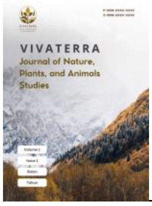

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Biomass Energy Potential from Agricultural Waste in Indonesia: A Review of National Statistical Data

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Abstract

Indonesia possesses vast potential for biomass energy derived from agricultural and plantation residues. This study explores the availability and prospective utilization of biomass from rice cultivation, other staple food crops, and palm oil plantations as alternative energy sources. National rice production in 2024 reached 53.14 million tons of milled dry grain (GKG), with an estimated 63 million tons of rice straw generated annually, equivalent to several hundred petajoules of theoretical energy potential. Other food crops such as maize, sugarcane, and soybean also contribute significant volumes of agricultural residues that could expand the national biomass supply. In addition to food crops, oil palm plantations represent the largest and most consistent contributor to biomass in Indonesia. Provinces such as Riau, Central Kalimantan, and North Sumatra produced millions of tons of fresh fruit bunches (FFB), generating residues including empty fruit bunches (EFB), mesocarp fiber, shell, and palm oil mill effluent (POME). These residues contain high calorific values, offering opportunities for energy generation through direct combustion, co-firing, and gasification technologies. Nevertheless, challenges remain in terms of high moisture content, distribution costs, and technological readiness. With proper policy support, fiscal incentives, and integrated management between agriculture and energy sectors, biomass from food crops and oil palm residues can play a crucial role in advancing Indonesia's renewable energy transition.

Keywords: biomass energy, agricultural residues, rice straw, oil palm waste, renewable energy.

INTRODUCTION

National energy demand continues to grow in line with Indonesia's population growth and economic development (Wijayanti, 2023). For decades, primary energy consumption has been dominated by oil, gas, and coal, which account for more than 85% of the national energy mix. This dependence on fossil fuels poses serious problems in the form of carbon emissions that exacerbate climate change, vulnerability to global price fluctuations, and the threat of declining fossil fuel reserves in the long term (ESDM, 2022). The Indonesian government, through the National Energy Policy (KEN), targets a share of new and renewable energy (EBT) of 23% by 2025 and 31% by 2050. However, the realization of renewable energy mix to date is still below 15%, which means that there is still a large gap that must be filled by utilizing alternative energy potential, including biomass (Siagian & Haykal, 2024).

As an agricultural country, Indonesia has great opportunities in the provision of biomass sourced from agricultural waste (Rhofita, 2022), (Elizabeth & Anugrah, 2020), (Prawitasari, 2025). Agricultural production waste generally consists of straw, husks, stalks, or other plant residues that are usually discarded or burned on the land (Gupta et al, 2023). In fact, these residues have significant energy potential if converted through direct combustion, gasification, or fermentation into bioenergy (Thaha, 2021). The utilization of agricultural waste not only reduces environmental pollution caused by open burning, but also adds economic value and provides a cleaner renewable energy source (Saleem, 2022), (Ufitikirezi, 2024), (Ribeiro, & Junior, 2023). With agricultural land covering tens of millions of hectares, the potential for agricultural biomass in Indonesia is believed to be enormous.

Rice production as a national strategic commodity provides a clear picture of the availability of biomass waste. Based on data from the Agricultural Statistics Agency (BDSP), national milled dry grain

(GKG) production reached 59.2 million tons in 2018, decreased to 54.6 million tons in 2019, remained relatively stable at around 54.4–54.7 million tons in the 2020–2022 period, then dropped to 53.9 million tons in 2023 and 52.7 million tons in 2024. These figures show a downward trend of around 6 million tons in the last six years. Assuming that each ton of grain produces 1–1.5 tons of straw, the potential for national straw waste could reach more than 50 million tons per year. If the average calorific value of straw is around 12–14 MJ/kg, then the energy stored in national straw reaches more than 600 PJ per year (BPS, 2025).

Palm oil is also a leading plantation commodity that produces a very large amount of biomass waste (Jafri et al., 2021). Indonesian Palm Oil Statistics 2023 recorded that national fresh fruit bunch (FFB) production reached 200.7 million tons with crude palm oil (CPO) production of 48.17 million tons. The palm oil processing process produces various types of waste, such as empty palm fruit bunches (TKKS), mesocarp fiber, kernel shells, and palm oil mill effluent (POME) liquid waste. Based on the mass balance, each ton of FFB produces around 210 kg of TKKS, 144 kg of mesocarp fiber, 64 kg of kernel shells, and 583 kg of POME. Based on total FFB production, the volume of national palm oil biomass waste reaches more than 110 million tons per year, making it one of the largest sources of biomass in Indonesia (Aulia, 2024).

