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RESEARCH ARTICLE

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Biomass potential from agricultural residues for energy utilization in West Nusa Tenggara (WNT), Indonesia

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Abstract

The West Nusa Tenggara (WNT) province is one of the regions that contribute the most to the production of rice, corn, and cacao. The residues of these crops increase as production increases. The potential availability of the residue was calculated on the basis of the amount of agricultural product and the availability of unutilized residues. The estimated potential energy and collected data were processed and combined with converted factors, such as the yield per hectare and the calorific value, taking into account another purpose, the use of domestic residues for animal feed. Paddy straw, corn straw, and corn cobs had the highest percentage of residue availabilities, 85.91%, 82.26%, and 88.25%, respectively. In addition, the WNT regency has a rich diversity of agricultural residues from superior commodities such as rice, corn, coffee, coconut and cacao. The calculation of the total heating value (THV) of the agricultural residue available reached up to 42.4 PJ. Furthermore, the use of biomass for bioenergy resources is promising, particularly for the WNT region, with the potential for unused agricultural residues. The dependence on unsustainable energy, such as coal and fossil fuel, can be reduced by deploying and developing energy production from biomass use. Therefore, the potential for bioenergy generation and the availability of biomass can be developed for sustainable agriculture and energy management.

KEYWORDS

agriculture, bioenergy potential, biomass, residue, sustainable, utilization

1 | INTRODUCTION

Indonesia is the largest country in Southeast Asia with a substantial agricultural sector, land, and abundant natural resources (Tun et al., 2023) and has a high potential for bioenergy sources (Mahidin et al., 2020). Agriculture is critical to economic development as a function of food suppliers and security. Biomass generation, particularly from agriculture, should cause the nation or investor to contribute and increase employment as an indicator of economic expansion (Tun et al., 2023). Without interrupting the food supply, the use of agricultural residues will be more economically profitable and helpful for environmental safety.

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The generation of energy from biomass is increasingly due to the availability of environmentally friendly and sustainable energy. Indonesia is one of the developing countries with abundant sources of agricultural waste that could be used as renewable energy (Tun et al., 2023). West Nusa Tenggara (WNT) is one of the potential regencies with renewable energy resources with a capacity equal to 20 GW, including hydro, solar, geothermal, wind, biomass, and waste resources (Tampubolon & Adiatma, 2019). Some of those resources had already been installed. Despite that, the WNT regency is mainly powered by fossil fuels for electricity generation and transportation (Islami et al., 2020), followed by coal (Danish Energy Agency, 2019). Furthermore, biomass conversion to produce energy through anaerobic processes uses primarily animal waste as feedstock instead of agricultural residues (Lantasi, 2021).

Based on data from Statistics Indonesia (Statistic Indonesia, 2021), the West Nusa Tenggara (WNT) province is listed as one of the regions that contribute the most to high rice and corn productivity in Indonesia. The residues of these crops increase as production increases. Agriculture production and residues increased as the rate of growth of agriculture in the WNT rapidly accelerated. After harvesting, only a few agricultural residues are used for animal feed (mostly in fresh/wet straws). The remaining agricultural residues tend to burn open or are left on the land (Khalil et al., 2019). The lack of waste management could have an impact on the environment as a potential pollutant. The high demand for waste management and energy encourages the development of a strategy in energy transition (Khalil et al., 2019) not only from animal waste but also from other sources, such as agricultural biomass waste. In addition, government policies and technology barriers become the main factor in waste management for the dissemination of energy, especially for biogas (Budiman, 2021).

