THE POTENTIAL OF BIOMASS ENERGY IN THREE NUSA ISLANDS

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Abstract The Three Nusa Islands consist Nusa Penida, Nusa Lembongan, and Nusa Ceningan are facing increased energy demands due to growing tourism, population, and economic activity. Biomass energy, as a renewable and locally available energy source, presents a viable solution to help meet the island's sustainable energy needs. This review explores the potential of biomass energy in the region, focusing on the availability of biomass feedstock, technological feasibility, environmental impact, and social acceptance. The study is based on secondary data from government reports, academic journals, and regional statistics, aiming to contribute to the development of decentralized and sustainable energy strategies in Eastern Indonesia.
***Keywords*-Potential Biomass Energy, Nusa Islands, Renewable Energy, Economics**

I. INTRODUCTION

Indonesia has made significant strides toward promoting renewable energy to address environmental concerns and ensure energy security. Biomass energy, derived from organic materials such as agricultural waste, livestock manure, and municipal solid waste, plays a critical role in the country's renewable energy mix. The utilization of biomass energy in remote and isolated regions like the Three Nusa Islands can offer multiple benefits, including energy independence, waste reduction, and economic empowerment for rural communities [1].

Globally, the role of biomass energy is becoming increasingly important as countries work to transition away from fossil fuels. Biomass is one of the most accessible forms of renewable energy, especially in rural and agricultural regions where waste from farming, forestry, and household activities can be collected and converted into usable energy. In Indonesia, where agricultural activity is widespread and waste management remains a challenge, the development of biomass energy serves a dual purpose, sustainable power generation and waste reduction.

The Three Nusa Islands, located in southeast Bali, are particularly well-suited for biomass energy due to their agrarian economy and growing tourism sector. The abundance of coconut plantations, animal husbandry, and food waste from hotels and households provides a reliable feedstock base for biomass conversion. Furthermore, the islands' dependence on diesel generators and limited grid connectivity presents both a need and an opportunity for clean, decentralized energy systems.

Implementing biomass energy solutions in the Three Nusa Islands aligns with Indonesia's broader energy policy objectives, including increasing renewable energy contributions to the national mix and enhancing local energy resilience. The government's commitment to achieving a 23% share of renewable energy in the national energy mix by 2025 underscores the urgency of deploying viable alternatives in remote areas.

This paper aims to explore the biomass energy potential of the Three Nusa Islands. By identifying existing resources, feasible technologies, and potential challenges, the study offers insights for policymakers, investors, and community stakeholders interested in supporting sustainable energy development in small island regions.

II. LITERATURE REVIEW

A. Renewable Energy

Renewable energy refers to energy derived from natural processes that are replenished constantly, such as sunlight, wind, water flows, geothermal heat, and biomass. Renewable energy sources are essential for decarbonizing energy systems and achieving sustainable development goals [2]. In Indonesia, the term Energi Baru dan Terbarukan (EBT) encompasses both new energy (such as liquefied coal or nuclear) and renewable energy sources like solar, hydro, wind, geothermal, and biomass [3].

B. Biomass Energy

Biomass energy is a renewable energy source derived from organic materials such as agricultural residues, wood waste, and municipal solid waste. It is considered carbon-neutral when the biomass is sustainably sourced, as the carbon dioxide released during combustion is approximately equal to the CO_2 absorbed during the growth of the biomass itself. Technologies used to convert biomass into usable energy include direct combustion, gasification, pyrolysis, and anaerobic digestion. These methods allow biomass to be converted into electricity, heat, or biofuels, providing a flexible solution for both on-grid and off-grid applications [4].

C. Biomass Eenergy Plant

A biomass energy plant is a facility that generates electricity and/or heat by converting organic material such as agricultural residues, wood chips, and palm oil waste into usable energy.

