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Biomass Potential from Agricultural Residues in Indonesia

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ABSTRACT

Biomass can serve as an alternative to fossil fuels, which cause significant harm to the environment and human health. As an agricultural country, Indonesia has substantial biomass energy potential. This study aimed to estimate the biomass potential derived from major food and plantation crops over the past five years and present its distribution map across the country's 38 provinces. Residues from paddy, corn, sugarcane, coconut, and oil palm were considered. The estimation of biomass potential from agricultural residues was calculated based on the average–2020-2024 production data of related crops using equations from previous studies. As a result of the study, the total available agricultural biomass residue potential (ABP) from these five crops residues was calculated to be 55.79 million tons, with a total heating value (THV) of approximately 857.44 PJ. The biomass potential from paddy, corn, and oil palm residues holds the highest value, approximately 98.23% (842.31 PJ) of the total estimated biomass potential. Among food crops, provinces with the highest biomass potential from paddy residues are East Java, Central Java, and West Java, while from corn residues, East Java and Central Java are prominent. For plantation crops, East Java and Lampung lead in biomass potential from sugarcane residues, Riau and North Sulawesi from coconut residues, and Riau, Central Kalimantan, and West Kalimantan from oil palm residues. This study is expected to contribute to the development of biomass energy utilization from agricultural residues in each province in Indonesia, and enhancing biomass availability could further promote sustainable agriculture and energy management in Indonesia.

Keywords:
Agricultural residue; biomass; renewable energy; Indonesia.

1. Introduction

Biomass is a renewable energy resource available worldwide and can be derived from various organic wastes and materials (Tun et al., 2023). The major sources of biomass include agricultural and forestry residues, animal waste, sewage, algae, and aquatic plants. As biomass originates from biogenic sources, the CO_2 released during its combustion and utilization does not contribute to an increase in atmospheric carbon dioxide, making it completely renewable. Brás et al. (2025) evaluated the environmental impact of using wood-based biomass as an alternative to fossil fuels and found that biomass utilization reduces greenhouse gas emissions and fossil resource depletion.

Therefore, biomass can serve as a sustainable alternative to fossil fuels, which have severe effects on both the environment and human health (Tursi, 2019).

As an agricultural country and one of the largest countries in the world, Indonesia has significant energy potential from its biomass resources (Dani and Wibawa, 2018; KESDM, 2024). In 2018, Indonesia had approximately 48.96% forest area and 31.77% agricultural area. Given that biomass has great potential as a feedstock for sustainable energy, there are large amounts of agricultural residues that can be converted into heat and electricity (Mahidin et al., 2020; Rhofita et al., 2022, Primadanty, 2023). Energy consumption in Indonesia, like in other countries, is increasing rapidly in parallel with population growth, economic growth, and technological development (Dani and Wibawa, 2018). Biomass can be a solution as a renewable energy source for non-renewable energy sources and the problems they create (Rhofia et al., 2022).

It is estimated that the theoretical potential for renewable energy-based power plants in Indonesia is 3.6 TW, but the utilization has only reached approximately 0.4% of the total potential of existing renewable energy. Included in this big potential, Indonesia has a bioenergy or biomass potential of 57 GW. This large potential is not proportional to the installed capacity of 3668.7 MW or 6.44 percent of it (KESDM, 2025). This low realization of the predicted biomass potential has also been observed in previous years (Budhijanto et al., 2019).

In 2023, 2.55% of Indonesia's total primary energy production was from biomass, amounting to 612.28 PJ. In terms of consumption, biomass accounts for 2.45% of Indonesia’s final energy consumption (BPS, 2024). These numbers can be increased by maximizing the utilization of biomass in Indonesia as an energy resource, which can be converted through various conversion methods (Mahidin et al., 2020; Fitri et al., 2023). Biomass residues in Indonesia can be categorized into five groups: agricultural, forest, animal, aquatic, and urban waste (Rhofita et al., 2022). In this study, we assessed the biomass potential derived from agricultural residues in Indonesia.