Biomass from agro-waste consists of a lignocellulosic component (cellulose, hemicellulose, and lignin). Several studies have shown that the component of agro-waste has a very high potential for bioenergy generation through various conversion methods. Physically, chemically, and biological conversion methods have been studied and developed to improve strategic and management to efficiently transform agricultural waste into bioenergy (Aftab et al., 2019; Guan et al., 2018). The management of biomass from remaining agricultural residue would create environmental benefits with regard to the reduction of greenhouse gases. Despite all this time, farmers are still adopting the traditional way to accelerate the planting session by burning the waste after harvesting the plants. Households in southeast Asian countries use fuelwood and LPG for cooking and heating (Budiman, 2021). Additionally, the conversion of biomass to renewable energy establishes an alternative solution to the unrenewable energy. As Indonesians depend on coal, fossil fuel, natural gas, and diesel for power generation, their demand continues and increases (Indrawan et al., 2018; Yana et al., 2022). This study aims to estimate the potential biomass of agricultural residues as energy resources, especially for main commodities such as rice, maize, cacao, coconut, and other crops. Therefore, farmers or future researchers could determine the yield of abundant agricultural residues and calculate the number of bioenergy estimations. The surplus residue of agriculture products could be considered not only for feed and animal feed but also for energy sources. In addition, there were not many studies on the use of agricultural residues as bioenergy resources in the WNT. Otherwise, this research will provide valuable information and reference on the potential of renewable energy from biomass.

2 | MATERIALS AND METHODS

The province of West Tenggara Barat (WNT) located between 115° 46′–119° 5′ East longitude and 8° 10′–9°g 5′ South latitude. The WNT consists of Lombok (4738.70 km^2), Sumbawa (15,414.45 km^2), and many other small islands with a total area of 20,153.20 km^2. It has 10 districts/cities divided into two main Islands that are Lombok Island, which includes Lombok Barat, Lombok Tengah, Lombok Timur, Lombok Utara, and Mataram, and Sumbawa Island, which includes Sumbawa, Dompu, Bima, Sumbawa Barat, and Bima Citi. The area (WNT regency) was chosen due to the lack of utilisation of agricultural residues that caused mounted and polluted wastes.

Analysis of bioenergy potential will focus on agricultural residues from crops such as paddy (rice) and corn, which is the most extensive crop production in the WNT, and plantations such as coconuts, cacao, coffee, and tobacco. This research collects data from various sources such as Statistics Indonesia (BPS) (Statistic Indonesia, 2021; Statistic of NTB, 2022), One Data WNT (Department of Energy and Mineral Resources, 2022), Department of Agriculture and Plantation of WNT (NTB satu data, 2022), Department of Energy and Resources, and journal articles (Department of Energy and Mineral Resources, 2022).

2.1 | Determining agriculture residues

Assessment of potential residues is based on the availability of resources. The statistical method used in this study was based on statistical data such as agriculture area, crop production data that were obtained from sources

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mentioned in paragraph above, and other literature. The collected data such as agriculture production, production area, and livestock number were then processed to obtain the number of potential energy estimates. It is combined with converted factors, such as the yield per hectare and calorific value, considering other purposes, such as the use of domestic residues for animal feed. We take into account the use of straw for animal feed according to the total unit of livestock (Sayudin et al., 2020; Statistic of NTB, 2022; Sunarto, 2013) and other purposes according to several articles (Waste et al., n.d.) for the estimation of the potential availability of residue (see Figure 1). On the basis of data obtained from sources, we calculated the agriculture residue (AAR) and the residue-to-product ratio (RPR). Then, to estimate available residue, we considered utilization for animal feed, fertilizer, and other purposes.

The potential availability of the residue was calculated based on the amount of agricultural product and the availability of unutilized residues using equation (Karaca et al., 2017):

$$\mathrm{AAR}_i = \mathrm{AAP}_i \times \mathrm{RPR}_i \times A_i$$

AAR (ton) is the amount of agricultural residue (such as rice straw and corn stem) availability for a specific crop i. AAP is the total amount of agricultural product (ton). The residue-to-product ratio (RPR) is the total residue divided by the total amount of agricultural product. A (%) is the percentage of availability of residue (total amount of unused residue).

2.2 | Determining bioenergy potential

After the availability of crop/plant residue is calculated, the energy potential is more easily estimated (see Figure 1). The energy content in biomass determines the energy production indicated by the conversion of energy as a result of the heating of different types of biomass. The total heating value either lower heating value (LHV) or high heating value (HHV) can be used for the calculation of the biomass energy potential. The following equation for the estimation of the energy potential of the residue (Karaca et al., 2017):

$$\mathrm{THV}_i = \mathrm{AAR}_i \times \mathrm{LHV}_i$$

THV is the total heating value of the agricultural residue (GJ). LHV is the lower heating value of the air-dry residue ($\mathrm{MJ\,kg^{-1}}$).