Estimates of the energy potential of palm oil waste further reinforce this enormous opportunity. Data from GAPKI and various studies estimate TKKS production in Indonesia at around 46.16 million tons, mesocarp fiber at 26–30 million tons, and kernel shells at 12–16 million tons per year. If the calorific value of palm oil biomass ranges from 17–19 MJ/kg, the energy contained in palm oil waste can reach more than 1,500 PJ per year. In addition to solid waste, POME, which is estimated to reach 130 million tons per year, has the potential to be processed through biogas technology to generate electricity or heat energy. Thus, palm oil waste has not only solid biomass energy potential but also gas energy through the use of anaerobic digestion (GAPKI, 2024).

Other commodities such as corn, sugarcane, soybeans, and rubber also contribute significant biomass potential. Corn production, which reaches more than 18 million tons per year, produces stalk and cob waste with a residue ratio of about 1:1, providing tens of millions of tons of additional biomass. Sugarcane plants produce bagasse or sugarcane pulp with high energy potential, while rubber plantations produce replanting rubber wood that can be used as raw material for energy and industry. Nationally, all types of agricultural waste add to the abundant amount of biomass available to support Indonesia's energy mix (Justianti, 2022).

The obstacles to utilizing agricultural waste as a source of biomass energy cannot be ignored. The high moisture content in some types of waste, such as TKKS or straw, results in low combustion efficiency if not dried or processed beforehand. The widespread distribution of waste in rural areas also poses logistical problems, transportation costs, and difficulties in consolidating large quantities of raw materials (Pratiwi, 2023). Technical factors such as calorific value, ash content, and conversion technology efficiency greatly determine how much actual energy can be utilized compared to theoretical potential, so that statistical data-based studies must be combined with technical parameters to produce realistic estimates.

National energy policy has begun to position biomass as one of the pillars of energy transition. The biomass co-firing program at coal-fired power plants, the development of biogas from palm oil and livestock waste, and the construction of biomass power plants (PLTBm) demonstrate concrete steps in this direction (Triani & Yunianto, 2024). However, implementation achievements in the field are still limited due to the lack of sustainable biomass supply, insufficient price incentives, and weak supply chain integration. In order to fully utilize the enormous potential of biomass from agricultural waste, a comprehensive analysis based on the latest national data is needed to map the potential, challenges, and utilization strategies in a more focused manner.

With this foundation, this study focuses on calculating the biomass energy potential from agricultural waste in Indonesia by utilizing available national statistical data and estimating the energy capacity that can be realistically utilized. The results of this study are expected to bridge the gap between theoretical potential and practical implementation, provide an overview of the contribution of biomass to national renewable energy targets, and offer policy recommendations to support sustainable energy development in Indonesia.

RESEARCH METHOD

This research method uses a descriptive qualitative approach by utilizing secondary data from various official sources such as the Central Statistics Agency (BPS), the Ministry of Agriculture, the Ministry of Energy and Mineral Resources (KESDM), and international data from the FAO. Data collection techniques were carried out through documentation studies, literature reviews, and online data searches on official portals containing statistics on agricultural and plantation production in Indonesia. The data obtained was analyzed descriptively to identify the main types of agricultural waste with potential as biomass, interpret the amount of waste based on production volume, and assess the potential energy that can be generated by referring to previous studies on the calorific value of biomass and its conversion technology.

Data analysis was conducted using source triangulation techniques to ensure the validity of the information, namely by comparing figures and findings from various official publications and scientific literature (Regmi, 2024). The researcher acted as the main instrument in selecting, interpreting, and compiling narratives based on the theoretical framework of renewable energy and sustainable development. The study focused on the biomass potential of rice, palm oil, sugar cane, corn, and soybean waste, as well as its relevance to national renewable energy targets. The limitation of this study lies in its qualitative nature, so it does not precisely calculate quantitative estimates of the energy that can be produced, but rather emphasizes mapping the potential, opportunities, challenges, and relevance in the context of energy transition in Indonesia.

RESULTS AND DISCUSSION

Biomass Potential from Rice Waste and Other Food Commodities

National rice production is an important basis for estimating the potential biomass waste from the food sector. In 2024, Indonesia's rice harvest area will reach around 10.05 million hectares with a milled dry grain (GKG) production of 53.14 million tons. According to BDSP data, national rice production between 2018 and 2024 will range from ± 52.77 million to ± 59.20 million tons. Assuming that each ton of grain contains approximately 1.2 tons of straw (residue ratio ≈ 1.2), the theoretical rice straw waste will reach more than 63 million tons per year. The calorific value of rice straw is estimated to be in the range of 12–14 MJ/kg based on technical literature. With conservative assumptions and conversion efficiency, the energy potential from rice straw alone can contribute several hundred PJ per year on a national scale (BPS, 2025).

