12 PJ/year. Viewed as a great potential, they can be used to reduce dependence on fossil energy sources if it is managed properly.

The GEP allocation of food crop waste in all provinces is shown in the spatial map, Fig. 4 to 8. Figure 4 shows the GEP distribution of rice waste, a combination of straw and rice husks. The GEP of rice waste seems dominant in Java, namely East Java, Central Java, and West Java, with quantities of 202,55 PJ/year, 199,02 PJ/year, and 188,57 PJ/year, respectively. Outside Java province with considerable potential is South Sulawesi, with a GEP of 105,33 PJ/year. In addition, several provinces on the island of Sumatra with moderate GEP are Aceh, North Sumatera, West Sumatera, South Sumatera, Lampung, and South Kalimantan, with GEP below 60 PJ/year. Other provinces only have GEPs below 20 PJ/year.

Corn is the second largest producer of GEP after rice. Figure 5 shows the GEP distribution of corn waste. The five largest GEP-producing provinces of corn waste are East Java, Central Java, Lampung, South Sulawesi, and West Nusa Tenggara, which had GEP of 76.95 PJ/year, 43.38 PJ/year, 30.36 PJ/year, 27.54 PJ/year, and 24.22 PJ/ years, respectively. Meanwhile, those with GEP between 10 and 20 PJ/year were North Sumatra, Gorontalo, West Java, North Sulawesi, West Sumatra, South Sumatra, and East Nusa Tenggara. Another 22 provinces had GEP below 10 PJ/year.

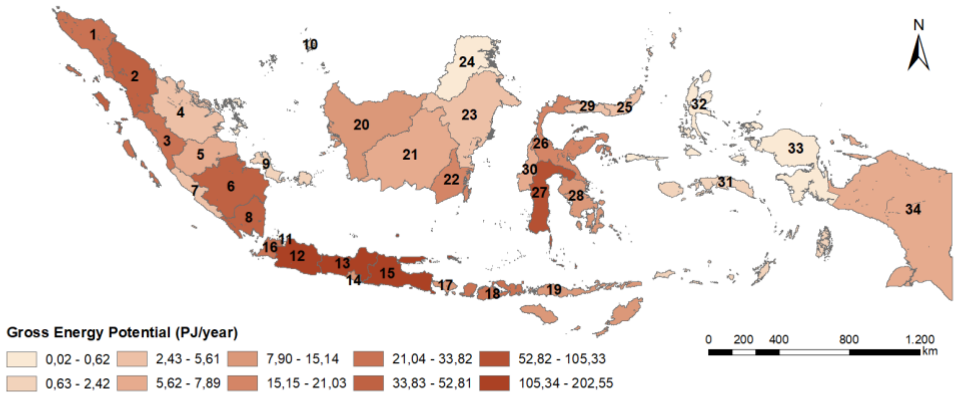

Fig. 4. Spatial map of the gross energy potential of rice waste

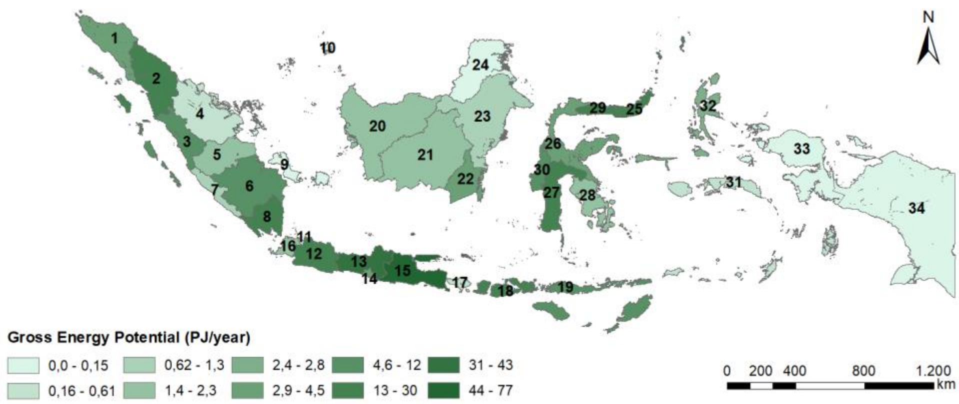

Fig. 5. Spatial map of the gross energy potential of corn waste

Like the GEP of rice waste, cassava waste is also the most abundant on the island of Java. Figure 6 shows the GEP distribution of cassava waste. However, the province with the highest GEP of cassava waste is Lampung, which was 31.97 PJ/year. Next is Central Java with a GEP of 15.63 PJ/year, East Java with a GEP of 12.21 PJ/year, and West Java with a GEP of 7.82 PJ/year. Other provinces only had GEPs below 5 PJ/year.

Based on the results of this study, peanuts and soybeans are not the main commodities in Indonesia. The GEP distribution of peanut and soybean wastes are shown in Fig. 7 and Fig. 8. Only three provinces widely cultivate peanuts, namely East Java, Yogyakarta, and Central Java. The GEP from peanut waste from the three provinces was 3.56 PJ/year, 2.55 PJ/year, and 2.24 PJ/year, respectively. Other provinces had GEP below 1 PJ/year. There are not many provinces that cultivate soybeans. Only four provinces have GEP of soybean waste above 1 PJ/year, namely East Java, West Java, Central Java, and West Nusa Tenggara.

