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Biomass energy from agricultural waste: A green solution to achieve energy security and national economic development

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ABSTRACT

Background: Biomass energy is considered a sustainable solution with significant potential to enhance energy security and the national economy of Indonesia. Indonesia has vast potential for developing biomass energy from sources such as agricultural waste and wood. Biomass energy serves various purposes and can be used in electricity generation, household heating, industrial applications, and transportation. **Methods:** This article utilizes literature review to discuss the current status of biomass energy in Indonesia and the policies regulating its utilization for optimal benefits. **Finding:** Several policy recommendations based on the pentahelix scheme are proposed. The government should establish regulations and provide incentives for biomass energy from agricultural waste, as well as promote infrastructure investments. Private corporations should engage in technology development and partnerships with farmers. The community should be educated about the importance of agricultural waste management and encouraged to participate in biomass energy programs. Media should disseminate information and cover biomass energy projects. Academics should research new technologies and conduct training to enhance farmers' capacities**. Conclusion:** Therefore, biomass energy can be developed as a solution to achieve energy security and national economic development. **Novelty/Originality of This Study:** This study offers a novel integrative approach by applying the pentahelix model to formulate comprehensive policy recommendations for optimizing biomass energy utilization in Indonesia.

KEYWORDS: agricultural waste; biomass; energy security; renewable energy.

1. Introduction

Energy is one of the most critical issues of the 21st century, as it forms the foundation for economic growth, national security, and sustainable development (Nguyen et al., 2024). Global energy demand continues to rise; in 2022, primary energy data showed an increase of nearly 6% compared to 2021 (the post-COVID-19 effect) across many countries worldwide (Surono et al., 2023). Indonesia's total primary energy consumption grew by 16% between 2010 and 2020. The country's economic growth reached 5.44% in the second quarter of 2022 compared to the previous year (US Energy Information Administration, 2021). Indonesia's large population and rapid economic growth have led to a correspondingly high energy demand. The transportation sector is the highest energy consumer, followed by the household and industrial sectors.

The global target to limit temperature rise to 1.5°C has yet to be achieved, making the energy transition crucial for Indonesia, where fossil fuels still dominate energy consumption at 90%, despite having a renewable energy potential exceeding 3,000 GW.

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Renewable energy potential is vital in meeting Indonesia's commitment to reduce greenhouse gas emissions by 29% by 2030 and achieve net-zero emissions by 2060, supporting a high share of renewables in the national energy mix (IRENA, 2022).

Biomass is one of the diverse and sustainable energy solutions, characterized by its near carbon-neutral nature and abundant availability from various sources, enabling it to meet various energy needs such as electricity generation, vehicle fuel, and industrial process heating (Kibria et al., 2024). Biomass energy originates from organic materials such as plants, agricultural waste, and wood residues, which can be replenished through natural processes (Nguea & Fotio, 2024). Biomass contributes over 6% of the world's energy supply and 55% of renewable energy (excluding traditional biomass use) (REN21, 2021). Beyond being an alternative to fossil fuels, biomass energy has many applications, including electricity generation, home heating, cooking, industrial use, and transportation (Pelkmans, 2021). Biomass production is relatively straightforward, with raw materials readily available in large quantities (Sarkodie et al., 2019). Additionally, biomass energy can aid in the regeneration of mined lands and improve water quality, biodiversity, and soil fertility (Solarin & Bello, 2019). As a carbon-neutral energy source, biomass production can stimulate local economies by creating jobs in harvesting, processing, and biomass energy generation (Bildirici & Özaksoy, 2018).

In Indonesia, biomass can be extracted from industrial waste such as palm oil, tapioca, pulp and paper, sugarcane, rice, and wood. The biomass potential for electricity generation is estimated at 32,654 MW, with an installed capacity of 151.52 MW on-grid and 1,969.64 MW off-grid as of 2021 (Ministry of Energy and Mineral Resources, 2023). The National Energy General Plan (RUEN) targets 9.6 GW from bioenergy power plants and 1.09 GW from biomass, biogas, and bio-waste energy. The current prospects for biomass energy utilization include co-firing methods by mixing biomass with coal in steam power plants (Pambudi et al., 2023). Based on the aforementioned background, the author acknowledges that biomass is a renewable energy source that can help Indonesia achieve energy security and national economic development, thus necessitating a comprehensive study on the state of biomass energy in Indonesia along with the policies governing its development.

2. Method

A literature review was conducted for this paper using search features available on Google Scholar and the Remote Library UI. The keywords used included renewable energy security, biomass energy potential, agricultural biomass energy, as well as the potential and challenges of biomass energy in Indonesia, with a search period limited from 2010 to 2024. Comprehensive data related to biomass energy policies in Indonesia were collected through Google searches without year restrictions in order to capture the development of biomass policies in Indonesia.