Understanding the current biomass energy potential and its spatial distribution is crucial. Several studies have estimated Indonesia’s biomass potential from agricultural residues using various methods. Reported values include 302 PJ year^{-1} (Abdullah, 2002), 441.1 PJ year^{-1} in 2007 and 614.6 PJ year^{-1} in 2010 (Prastowo, 2007; Prastowo, 2011), 896.9 PJ or approximately 249.1 million MWh (Febijanto, 2007), 35.6 GW based on 2004-2009 production data (Pranoto et al., 2013), 857 PJ year^{-1} in 2018 (Hidayati and Ekayuliana, 2022), and over 300 PJ for the 2011–2020 period (Rhofita et al., 2022).

This study aimed to estimate the biomass potential from agricultural residues as energy resources, especially for the main commodities of food and plantation crops in Indonesia over the last five years. It also aims to present a spatial distribution map of the calculated potentials across provinces. Therefore, farmers, future researchers, and related stakeholders can determine the yield of abundant agricultural residues and the number of bioenergy estimations per province. The surplus residue of agricultural products can be considered not only for animal feed but also for energy resources (Fitri et al., 2023). The results of this study can be used as a reference for waste management and biomass utilization assessments and can be beneficial for governments and stakeholders to take action in developing and maximizing the use of biomass energy in Indonesia on a larger scale.

2. Materials and Methods

2.1 Research setting

Indonesia is located between the latitudes of 6˚ north and 11˚ South, and the longitudes of 95˚ to 141˚ East. Geographically, it lies between the continents of Asia and Australia and between the Indian Ocean and the Pacific Ocean (Figure 1).

Figure 1. Map of Indonesia and its provinces (Yug, 2022)

The country consists of 38 provinces and includes a total of 17,001 islands, with five major islands: Sumatera, Jawa, Kalimantan, Sulawesi, and Papua. The land area measures 1,892,410.09 km², which constitutes 34.8% of the total area, while the maritime area covers 3,544,743.9 km², making up 65.2% of the total area. Indonesia spans an area of 5,437,153 km² (Baiquni et al., 2020; BPS, 2023a).

2.2 Materials and equipment

Table 1. Agricultural residue properties

Agriculture Subsector	Agricultural Product	Residue	Harvested Area (thousand ha)	AAP (ton)	RPR	MC (%)	A (%)	LHV (MJ kg^{-1})
Food Crops	Paddy	Straw	10,356	54,187,439	1.11	12.50	55.00	15.04
		Husk			0.23	11.45	55.00	16.42
	Corn	Cob	2,491	14,556,896	0.57	8.20	40.00	15.50
		Stalk			2.14	15.90	40.00	17.00
Plantation Crops	Sugarcane	Bagasse	473	2,330,290	0.31	25.00	35.00	14.29
		Top and leave			0.19	56.50	50.00	13.41
	Coconut	Shell	3,344	2,838,086	0.21	12.00	30.00	18.32
		Husk			0.42	10.50	50.00	15.47
	Oil Palm	Empty fruit brunch	15,360	47,179,760	0.30	11.41	30.00	11.58
		Shell			0.06	11.50	30.00	17.87
		Fiber			0.14	11.50	30.00	14.21

Source: Rhofita et al., 2022; BPS, 2025a; BPS, 2025b; BPS, 2025c; BPS, 2025d; BPS, 2026.

In this study, several important crops with high production volumes and significant potential for energy recovery from residues in Indonesia were considered. These include paddy (rice) and corn among food crops, as well as sugarcane, coconut, and oil palm among the plantation crops. These types of crops are crops have a fixed area and are produced every year in Indonesia; therefore, they are included in most related studies or government reports as a strategic consideration. (KESDM, 2025).

The data used for calculating biomass potential in Indonesia were collected from various sources and literature (Table 1). To reduce the influence of short-term fluctuations, the average production data for 2020-2024 were used for each commodity and province, and the harvested area was shown as an average. These data were collected from Statistics Indonesia, while other specifications of related commodities were collected from the literature. The availability factor of each commodity was taken from the study by Rhofia et al. (2022), which resulted from estimation in the fields with random sampling and was assumed to be uniform across all provinces.