Other food commodities such as corn, soybeans, and sugarcane also contribute to a significant amount of agricultural waste. Indonesia's corn production has continued to increase, reaching more than 18 million tons per year in recent years (data from BPS/Kementan). Corn cobs and stalks can account for a residue ratio of approximately 1:1 to the grain harvest. For sugarcane, each ton of sugarcane produces bagasse with a residue ratio of approximately 0.25–0.32 tons per ton of sugarcane, although high moisture content reduces its effective calorific value. Soybean waste in the form of post-harvest stalks or rapa can also be processed into biomass, although the volume is smaller than corn or rice. By combining all of this food waste, the biomass potential of the national food sector can be expanded beyond just rice straw.

Table 1. Rice Harvest Area, Production, and Productivity by Province (2024)

Province	Harvest Area (Ha)	Production (Ton, GKG)	Productivity (Kw/Ha)
Central Java	1,603,571	9,623,625	60.02
East Java	1,494,231	9,286,823	62.14
West Java	1,322,106	8,017,586	60.65
South Sulawesi	1,014,307	5,592,537	55.16
South Sumatra	516,342	2,731,458	52.90
Indonesia	**10,055,000**	**53,140,000**	**59.40**

Source: BPS, 2025

The table data shows that rice production is concentrated in Java and Sulawesi, which automatically become the main centers for rice straw waste availability. With a straw residue ratio of around 1.2 times the weight of grain, Central Java alone can produce nearly 11.5 million tons of straw per year. The energy potential contained in this amount can support the biomass supply for local power plants.

Although the theoretical potential is enormous, there are factors that limit the realization of biomass energy from food waste. The moisture content of waste, especially rice straw and bagasse, is often high (e.g., above 15–20%), requiring a drying process beforehand. The drying process consumes energy and reduces net efficiency. The distribution and consolidation of waste from scattered rice fields also requires significant logistics costs, especially in remote areas. Conversion technologies (e.g., solid combustion, gasification, thermochemical melting) have varying efficiencies depending on the quality of the biomass, so estimates of energy potential in the food sector must be given a technical correction factor to avoid being overly optimistic.

Inequality in food production between provinces also affects local biomass potential. For example, provinces that consistently contribute large rice production, such as Central Java, West Java, and South Sulawesi, will be sources of relatively accessible straw waste. Meanwhile, areas outside Java with lower production face distribution challenges. Data on "Rice Harvest Area, Production, and Productivity by Province in 2024" shows the main provinces as contributors to national rice production. Therefore, spatial mapping of biomass is necessary so that regional estimates are more realistic than simply calculating national aggregates.

The contribution of food biomass needs to be compared with renewable energy targets. For example, if Indonesia's total primary energy consumption is in the range of thousands of PJ per year, the potential of food biomass contributing several hundred PJ is still a moderate proportion but not insignificant. Policies need to be directed so that the use of food waste as an energy source does not compete directly with the need for organic fertilizers or other uses in agriculture. Then, priority use should be directed to areas close to energy consumption centers or electricity infrastructure so that energy transportation does not incur high costs.

Policy analysis and fiscal incentives are also important in the context of food biomass. The government can encourage biomass absorption contracts from farmers, subsidies for drying or processing facilities at the village level, and support research into efficient conversion technologies. Several local studies have shown that rice co-firing programs can be integrated into small coal-fired power plants in provinces with high rice production. However, there have not been many measurable pilot projects at the provincial level. Cross-sectoral understanding (agriculture–energy) needs to be strengthened so that this potential can be realized and not just remain on paper.

Sustainability aspects must be considered so that the utilization of food waste does not interfere with soil quality or the local carbon cycle. If all straw is removed, the organic content of the soil may decrease, so a mechanism for limited residue removal is needed. Rotation, soil conservation, and integrated farming must be maintained. Thus, the interpretation of biomass potential in the food sub-discussion must include ecological balance. This sub-discussion shows that food waste such as rice straw and corn/sugarcane residues has significant biomass potential when mapped based on national production data. However, technical, logistical, conversion, and sustainability factors limit the realization of this potential. For robust research results, production tables and residue potential as well as calorific values need to be elaborated in the quantitative chapter later so that the final figures are valid and can be compared between commodities.

Biomass Potential from Palm Oil Plantation Waste

Oil palm is a plantation commodity that produces large amounts of biomass waste on a continuous basis. In the 2023 Oil Palm Statistics, BPS recorded detailed data on oil palm area and production by province. In 2023, the national oil palm plantation area reached tens of millions of hectares and fresh fruit bunch (FFB) production was at the level of tens of millions of tons. This data shows that oil palm plantations are one of the largest contributors to solid biomass waste in Indonesia. These statistics are important so that estimates of the biomass potential of palm oil waste are not based solely on assumptions in the literature.