3 | RESULTS

The rate of agricultural production in WNT depends on the location due to its different geographics. Lombok Tengah shows the highest rice production according to its largest arable land. However, maize production has resulted in high yields in Sumbawa, Dompu, and Bima, located on Sumbawa Island. It has enormous arable land and higher temperature, which is suitable for maize growth. Lombok Barat and Lombok Utara have the highest yield for coconut production. Each region has its superior agricultural commodity. Rice, cacao, and tobacco are some of the superior commodities in the WNT region. Sumbawa comprises two-thirds of the province area. It has substantial arable land that produces the highest yields of maize and coffee (Statistic of NTB, 2022).

A study on the management of agricultural residues in Southeast Asia, including Indonesia, said that farmers generally burn the remaining straw from rice in the field (Goswami et al., 2020). After harvesting and

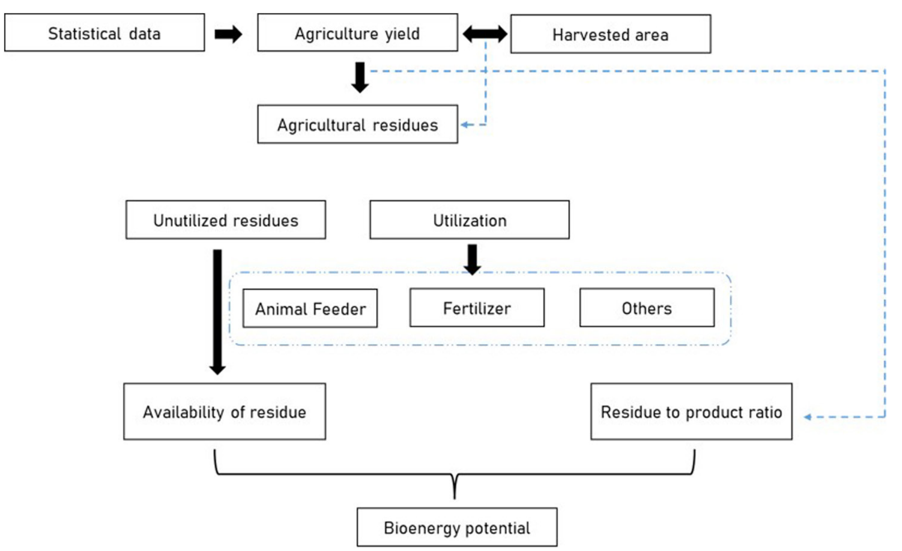

FIGURE 1 Scenario of bioenergy potential estimation.

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processing agricultural production, abundant residues resulted such as straws, stalks, cobs, husks, fibres, and pod husk. Figure 2 shows the distribution of specific biomass residues in each area of the West Nusa Tenggara regency, so it can be properly decentralized according to the area and the crop residues. Some are used for animal feed, fertilization, and other purposes, but most farmers left the straw residue in the field and burnt it openly (Danish Energy Agency, 2021). For example, cacao farmers dispose of by burying pod husks in a plantation area for fertilization, and some are used for animal feeding. The open burning of agricultural waste, particularly rice straw, is a major source of CO_2 gas that contributes a great deal to GHG emissions (Andini et al., 2018). Instead, the agricultural residues available can be converted into energy, such as gas, heat, electricity, charcoal, and fuel. Less information and training at the local level causes inadequate and inadequate waste management, which has a negative impact on the environment.

Biomass refers to the organic material used for energy production, which varies in the sources of feedstocks such as agricultural residues, animal waste, municipal waste, and industrial waste. While most of the biogas plants consider only animal waste instead of agriculture waste (Indrawan et al., 2018). Table 2 shows that the availability of paddy, maize, and other crops produces abundant residues that have a good prospect of promoting renewable energy resources. This means that there has been abundant biomass from agricultural residues, which can be used for bioenergy resources. Biomass is the largest renewable energy resource that is becoming a great opportunity to develop the new energy supply from the residue of agriculture (Tun et al., 2019). Implementing a proper strategy and managing agricultural waste into a valuable product, such as energy or fertilizer, can generate a sustainable bioeconomy for the local farmers, in particular (Meza-Sepúlveda et al., 2021).