2.3 Research methodology

Several methods have been used to calculate the biomass potential from agricultural residues (Prastowo, 2011; Karaca et al., 2017; Mboumboue and Njomo, 2018; Di Fraia et al., 2020; Polat, 2020; Hidayati and Ekayuliana, 2022; Rhofita et al., 2022; Fitri et al., 2023). In this study, the biomass potential of Indonesia from agricultural residues was estimated using the following sequence of equations (Di Fraia et al., 2020; Rhofita et al., 2022; Fitri et al., 2023).

First, the theoretical biomass residue potential (TBP) was calculated as follows:

$$TBP = AAP \times RPR \times (1 - MC) \tag{1}$$

Where TBP represents the total amount of residue in dry conditions (tons), AAP is the amount of agricultural production (tons) averaged over 2020–2024, RPR is the residue-to-product ratio, and MC is the moisture content of the agricultural residue (%).

Next, the available biomass residue potential (ABP) was determined as follows:

$$ABP = TBP \times A \tag{2}$$

Where A percentage availability of the residue (%) and ABP is the available biomass residue potential measured in dry metric tons (tons). ABP represents the unutilized residue available specifically for bioenergy purposes after subtracting the amounts already designated for other competing uses (e.g., animal feed and fertilizer). In other words, ABP is the total amount of unused and completely wasted residue (Karaca et al., 2017; Rhofita et al., 2022; Fitri et al., 2023).

Finally, the theoretical energy potential of the residue was calculated as follows:

$$THV = ABP \times LHV \tag{3}$$

Where THV is the total heating value (GJ), and LHV is the lower heating value of the biomass residue on a dry basis (MJ kg^{-1}). Thus, the THV represents the cumulative macro-energy potential derived from the evaluated agricultural crop residues.

2.4 Observation parameters

These calculations were performed for each agricultural residue from each commodity. The total biomass potential from agricultural residues in Indonesia was determined by summing all the results. To assess inter-annual variability, the standard deviation (SD) and coefficient of variation (CV) of the national total biomass potential were calculated across the five-year period.

Using the average production data for 2020–2024, the biomass potential of each crop residue was calculated for the 38 provinces in Indonesia. The total biomass potentials were then summarized in tabular format and visually mapped as spatial distributions using the Datawrapper platform (https://www. datawrapper. de/).

3. Results and Discussion

Paddy, corn, and oil palm are the agricultural products with the highest production in Indonesia. Coconut and sugarcane are other products taken into account in this study. The total available agricultural biomass residue potential in Indonesia for the average production from 2020-2024 production was calculated at approximately 55.79 million tons. The utilization of agricultural residues for animal feed, fertilizer, and other purposes was considered when estimating this potential. After all estimations, the total heating value of the agricultural residues was approximately 857.44 PJ. The heating values of the agricultural residues for each product are listed in Table 2. These results are in line with earlier studies, with slight variations attributed to the year of production taken into account, the type of crops included, and the calculation methods applied.

Table 2. TBP, ABP and THV of agricultural residues

Agriculture Subsector	Agricultural Product	Residue	TBP (ton)	ABP (ton)	THV (GJ)	THV (PJ)
Food Crops	Paddy	Straw	52,629,549.80	28,946,252.39	435,351,635.93	435.35
		Husk	11,036,084.69	6,069,846.58	99,666,880.88	99.67
	Corn	Cob	7,617,041.36	3,046,816.55	47,225,656.46	47.23
		Stalk	26,198,627.88	10,479,451.15	178,150,669.59	178.15
Plantation Crops	Sugarcane	Bagasse	541,792.43	189,627.35	2,709,774.81	2.71
		Top and leave	192,598.47	96,299.23	1,291,372.73	1.29
	Coconut	Shell	524,478.29	157,343.49	2,882,532.70	2.88
		Husk	1,066,836.53	533,418.26	8,251,980.54	8.25
	Oil Palm	Empty fruit brunch	12,538,964.82	3,761,689.44	43,560,363.77	43.56
		Shell	2,505,245.26	751,573.58	13,430,619.82	13.43
		Fiber	5,845,572.26	1,753,671.68	24,919,674.56	24.92
Total			**120,696,791.79**	**55,785,989.70**	**857,441,161.79**	**857.44**

Note: TBP= theoretical biomass residue potential, ABP= available biomass residue potential, THV= theoretical energy potential (total heating value)

Paddy (62.40%), corn (26.28%), and oil palm (9.55%) are the agricultural products with the highest potential for biomass production from their residues (Figure 2). The estimated biomass energy potential of 98.23 % (842.31 PJ) in Indonesia was produced only from the residues of these three products.