3. Result and Discussion

3.1 Biomass energy potential and policies in Indonesia

Energy obtained from biomass generally originates from the waste produced by the primary activities generating the biomass (Arsyad et al., 2023). The biomass production flow from the agricultural sector is illustrated in Figure 1. Increasingly intensive agricultural activities to meet the growing food demand have resulted in a corresponding rise in agricultural waste, which poses a threat to global environmental conservation efforts. Therefore, prioritizing the management of agricultural waste is crucial (Shabrina, 2022). Agricultural and forestry biomass waste represents an important source of renewable energy. Indonesia possesses a vast amount of agricultural and forestry biomass waste, much of which is sold without further processing to produce higher-value products (Hardoyo, 2013).

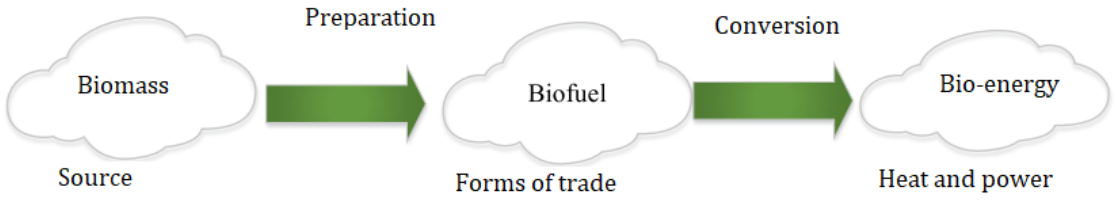

Fig. 1 Biomass energy production flow
(FAO, 2004)

The sources and potential of agricultural and forestry biomass waste in Indonesia, as shown in Table 1, indicate that the country has a significant biomass energy potential. The large potential from Indonesia's agricultural sector, supported by extensive land and favorable climatic conditions, reflects the country's capacity in terms of biomass raw material supply, accessibility, and sustainability, with projections estimating a supply potential of 2,594.6 PJ by 2050. This is mainly expected to fulfill the industrial sector's needs, which is projected to consume more than 87% of the total biomass demand (IRENA, 2022).

Tabel 1. Potential of biomass waste as an energy source in Indonesia

Biomass	Region	Production (million tonnes/year)	Energy potential (million GJ/year)	Information
Rubber tree	Sumatera, Kalimantan, dan Jawa	41 (*replanting*)	120	- Small logs Ø < 10 cm - Large and medium logs are used as firewood for the brick and tile industry; price IDR 20,000–30,000/m^3.
Deforestation waste	Sumatera dan Kalimantan	4.5	19	-
Log waste	Sumatra and Kalimantan	1.3	13	- Used as firewood by local people, the waste is freely available.
Plywood and veneer production waste	Kalimantan, Sumatra, Java, Papua and Maluku	1.5	16	- Waste is generally used.
Sugarcane waste	Java, Sumatra, and South Kalimantan	Belotong: 10 Sugarcane shoots: 4 Sugarcane leaves: 9.6	78	- Blotong is generally used in sugar factories (90%). - The use of sugar cane shoots and leaves needs to be observed.
Paddy field waste	Java, Sumatra, Kalimantan, Bali and Nusa Tenggara	Husk: 12 Bran: 2.5 Stalk: 2 Straw: 49	150	- Stalks and straw produced in the fields and generally burned; in some areas used for animal feed or industrial raw materials. - Husks are often burned uncontrolled.
Coconut waste	Sumatra, Sulawesi, and Java	Coconut shell: 0.4 Husk: 0.7	7	- The waste produced is separated and usually left on the plantation land. Most of it is used as firewood and for charcoal production.

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Palm oil waste	Sumatra, Kalimantan, Sulawesi, Maluku, Nusa Tenggara, and Papua	Empty fruit bunches: 3.4 Fiber: 3.6 Fruit shell: 1.2	67	- Palm kernel shells and fibers are common fuel sources. - Empty fruit bunches are generally burned.

(Dani & Wibawa, 2018)

Indonesia's biomass energy policy is primarily established through Presidential Regulation Number 5 of 2006, which aims to align with national energy targets by promoting the utilization of biofuels and emphasizing their role in achieving a more sustainable energy mix. Existing policies focus on both macro and micro levels, including biofuel projects that support job creation and local development (Dani & Wibawa, 2018). The development of biomass energy policies in Indonesia is summarized in Table 2. Indonesia's commitment to the Clean Energy Demand Initiative (CEDI), climate change mitigation, and green economy aligns with international goals such as achieving net zero emissions by 2060. The vision to reach 23% renewable energy in the primary energy mix by 2025 aims to close the renewable energy share gap within the ASEAN region. Government Regulation No. 79 of 2014 provides a framework for sustainable energy management and security, guiding future national energy policies (Pambudi et al., 2023).