Agro-waste products that are prone to having a high cellulosic component consist of organic material, which

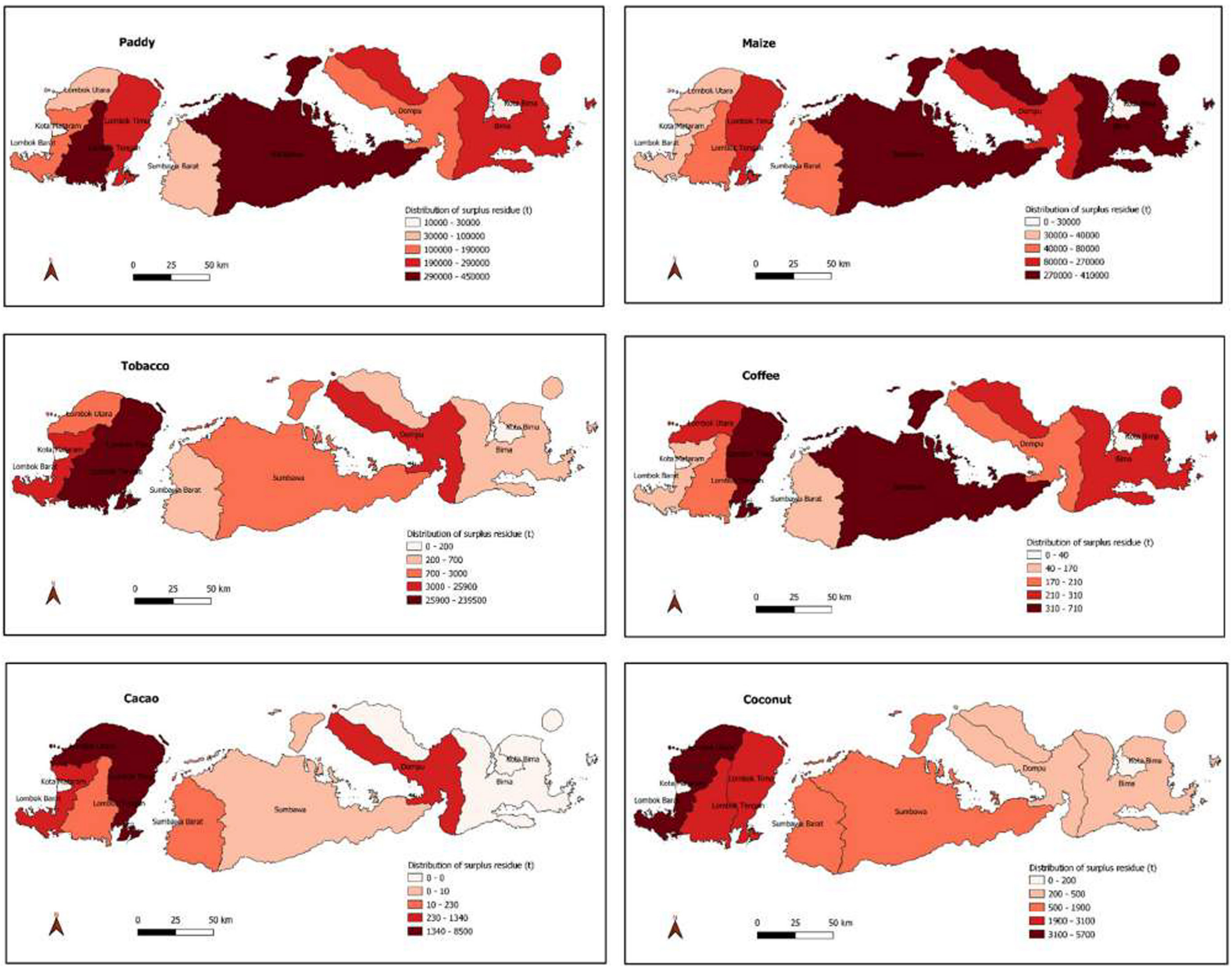

FIGURE 2 Distribution of surplus residue after considerate uses such as animal feed, fertilizer, and for other purposes.