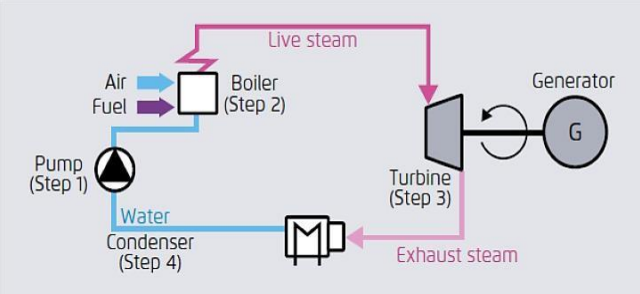

Figure 1. Principle of Biomass Energy Plant [5]

The process usually involves burning the biomass in a boiler to produce steam, which is then used to drive a turbine connected to a generator. In some systems, biomass is first converted into gas through pyrolysis or gasification before being used for power generation. This method of energy production is considered renewable because the carbon dioxide (CO_2) released during combustion is roughly balanced by the CO_2 absorbed by plants during their growth cycle, making it a low-carbon energy source when managed sustainably [4]

D. 3 Nusa Islands

The Three Nusa Islands consist of Nusa Penida, Nusa Lembongan, and Nusa Ceningan are located southeast of Bali and are part of the Klungkung Regency, Indonesia.

These islands have increasingly gained attention for their tourism potential, ecological richness, and renewable energy opportunities. Nusa Penida, the largest of the three, is characterized by hilly terrain, dry land agriculture, and limited freshwater sources, while Nusa Lembongan and Nusa Ceningan are smaller, more densely populated, and rely heavily on tourism and seaweed farming. Access to electricity and clean water remains a challenge, especially in remote areas, creating a need for sustainable infrastructure solutions [6].

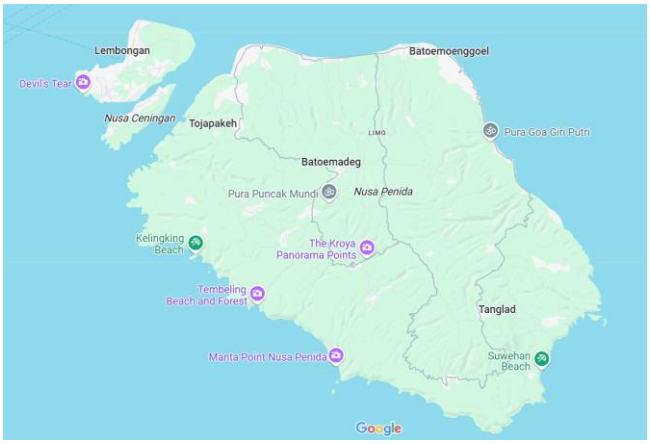

Figure 2. 3 Nusa Islands Map [7]

Electricity supply in the islands primarily comes from diesel-powered generators via undersea cables from mainland Bali, which is both costly and environmentally unsustainable. In 2022, PT PLN (Persero) reported that the electricity consumption in Nusa Penida alone reached over 22 GWh annually, with peak demands increasing due to tourism growth [8]. These conditions have prompted interest in renewable energy deployment, especially solar and biomass, to improve energy access and reduce dependence on fossil fuels. The islands' isolation, abundant solar irradiation, and agricultural residue potential make them suitable locations for pilot renewable energy projects [9].

III. RESEARCH METHOD

This study employs a literature-based research approach using the literature review method. A literature review serves as a research technique that offers a comprehensive understanding of the progress and current state of a specific topic. The method involves several key stages:

1. Gathering relevant research literature aligned with the study's focus,
2. Analyzing and synthesizing the collected data,
3. Interpreting the findings, and
4. Drawing conclusions based on the analysis.

The data utilized in this research were obtained from secondary sources, including scholarly journals addressing similar research themes, as well as official documents from relevant institutions such as PT PLN (Persero) East Bali Unit, the Ministry of Energy and Mineral Resources, and the Central Statistics Agency.

IV. RESULTS AND DISCUSSION

A. Biomass Resource Avaibility

The availability of biomass resources in the Three Nusa Islands Nusa Penida, Nusa Lembongan, and Nusa Ceningan is closely linked to the islands' agricultural practices, livestock activities, and increasing volumes of organic waste from the tourism sector. These biomass feedstocks offer a significant opportunity for renewable energy generation, particularly in remote island settings where centralized energy access is limited.