Tabel 2. Development of biomass energy related policies in Indonesia in 2005—2023

Policy	Allocation
Government Regulation Number 3 of 2005 concerning Electricity Provision	• Supporting Law No. 15 of 1985 on Electricity, which was reinstated at the end of 2005 following the Constitutional Court's decision to annul Law No. 20 of 2002 on Electricity. • Regulating partnerships between independent power producers (IPPs) and PLN to develop electricity projects, with exceptions granted to companies generating electricity for their own use or utilizing renewable energy sources, allowing them to build power plants independently without the obligation to partner with PLN.
Draft of the National Energy Implementation Program 2005—2025 by the Minister of Energy and Mineral Resources	• Outlines measures to enhance energy supply security. • Provides a development roadmap for various sectors, including both renewable and non-renewable energy sectors. • Designs programs aimed at phasing out subsidies and improving energy efficiency.
Presidential Regulation Number 5 of 2006 concerning National Energy Policy	• Sets energy diversification targets for 2025, including 5% biofuels and 5% from geothermal and other renewable sources such as biomass. • Establishes energy conservation targets to reduce energy intensity by 1% annually.
Presidential Instruction Number 1 of 2006 concerning the Provision and Utilization of Biofuels	• Establishes utilization targets and guidelines for multisectoral coordination in the development of biofuels.
Regulation of the Minister of Energy and Mineral Resources Number 2 of 2006 concerning Medium-Scale Power Plants from Renewable Energy Sources	• Imposes pricing guidelines consistent with Ministerial Decree No. 1122 of 2002 for projects ranging from 1 MW to 10 MW.
Law Number 30 of 2007 concerning Energy	• Regulates policies on renewable energy development and energy efficiency, particularly by enhancing the utilization of renewable energy and providing time-bound incentives to renewable energy developers.

Law Number 30 of 2009 concerning Electricity	• Invites private companies to participate in electricity supply. • Gives higher priority to the use of renewable energy and clean technologies for electricity provision. • Encourages increased utilization of small-scale distributed power generation from renewable sources such as biomass energy.
Regulation of the Minister of Energy and Mineral Resources Number 4 of 2012	• Establishes the feed-in tariff rates for electricity generated from biomass.
Regulation of the Minister of Energy and Mineral Resources Number 27 of 2014	• Increase the share of renewable energy to at least 23% by 2025 and 31% by 2050. • Focus biomass utilization on electricity generation and transportation. • Set electricity selling prices for renewable energy. • Encourage government and private companies to use biomass and biogas as fuel for power plants. • Increase electricity tariffs for biomass-fueled power plants.
Government Regulation Number 79 of 2014	• National energy policy
Regulation of the Minister of Energy and Mineral Resources Number 21 of 2016	• Purchase of electricity from biomass power plants and biogas power plants by PT PLN

3.2 Policy recommendations

The utilization of waste as biofuel offers three main advantages: increased energy efficiency, cost savings, and reduced landfill requirements, particularly in urban areas. The use of biomass for biodiesel and bioethanol has shown rapid development as a primary energy source in recent years (Sulasminingsih et al., 2023). Based on the biomass waste potential from the agricultural sector previously shown in Table 1, Indonesia has significant biomass energy potential, evident from the large amount of agricultural waste that remains underutilized. Biomass conversion technologies into fuel include direct combustion, thermochemical conversion, and biochemical conversion, each requiring different processes such as simple direct combustion, thermal treatment in thermochemical conversion, and microbial usage in biochemical conversion (Parinduri & Parinduri, 2020).

The utilization of biomass waste as a substitute for fossil fuels through the Clean Development Mechanism (CDM) presents opportunities for foreign investment and beneficial technology transfer for developing countries like Indonesia. The relatively small scale of renewable energy power plant projects under the CDM scheme can enhance project attractiveness by increasing the internal rate of return (IRR) and contributing to global warming prevention and fossil energy conservation. Interaction between domestic and foreign interests occurs through the CDM scheme, where domestic industries require foreign investment for renewable energy projects, while foreign parties seek emission reductions achievable through net zero emission (NZE) projects in Indonesia. CDM schemes for several agricultural wastes can be implemented in Indonesia through electricity generation projects with surplus electricity sold to PT PLN (Febijanto, 2007).

Constraints on the biomass potential from the agricultural sector arise from ecological aspects (declining biomass yields due to soil characteristics, topography, and climate), social, and technological factors, with increasing demands to provide non-productive functions that contribute to sustainable land use and ensure the economic viability of agricultural biomass (Králík et al., 2023). Barriers or challenges from various aspects related to biomass energy from agricultural waste in Indonesia are summarized in Table 3.