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can be suitable feedstock for bioenergy generation. However, a lignocellulosic material has a very complicated structure and this poses a major challenge to its conversion. Several techniques and technologies studies have been conducted to improve the utilization of agro-based materials for the transition to bioenergy transition (Baêta et al., 2017; Haque et al., 2022; Sumardiono et al., 2022). Many current studies have revealed that the organic material has been effectively transformed by anaerobic digestion, which is known as an alternative technology. The use of leftover residues in energy conversion is not competing with food security. The government needs to have widespread information on bioenergy conversion technologies such as biogas, biofuels, or bio-oil. For example, the policy of open burning on land needed to be emphasized due to its impact on GHG emissions. Mouratiadou et al. (2020) subjected to the spatial variability of agricultural residues for their utilisation to determine the appropriate management strategy. Thus, the government and farmers can develop a waste management plan strategy based on agro-residue distribution.

4 | DISCUSSION

The potential of different types of agriculture residues that can be used for bioenergy feedstock in the WNT province are described below:

4.1 | Paddy

Residues such as paddy straws, maize stalks, and corn cobs have the highest potential to generate new energy resources in WNT. A study by Papilo showed that paddy residue had greater potential for bioenergy resources (Tun et al., 2019), which is rich in organic compounds and essential for biogas production. The mixture of paddy straw and animal manure can improve biogas production due to their C/N ratio balance (Haque et al., 2022) Rice husks have been used mainly for animal feed and mushroom cultivation, which means that paddy straw has more potential than husks. The use of rice straw is limited to fresh straw for livestock feeding, not to the dry fraction. This resulted in huge unutilized residue on land that tends to burn.

4.2 | Maize

Maize silage revealed maximized biogas production by adding more silage to the digester (Cheng et al., 2016) and mixing with livestock manure (Sumardiono et al., 2022) due to its lignocellulosic content. Treatment of corn waste by physical, chemical, and biological pretreatment had a positive effect on biogas production (Sumardiono et al., 2022). The use of corn stalks is similar to the use of rice straw that is used to feed animals in fresh form. Corn cobs are usually used for mushroom cultivation; however, the number of leftover residues is still higher than its utilisation.

4.3 | Cacao

The residue of cacao consists of three fractions: cacao pod husk (CPH), cacao bean shells, and cacao sweating. CPH is the most abundant by-product, which contains approximately 67%–76% of the cacao fruit. The disposal of CPH can lead to plant disease caused by fungal contamination. The study by Atmowidjojo et al. (2023) conducted the biomethane potential (BMP) test on CPH which resulted in a suitable substrate for co-digestion with waste of lower *C/N* ratio. Furthermore, **t**he cacao pod husk has a similar heating value similar to the paddy and maize residues (see Table 1) that are potentially becoming the source material of energy transformation and adding more value to

TABLE 1 Availability (*A*), residue-to-product (RPR), and lower heating value (LHV) of different potential biomass.

Crop	Residue[a]	*A* (%)	RPR	LHV $MJ\,kg^{-1}$
Paddy	Straw	85.91	0.80	16.7 (Karaca et al., 2017)
	Husk	16.00	0.41	13.0 (Karaca et al., 2017)
Maize	Stalk	82.26	1.76 (Papilo et al., 2018)	18.5 (Karaca et al., 2017)
	Corncobs	88.25	0.30 (Papilo et al., 2018)	18.4 (Karaca et al., 2017)
Coconut	Husk	64.91	0.35	10.01 (Amoako & Mensah-Amoah, 2018)
Cacao	Pod husk	60.60	4.90	17.0 (Syamsiro et al., 2012)
Coffee	Husk	60.48	0.35	18.9 (Amertet et al., 2021)
Tobacco	Stem	85.00	2.21	16.1 (Karaca et al., 2017)

[a]The agricultural residues were calculated on a wet substrate.

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the products (Meza-Sepúlveda et al., 2021). Furthermore, the WNT region supported by the diversity of biomass resources needs to be recognized and considered for the development of its management strategy.

4.4 | Coffee

In Indonesia, coffee husk is still not properly managed, while its production is high, as well as its waste. The use of husk is still limited for fertilizers and the abundant remains are disposed without good treatment (Endar Hidayat et al., 2020). Coffee husks with lignocellulosic content can inhibit the biogas process because of their non-biodegradable compounds. Pretreatment such as steam explosion and microbial treatment can improve biomethane production by optimising biodegradability (Baêta et al., 2017; Battista et al., 2016).