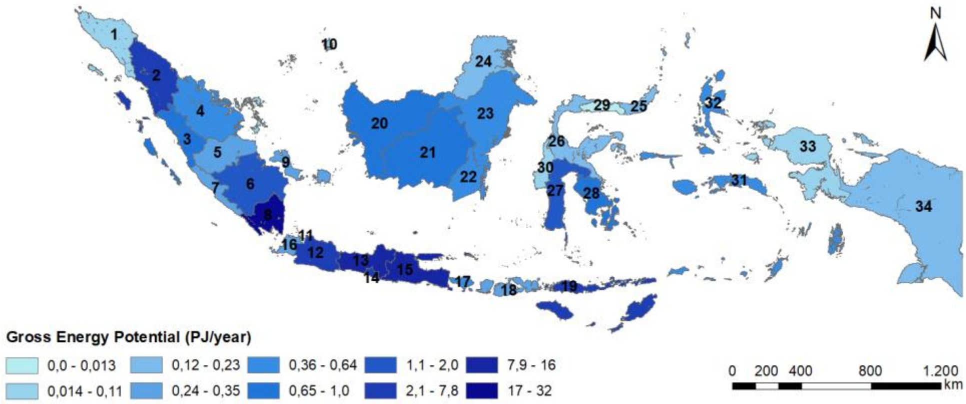

Fig. 6. Spatial map of the gross energy potential of cassava waste

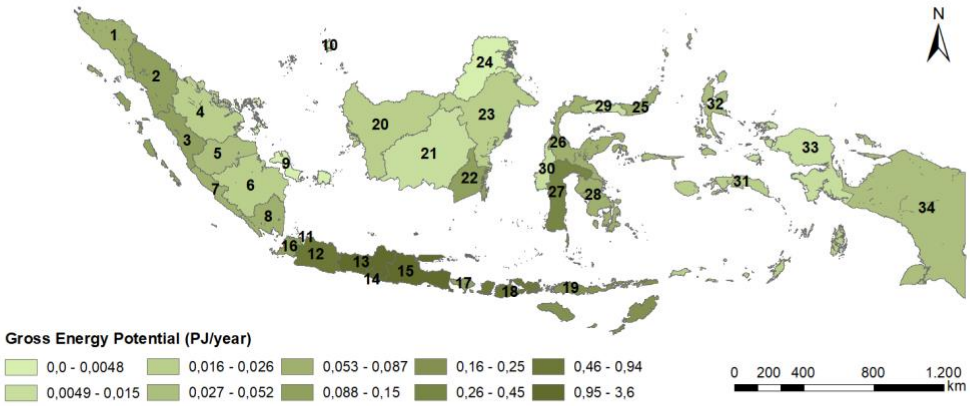

Fig. 7. Spatial map of the gross energy potential of peanut waste

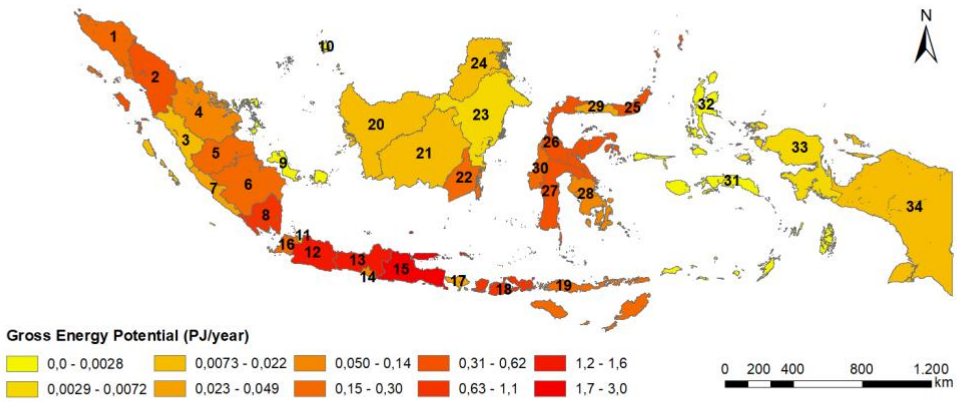

Fig. 8. Spatial map of the gross energy potential of soybean waste

4. Conclutions

This study investigated the physical, chemical, and thermal properties of food crop wastes. Analyzing the characterization of selected food crop wastes showed that rice husk had the lowest moisture content of 10.31 wt.% followed by corn stalk (10.36 wt.%) and cassava stem (10,52 wt.%). For ash content, the four lowest were corncob, corn husk, corn stalk, and soybean stem. Cassava stem had the highest fixed carbon of 17.12 wt.% while peanut stem had the lowest of 11.73 wt.%. Calorific value is an important parameter in selecting fuel. Based on the calorific value, cassava stem, which has characteristics similar to wood, is a potential candidate among the wastes for biofuel due to its high calorific value. Food crop waste has the advantages of low sulfur and nitrogen contents so that when combusted, it releases extremely low NOx and SOx. Moisture absorption of food crops waste is in the range of 10.3 % (rice husk) to 15.7 % (corn cob) of the initial mass. Rice is the principal food crop broadly planted in Indonesia. Indonesia produced about 115.73 million tons of food crop waste and 1596.12 PJ of GEP annually. Rice generated the largest amount of waste and GEP, followed by corn, cassava, peanut, and soybean. East Java Province has the largest amount of waste and GEP for almost all food crop waste.

Acknowledgement

The authors acknowledge the financial support provided by The Indonesia Ministry of Education, Culture, Research, and Technology on this study.

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