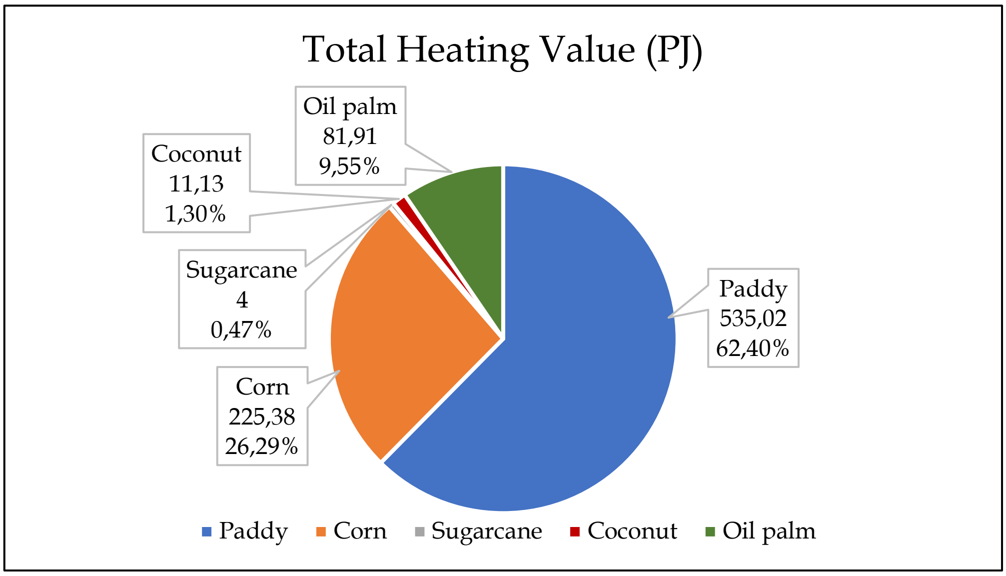

Figure 2. Distribution of total heating value for each agricultural product (PJ)

The national total biomass potential was also calculated for each year from 2020 to 2024. The five-year data in Table 3 show that Indonesia's biomass energy potential is relatively constant, with THV values varying only modestly between 838.29 and 893.10 PJ. The average potential of 857.44 ± 21.94 PJ and a CV of 2.6% confirmed that annual variations were minor. This stability indicates that biomass resources can reliably contribute to national renewable energy planning.

Table 3. Total biomass energy potential (THV) in Indonesia, 2020–2024

Year	THV (PJ)
2020	838.29
2021	840.56
2022	893.10
2023	858.43
2024	856.82
Mean ± SD	**857.44 ± 21.94**
Min – Max	**838.29 – 893.10**
CV (%)	**2.6%**

Note: CV= coefficient of variation, SD= standard deviation, THV (PJ)= theoretical energy potential (total heating value)

The biomass energy potential from agricultural residues in each province in Indonesia is presented in Table 4. From food crops, the provinces with the highest biomass potential from paddy residues are East Java, Central Java, and West Java. The use of paddy straws and husks as fuel substitutes has been implemented at the household scale in villages by combustion or gasification processes. Other conversion methods, such as

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pyrolysis and anaerobic digestion, have also been used. In addition to direct energy conversion, it is also used for briquettes and animal feed (Febijanto, 2007; Chandra et al., 2025; Priscillia et al., 2025; Susana et al., 2025).