4.5 | Coconut

The whole coconut can produce about 50% husk waste that consist of high cellulose (Obeng et al., 2020) with average annual production reached 47,879 (Statistic of NTB, 2022). The diversity of coconut products has been recognized and traded such as coco peat, mat from coconut husk, charcoal, or handcraft from coconut shell. The data showed that coconut products come mainly from small local farmers because medium or large industries are only available in several large regions such as Kalimantan, Sumatra, Java, and Sulawesi (Alouw & Wulandari, 2020).

4.6 | Tobacco

WNT, especially Lombok recognized as one of the main tobacco producers (Statistic of NTB, 2022), the use of tobacco is based only on leaves for cigarette production, nevertheless the residue of the tobacco stem has not been used well. The tobacco plant can be contaminated by tobacco mosaic virus (TMV) and cucumber mosaic virus (CMV) that can only be killed by heat. Thus, improper disposal of its waste can spread and infect other plants. Using tobacco stems as biogas feedstock may reduce its impact on the environment. TMV and CMV only can be inactivated by mesophilic and thermophilic anaerobic digestion (Liu et al., 2015).

The distribution of biomass availability is shown in Figure 3 where the largest arable land contributes to the production of high yields and residue. It is obvious that crop or plant production is a key factor that influences the amount of residue or biomass potential, as well as other unneglected uses of its residue. Understanding the type of agricultural residue, the source area and the quantity is crucial before determining the next step for energy conversion (Koul et al., 2022). On the basis of the spatial distribution of the residue, it would help to show the next step in its management, such as collecting, assigning, and transferring the raw material. Also, depending on each area and main growing plants, it must be taken into account for the technology, economic and environmental development.

The crop residue (see Table 2) was calculated using the residue-to-product ratio and the availability of the residue, based on the crop yield. The study shows that the number of crop residues and its distribution are quite significant. As Lombok Timur and Sumbawa (see Figures 2 and 3) currently play an important role in generating high agriculture residue. Their main crops, such as paddy, maize, coffee, and cacao, have a relatively high LHV, which means that they have the potential to become an alternative source of renewable energy. The heating value should be analyzed to estimate the amount of heat generated from selected materials as energy resources (Motghare et al., 2016). LHV is an indicator of the energy content of specific biomass (Motghare et al., 2016), which is the most important parameter for measuring and selecting appropriate feedstock for energy conversion.

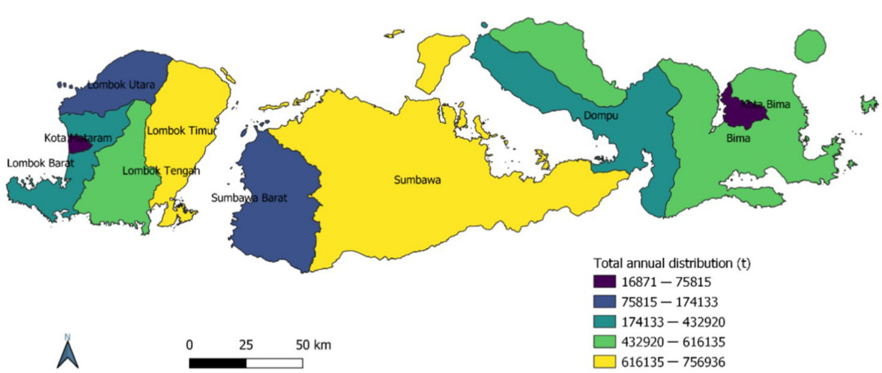

FIGURE 3 Total distribution of the availability of biomass potential in the WNT regency area.

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Regarding energy resources, the heating value is the most significant characteristic of agricultural biomass (Huang & Lo, 2020). A combination of many resources is required to meet the desired heating value. Residues have heating values that are based on their chemical composition. Table 1 shows that the coconut and rice husks resulted in low heating values. Then, when combined with corncobs or other residues, they can increase their heating value. Table 3 shows the THV of each residue of agricultural biomass. Table 2 shows that the THV value of paddy and maize is indicated as the very potential biomass for energy conversion as stated by (Sumardiono et al., 2022), the lignocellulosic substrate (Haque et al., 2022) is the most favorable feedstock, particularly mixed with animal manure to improve the generation of sustainable energy.