Agricultural waste is a primary biomass source in the region. Nusa Penida, the largest of the three islands, is well-known for its extensive coconut plantations with more than 500 tons of coconut shells, husks, and fronds are produced annually, much of which remains unutilized [6]. These residues have high calorific value and can be converted into energy through combustion or pyrolysis processes [10]. Additionally, seasonal crop residues such as corn stalks and cassava peels further augment the availability of lignocellulosic biomass.

Livestock manure also contributes significantly to the islands' biomass resource potential. Nusa Penida maintains a relatively stable population of cattle, goats, and pigs, primarily in inland rural villages. Approximately 4–5 tons of manure are generated daily across the island, which can be used in anaerobic digesters to produce biogas [11]. Small-scale biogas systems have been successfully piloted in other Indonesian rural areas, demonstrating their applicability for decentralized energy systems [12].

The growing tourism sector on the Three Nusa Islands generates considerable amounts of organic waste, especially food waste from restaurants, resorts, and homestays, that over 35% of total municipal solid waste in Nusa Lembongan is organic, making it a promising feedstock for waste-to-energy initiatives, including composting and anaerobic digestion [13]. Proper segregation and collection of this organic fraction can ensure a steady supply of biomass material while simultaneously addressing waste management challenges.

Moreover, the region's coastal vegetation such as seagrass residues and mangrove litter has also been studied as an unconventional biomass source. Although still in early stages of research, if processed sustainably, could serve as a supplementary energy feedstock without harming the local ecosystem [14].

B. Electricity Consumption

Electricity consumption in the Three Nusa Islands has seen a steady increase over the past decade, driven by the tourism boom and growing population. The total electricity demand in Nusa Penida reached approximately 22 GWh in 2022, with peak loads occurring during the dry season when tourism is at its highest. Nusa Lembongan and Nusa Ceningan, though smaller, also exhibit rising consumption trends, especially in hotel and hospitality sectors [15]. The heavy reliance on diesel generators has resulted in electricity supply costs that are 2 to 3 times higher than those of the Bali mainland, affecting the affordability and reliability of power in the islands [16]. Additionally, the infrastructure for power transmission remains limited, causing frequent voltage drops and power outages during peak periods [17].

Furthermore, the increase in electricity consumption has not been matched by improvements in energy efficiency or significant renewable energy deployment, leading to continued dependence on fossil fuels. This has implications not only for environmental sustainability but also for the economic viability of local businesses, especially those in the hospitality industry that require stable and affordable electricity. The lack of reliable and affordable electricity limits economic growth and impacts the quality of life for residents. This situation highlights the urgent need for renewable and decentralized energy solutions, such as biomass, to supplement the current supply and enhance energy resilience.

C. Technological Feasability

The deployment of biomass energy technologies in the Three Nusa Islands must consider local resource types, geographic constraints, and operational capacity. Small-scale biomass systems such as fixed-dome biogas digesters, downdraft gasifiers, and pyrolysis units have been successfully implemented in other isolated parts of Indonesia, suggesting their adaptability to island settings [9]. These systems are particularly suitable due to their ability to operate independently of the central grid and use diverse feedstock types, including coconut shells, manure, and food wasted.

Fixed-dome digesters are ideal for converting livestock manure and organic waste into biogas for cooking and electricity. Downdraft gasifiers can be used for dry biomass like coconut husks, providing a relatively stable supply of syngas that can power small generators. Pyrolysis units are more complex but offer higher energy efficiency and can produce valuable by-products like biochar.

However, successful implementation depends on the availability of spare parts, technical know-how, and consistent feedstock supply. Regular maintenance and operator training are essential to ensure system longevity and performance. Pilot projects in similar regions have highlighted that community involvement and technical support significantly influence project sustainability [9].

D. Challenges in Implementation

Despite the considerable potential for biomass energy development in the Three Nusa Islands, several significant challenges must be addressed. Technically, the lack of proper waste segregation is a major obstacle. Most households and tourism-related businesses do not separate organic from inorganic waste, making it difficult to process biomass efficiently for biogas or compost production. This is compounded by limited access to appropriate technology. Transporting, installing, and maintaining biomass energy systems such as digesters or gasifiers is logistically difficult and expensive due to the islands' remoteness. Furthermore, there is a seasonal variability in the availability of biomass feedstocks such as coconut shells or livestock manure, which can affect the continuity and efficiency of biomass power generation.