Table 4. Biomass energy potential (THV) of 38 provinces in Indonesia

Province	THV (PJ)						
	Paddy	**Corn**	**Sugarcane**	**Coconut**	**Oil Palm**	**Total**	**%**
Aceh	15.73	0.97	0.00	0.25	1.83	18.78	2.19
North Sumatera	20.59	17.85	0.03	0.40	9.10	47.97	5.59
West Sumatera	13.66	7.57	0.00	0.31	2.38	23.92	2.79
Riau	2.18	0.01	0.00	1.59	15.95	19.74	2.30
Jambi	3.00	0.13	0.00	0.45	4.36	7.94	0.93
South Sumatera	27.28	4.99	0.18	0.23	6.75	39.43	4.60
Bengkulu	2.77	0.76	0.00	0.03	2.16	5.72	0.67
Lampung	26.41	17.82	1.22	0.32	0.76	46.54	5.43
Bangka Belitung Islands	0.66	0.00	0.00	0.02	1.49	2.17	0.25
Riau Islands	0.01	0.00	0.00	0.05	0.03	0.09	0.01
DKI Jakarta	0.03	0.00	0.00	0.00	0.00	0.03	0.00
West Java	89.51	8.60	0.08	0.34	0.06	98.61	11.50
Central Java	91.70	35.40	0.35	0.63	0.00	128.09	14.94
DI Yogyakarta	5.19	3.07	0.01	0.19	0.00	8.47	0.99
East Java	95.26	69.58	1.92	0.91	0.00	167.68	19.56
Banten	16.36	0.21	0.00	0.18	0.05	16.79	1.96
Bali	6.20	0.69	0.00	0.26	0.00	7.16	0.83
West Nusa Tenggara	14.18	17.94	0.02	0.19	0.00	32.33	3.77
East Nusa Tenggara	7.28	4.30	0.01	0.26	0.00	11.85	1.38
West Kalimantan	7.28	0.91	0.00	0.31	9.40	17.90	2.09
Central Kalimantan	3.71	0.53	0.00	0.06	14.44	18.75	2.19
South Kalimantan	9.66	2.05	0.00	0.09	2.36	14.16	1.65
East Kalimantan	2.42	0.18	0.00	0.04	6.78	9.42	1.10
North Kalimantan	0.29	0.01	0.00	0.00	0.93	1.24	0.14
North Sulawesi	2.44	2.03	0.00	1.04	0.00	5.52	0.64
Central Sulawesi	7.87	1.19	0.00	0.78	0.73	10.57	1.23
South Sulawesi	49.08	16.81	0.06	0.26	0.20	66.42	7.75
Southeast Sulawesi	5.09	1.25	0.02	0.17	0.12	6.65	0.78
Gorontalo	2.35	9.59	0.09	0.25	0.03	12.31	1.44
West Sulawesi	3.20	0.34	0.00	0.15	0.63	4.31	0.50
Maluku	0.97	0.19	0.00	0.42	0.04	1.61	0.19
North Maluku	0.30	0.10	0.00	0.81	0.02	1.24	0.14
West Papua	0.23	0.07	0.00	0.04	0.14	0.49	0.06
Southwest Papua	0.01	0.01	0.00	0.02	0.02	0.06	0.01
Papua	1.29	0.15	0.00	0.05	0.95	2.44	0.28
South Papua	0.79	0.01	0.00	0.01	0.17	0.97	0.11
Central Papua	0.03	0.04	0.00	0.00	0.01	0.09	0.01
Papua Mountains	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	**535.02**	**225.38**	**4.00**	**11.13**	**81.91**	**857.44**	**100.00**

Note: THV (PJ)= theoretical energy potential (total heating value)

The highest biomass potential from corn residues is in the provinces of East and Central Java. In Indonesia, corn residues such as cobs and stalks are generally used as animal feed, for activated carbon, or are simply burned. Recently, these residues have also been utilized by state-owned enterprises as biomass fuel in co-firing systems at coal-fired power plants, where they are subjected to combustion with coal to produce steam that drives steam turbine generators for electricity production. In addition, other applications of corn cob residues are being developed, such as for the production of briquettes and compressed biogas (CBG) (Febijanto, 2007; Setiapraja et al., 2023; MTA et al., 2024; Ariwibawa and Brunner, 2025; Muflih et al., 2025).

While from plantation crops, provinces with highest biomass potential from sugarcane residues are East Java and Lampung. In almost all sugar factories in Indonesia, bagasse residues are utilized through the combustion process as boiler fuel to generate steam for sugar milling operations and produce electricity that supplies the factory and nearby residential areas (Febijanto, 2007; Adi, 2025).