The area of Indonesian oil palm plantations has grown significantly in recent decades (Kurniadinata & Rahman, 2025). According to research (Hasan et al., 2023), in one decade the area of oil palm plantations grew by around 56%, from around 14.33 million hectares in 2018 to a larger area in 2023. With this expansion, the supply of solid waste such as empty fruit bunches (EFB), mesocarp fiber, and shells has increased proportionally. Liquid waste (POME) has also increased in line with TBS production capacity. Thus, the potential energy scale of palm oil waste can far exceed that of food commodities.

According to the palm oil industry mass balance, each ton of fresh fruit bunches (FFB) produces solid residues such as TKKS (± 210 kg), mesocarp fiber (± 144 kg), and kernel shells (± 64 kg), as well as approximately 583 kg of POME liquid waste. (These balance figures are widely used in palm oil biomass studies). If national FFB production is around 200 million tons (for example), then solid waste can exceed 40 million tons. The 2024 Palm Oil Plantation Commodity Outlook publication records palm oil production and area as the basis for calculating residues. The energy potential of solid palm oil waste is very high because the calorific value of solid residues is in the range of 17–19 MJ/kg (PDSIP, 2024).

The following narrative table illustrates palm oil production per major province as the basis for waste estimation:

Table 2. Palm Oil Production by Province (Thousand Tons, 2023–2024)

Province	Production (Thousand Tons)
Riau	9,367.6
Central Kalimantan	8,473.3
West Kalimantan	5,437.4
North Sumatra	5,057.2
South Sumatra	3,951.4

Source: kabarsawitindonesia.com

With production in these core provinces, the development of local palm oil waste can be centralized to minimize transportation costs and maximize energy gains. Despite its great potential, technical and operational barriers are also significant in the utilization of palm oil waste. TKKS generally has a high moisture content (65% or more), requiring drying or pre-processing before combustion. The drying process requires additional energy and can affect net efficiency. The distribution and storage of large amounts of solid waste is also difficult, especially in remote areas of Kalimantan or Papua. In addition, the consistency of the waste supply must be ensured so that biomass facilities obtain stable raw material quality throughout the year (Meliana et al., 2023).

Solid biomass conversion technologies from palm oil waste include direct combustion and gasification. Modern combustion efficiency can reach 70–85% under ideal conditions. Gasification technology has the potential to produce synthesis gas (syngas), which is more flexible in its use. However, implementation in Indonesia is still limited to pilot scale. Energetic estimates based on this technology must take into account heat loss and auxiliary fuel during start-up (Zahro et al., 2023).

Government policies related to biodiesel, biomass co-firing, and the use of palm oil waste in power plants present strategic opportunities. A program for co-firing coal with biomass (palm oil waste mixture) has been proposed as a transition for medium-scale coal-fired power plants. If supported by price incentive regulations and drying subsidies, investment in palm oil biomass power plants could become attractive. However, implementation must consider environmental sustainability and land conflict aspects (Rimbawati, 2025).

Oil palm plantation waste offers much greater biomass potential than many food commodities, especially if oil palm production remains consistently high in core provinces. However, realizing this potential requires addressing technical, logistical, technological, policy, and sustainability aspects to make the use of palm oil waste as an energy source feasible on a national scale.

CONCLUSION

The biomass potential of Indonesia's food agriculture and plantation sectors is enormous, judging from available national production data. Rice production, which reaches more than 53 million tons of milled dry grain per year, generates more than 63 million tons of straw waste, which theoretically can contribute hundreds of petajoules of energy. In addition to rice, other food commodities such as corn, sugarcane, and soybeans also produce significant amounts of biomass residues, which, if managed properly, can strengthen the contribution of agriculture-based renewable energy. However, technical factors such as high moisture content, logistics costs, and conversion technology efficiency remain major obstacles limiting the realization of this energy potential.

Palm oil plantation waste occupies a strategic position as the largest source of biomass in Indonesia, in line with the large area of plantations and high production of fresh fruit bunches in key provinces such as Riau, Central Kalimantan, and North Sumatra. Waste types such as empty fruit bunches, mesocarp fiber, kernel shells, and POME can be a source of energy with high calorific value if handled with the right pre-processing. Technical challenges, including high moisture content, distribution issues, and the need for modern processing technology, must be addressed through government policy support, investment incentives, and research into conversion technologies. Through integrated cross-sectoral management of agriculture and energy, the biomass potential from food crops and plantations can be developed as a key pillar of Indonesia's sustainable energy transition.

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