From a socio-economic perspective, public awareness regarding biomass energy is still low. Many local residents are unfamiliar with how biomass systems work or are skeptical about their benefits. This lack of understanding often results in limited community support or involvement. Financial constraints also present a serious hurdle. Although small-scale biomass systems are relatively affordable compared to large-scale renewable projects, the initial capital investment remains beyond the reach of most local households or cooperatives. Additionally, land competition from tourism development makes it difficult to allocate space for biomass facilities, especially in Nusa Lembongan and

Nusa Ceningan, where land is primarily used for accommodation and tourist services.

Institutionally, the enforcement of regional waste management regulations is inconsistent. While Bali has introduced strong policies on reducing plastic and managing waste, their application in remote island areas remains weak. Furthermore, biomass development requires coordination among various government sectors, such as energy, agriculture, environment, and tourism. Unfortunately, these agencies often operate in silos, resulting in fragmented programs and overlapping responsibilities that hinder comprehensive project planning and implementation.

E. Policy Support and Opportunities

In response to growing energy needs and environmental concerns, Indonesia and the Bali Provincial Government have developed several supportive policies that can foster biomass energy development in the Three Nusa Islands. Nationally, Presidential Regulation No. 112 of 2022 about cceleration of Renewable Energy Development for Electricity Supply, promotes the acceleration of renewable energy supply, including bioenergy, through incentives and feed-in tariffs. At the regional level, Bali's Governor Regulation No. 45 of 2019 about aims to establish Bali as a Clean Energy Province, supports the development of clean energy and encourages local governments and communities to adopt decentralized renewable energy sources. These policy frameworks are complemented by the National Energy General Plan (RUEN) and the Bali Regional Energy Plan (RUED), both of which identify biomass as a key component in achieving sustainable rural electrification.

Beyond policy, there is growing institutional and civil society support for renewable energy. NGOs such as ICLEI, Yayasan IDEP, and Bali Fokus have implemented community-scale composting and waste-to-energy programs in Bali, offering valuable experience and networks that can be leveraged for projects in the Three Nusa Islands. National programs like PLN's de-dieselization initiative aim to replace diesel generators in remote areas with renewable alternatives, including biomass mini-grids. Additionally, funding opportunities are available through the Public Service Agency for Renewable Energy (BLU EBTKE), which provides grants and low-interest loans for small-scale bioenergy projects.

These developments present a range of promising opportunities. The concept of a circular economy where waste is repurposed into energy and fertilizers can be applied effectively in the Nusa Islands to address both energy and waste challenges. Biomass energy systems can also stimulate green job creation in fields such as waste collection, plant maintenance, and organic farming. For the tourism sector, adopting biomass-based systems can enhance eco-tourism branding, allowing resorts and hotels to appeal to environmentally conscious travelers. With adequate training and policy enforcement, biomass could become a cornerstone of sustainable development on the islands.

V. CONCLUSION

The Three Nusa Islands hold considerable but underutilized biomass energy potential. The abundant organic waste from agriculture, livestock, and tourism provides a rich feedstock base for renewable energy generation through biogas, briquettes, or gasification.

However, to realize this potential, an integrated and multi-sectoral approach is needed. Key barriers such as poor waste segregation, limited technology access, lack of funding, and weak institutional coordination must be addressed through inclusive planning and policy implementation.

Policy instruments at both the national and regional levels already exist, but require stronger enforcement and alignment. The islands could serve as a model for sustainable energy transition through community-driven biomass initiatives that improve waste management, reduce fossil fuel dependence, and create economic opportunities.

The development of biomass energy systems in the Three Nusa Islands will not only contribute to Bali's clean energy targets but also promote resilient, low-carbon island communities. Collaboration between governments, NGOs, researchers, and local stakeholders will be crucial in transforming biomass from waste into a sustainable energy solution.

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