Riau and North Sulawesi are the provinces with the highest biomass potential from coconut residues. In Indonesia, coconut shells and husks are used as raw materials for activated carbon, briquette production, car seats, and household appliances. The utilization of coconut shells as a substitute fuel for petroleum is generally practiced on a small or household scale in the Philippines. Large-scale collection poses challenges due to the scattered distribution and limited residue quantity (23% of the amount produced per tree), resulting in difficulties in collection and increased transportation costs (Febijanto, 2007; Setiapraja et al., 2023; Yunus et al., 2025).

The provinces with the highest biomass potential from oil palm residues are Riau, Central Kalimantan, and West Kalimantan. Most palm oil mills in Indonesia utilize oil palm residues, mainly shells and fibers, as boiler fuel through combustion to produce steam for crude palm oil (CPO) processing and to drive steam turbine generators for electricity production. The generated electricity primarily supplies the energy needs of the mills and nearby plantation housing, while the sale of surplus power to the electricity company remains limited (Febijanto, 2007). Oil palm residues may also be utilized for activated carbon, while energy production through pyrolysis is being developed (Setiapraja et al., 2023; Septia et al., 2025).

Figure 3. The distribution map of biomass potential from agricultural residues in Indonesia

Provincial biomass potential values were classified into five ranges (0–2.00, 2.01–10, 10.01–40.00, 40.01–100.00, and >100.00 PJ) to represent very low to very high categories. This classification was designed to reflect the uneven distribution of biomass resources among Indonesian provinces.

East Java (19.56%), Central Java (14.94%), West Java (11.50%), South Sulawesi (7.75%), North Sumatera (5.59%), and Lampung (5.43%) are the provinces with highest proportion of biomass energy potential from agricultural residues above 40 PJ, classified as high and very high. In these six provinces, most of the available agricultural residues are from paddy and corn. The distribution map of biomass potential in Indonesia, visualized using the Datawrapper platform, is shown in Figure 3.

Some challenges that potentially limit the utilization of this huge biomass potential in Indonesia are supply security, lack of capacity of the biomass industry, price policy, cost-related issues, land fragmentation (more than 70% of agricultural land in Indonesia is less than 1 ha), logistic management, and the lack of government incentives (ERIA, 2022; BPS, 2023b).

4. Conclusion

This study aimed to estimate the biomass energy potential of agricultural residues in Indonesia and map their spatial distribution across 38 provinces in Indonesia. Using 2020–2024 agricultural production data, the theoretical biomass residue potential (TBP), available biomass residue potential (ABP), and total heating value (THV) were calculated for five strategic crops: paddy, corn, sugarcane, coconut, and oil palm.

The results demonstrate that Indonesia has a massive and stable agricultural biomass resource, with approximately 55.79 million tons of available biomass residue, yielding a total heating value (THV) of approximately 857.44 PJ. Paddy (62.40%), corn (26.28%), and oil palm (9.55%) constitute the vast majority of this energy. Furthermore, analysis of the five-year period confirmed that this resource is highly stable with minor annual variations; the national THV exhibited a low coefficient of variation (2.6%) with a mean of 857.44 ± 21.94 PJ. This stability indicates that agricultural residues can provide a consistent and reliable contribution to national renewable energy planning.

However, this potential is not evenly distributed across the country. East Java, Central Java, West Java, South Sulawesi, North Sumatra, and Lampung are provinces demonstrated highest biomass potential. Each of these regions generates over 40 PJ of energy potential, driven mostly by abundant paddy and corn residues. As a result, these provinces are the most practical targets for initial bioenergy investments and infrastructure development.

Despite Indonesia's enormous biomass potential, its actual utilization is currently limited by real-world bottlenecks in supply security, logistics, industry capacity, land fragmentation, and economic policies. The spatial maps and calculations produced in this study provide a foundational reference for policymakers and stakeholders to address these gaps, ultimately contributing to Indonesia’s renewable energy transition and rural development. Future research should focus on optimizing the associated collection and local supply chain logistics, as well as identifying the most efficient conversion technologies for specific residues in potential provinces.

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