The WNT had a high potential for renewable energy that had already been installed (mostly from hydro, solar and wind resources) and used for electricity (Islami et al., 2020). In contrast, only small capacity is used compared to its potential. The government had already established an innovative program for the development of renewable energy. Biogas is the most widely used for the conversion of biomass energy in Indonesia, established in rural areas (Lantasi, 2021). According to statistical data for 2020, approximately 6219 small-scale biogas plants were recorded in WNT (Department of Energy and Mineral Resources, 2022). However, the potential use is still very low and its feedstock is mainly livestock manure (Roubík & Mazancová, 2020). Renewable energy has expanded very slowly in Indonesia mainly due to the dependence of energy on fossil fuels that increases every year (Yana et al., 2022).

Furthermore, this region has been importing gas to generate electricity (Danish Energy Agency, 2019). Considering the potential biomass that can also be used as biogas feedstock will increase the production of biogas for heating or electricity purposes. It parallels the government's goal of developing sustainable agriculture and energy management. Furthermore, the use of biomass for bioenergy resources is quite promising (Mahidin et al., 2020), particularly in the WNT region with potential unused agricultural residues. In particular, for biogas plants, which play a role in renewable energy as a pathway to cleaner energy and the environment and promote the circulatory economics in the agricultural sector (Task, 2022).

The electrification rate is up to 77% in the entire West Nusa Tenggara region, with the lowest level found in Sumbawa and Bima (Danish Energy Agency, 2019). Indonesia already adopted biogas and uses it predominantly for cooking and electricity with a gas lamp (Ludwig, 2019). The shortage of energy in particular of electricity in a remote area would also be overcome by bioenergy planning, at least by running either small-scale or home-scale biogas plants. The development of electrification in remote areas can be carried out using potential biomass according to the availability in each place. Table 3 shows that the total available heating value (THV) available agriculture residues reached 42.4 PJ. The dependence on unsustainable energy such as coal (up to 56% of electricity) (Cahyono Adi & Lasnawatin, 2021) can be reduced by implementing and developing energy production by using potential biomass, in particular agricultural residues. It suggests that more research and technology are needed in developing the technology for converting biomass into gas, fuel, and electricity to meet the increasing energy demand. Furthermore, through biomass conversion to energy, the contribution to the global and government goals of sustainable energy and zero net emission.

TABLE 2 Amount of agricultural residue available.

Crop	Residue	AAR (ton)
Paddy	Straw	980,727.88
	Husk	92,143.66
Maize	Stalk	653,909.10
	Corncobs	388,959.62
Coconut	Husk	11,097.85
Cacao	Pod husk	7834.39
Coffee	Husk	1339.35
Tobacco	Stem	305,924.80

Abbreviation: AAR, amount of agricultural residue.

TABLE 3 Total heating values from the availability of potential agricultural residues.

Crop	Production (ton)	THV (GJ)
Rice	1,419,540	17,576,023.15
Maize	2,061,978	19,654,030.88
Coconut	48,851	111,089.48
Cacao	2639	133,184.68
Coffee	6328	25,420.85
Tobacco	52,632	4,925,389.29
Total	3,591,968	42,425,138.32

5 | CONCLUSION

The West Nusa Tenggara region relies on fossil fuels and coal energy resources for electricity and transportation. Abundant unused agricultural residues can promote

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biomass conversion into a valuable product for energy needs. Paddy straw, corn straw, and corn kernels had the most considerable percentage of residues available: 85.91%, 82.26%, and 88.25%, respectively. Furthermore, the WNT regency has a rich diversity of agricultural residues from superior commodities such as rice, corn, coffee, coconut, and cacao that reached a total heating value (THV) of up to 42.4 PJ. The potential for bioenergy generation and the availability of biomass can be developed for sustainable agriculture and energy management. In general, Indonesia has a significant potential for the production of biomass energy from agricultural residues. The use of agricultural residues as feedstock for biomass energy production can contribute to the development of renewable energy sources and help reduce greenhouse gas emissions from fossil fuels or coal combustion. Therefore, it is important to understand the biomass source and its conversion technology to support the achievement of global or government goals and to promote circular economy in the agricultural sector.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in this published article.

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