Tabel 1. Biomass energy barriers in Indonesia

Aspect	Obstacle
Technology	The conversion of biomass into energy requires high investment costs, particularly with advancing technologies, and necessitates a large quantity of raw materials to meet production capacity (for example, the utilization rate of the biodiesel industry is only around 25% of its capacity).
Economy	The fluctuating and low global energy prices, such as the non-competitiveness of biodiesel, hinder investment in renewable energy. This situation requires long-term incentives and regulatory improvements to enhance investment attractiveness, while also addressing issues such as low tariffs, high interest rates, stringent collateral requirements, and challenges related to small-scale projects. Therefore, the provision of incentives and the involvement of financial regulatory authorities may serve as solutions to stimulate the future development of the renewable energy industry.
Production-consumption	There is potential for conflict with food and animal feed needs, as biomass is often also used for food production and livestock feed. In addition, ensuring the availability of feedstock and the stability of biomass prices remains a major challenge in the development of renewable energy.
Social	Farmers and local communities often lack access to necessary information and possess limited skills and knowledge regarding proper agricultural processing due to low levels of education. In addition, the use of traditional and limited agricultural equipment remains a major constraint in the development of the agricultural sector.
Ecology	Biomass processing centers are often located far from agricultural waste producers, resulting in an ecological footprint from the transportation of raw materials. Furthermore, the co-firing method, which involves mixing biomass with coal in coal-fired power plants, contributes to air pollution.

(Arsyad et al., 2023; Kasmaniar et al., 2023; Králík et al., 2023; Pambudi et al., 2023; Sulasminingsih et al., 2023)

Based on the various information presented earlier, the author puts forward several arguments regarding the policy framework for managing biomass energy derived from agricultural waste in Indonesia. The government needs to develop clear and comprehensive policies to regulate the use of biomass energy sourced from agricultural residues. These policies should encompass technical regulations, fiscal incentives, and market mechanisms that support the efficient and sustainable development and utilization of biomass energy.

Fiscal and non-fiscal incentives for industry players and farmers are crucial to encourage investment in the development and use of biomass energy. Such incentives may include tax reductions, subsidies, or low-interest loans for biomass energy projects. Extension programs and training for farmers and industry actors regarding technology and best practices in managing agricultural waste for biomass energy can enhance their understanding and skills in producing and using biomass efficiently. Public education programs to raise awareness about the importance of biomass energy from agricultural waste as an environmentally friendly and sustainable alternative can stimulate active community participation in supporting and adopting biomass energy.

Infrastructure development supporting the collection, processing, and distribution of agricultural waste as a biomass energy source is also essential. This includes biomass processing facilities, transportation networks, and efficient storage systems. Finally, collaboration among the government, private sector, and academic institutions in research, technology development, and innovation in the field of biomass energy is necessary to accelerate the development of sustainable and effective solutions for managing agricultural waste. Such efforts are expected to harness the potential of biomass energy from agricultural residues in Indonesia more effectively and sustainably, thereby enhancing the agricultural sector's contribution to sustainable development and climate change mitigation. This paper summarizes the necessary policies for managing biomass energy derived from agricultural waste in Indonesia through a pentahelix scheme, as presented in Table 4.

Tabel 2. Pentahelix scheme in biomass energy management from agricultural waste in Indonesia

Element	Policy suggestions
Government	• Establish clear and supportive regulations to govern the use of biomass energy derived from agricultural waste, including fiscal and non-fiscal incentives for industry players and farmers. • Promote investment in the development of infrastructure supporting agricultural waste management, such as biomass processing centers and distribution networks.
Corporation (private)	• Open investment opportunities for private companies in the development of technology and infrastructure related to biomass energy from agricultural waste. • Encourage partnerships between private industry and farmers or farmer groups in the management and utilization of agricultural waste.
Public	• Conduct outreach and education for farmers and local communities on the importance of managing agricultural waste for biomass energy. • Promote the formation of farmer working groups or cooperatives to collectively manage agricultural waste and enhance participation in biomass energy programs.
Media	• Conduct information campaigns and education through mass media on the benefits and potential of biomass energy from agricultural waste. • Provide extensive coverage of successful biomass energy initiatives and projects in Indonesia to inspire the public and other stakeholders.
Academics	• Conduct research and development of new technologies for processing and converting agricultural waste into more efficient and environmentally friendly biomass energy. • Organize training programs and workshops to enhance the capacity of farmers and agricultural workers in managing and utilizing biomass energy.

4. Conclusion

Based on the background presented, it can be concluded that biomass energy holds significant potential to support Indonesia's transition toward sustainable and secure energy systems. As a renewable, carbon-neutral, and locally available resource, biomass offers multiple benefits—from reducing dependence on fossil fuels and lowering greenhouse gas emissions to stimulating local economies and enhancing environmental quality. Given Indonesia's abundant biomass resources and the urgent need to meet national and global climate targets, a comprehensive examination of the current state of biomass energy and the regulatory framework guiding its development is essential to optimize its role in achieving energy security and national economic growth.

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