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Sustainable Management of Renewable Energy Resources in the Ecotourism Village of Pancoh, Indonesia

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Abstract
The exhaustion of fossil fuel resources and the adverse impacts of greenhouse gas emissions have prompted countries worldwide to shift for clean energy by utilizing various forms of renewable energy. Biogas, derived from livestock waste, presents a viable alternative to conventional fuels, especially in rural areas where such waste remains underutilized. This study employs a qualitative descriptive approach to examine the transformation of livestock waste into biogas in Pancoh Ecotourism Village, Yogyakarta, Indonesia. The objective is to analyze the implementation of sustainable renewable energy management based on the three pillars of Sustainable Tourism Development (STD) as well as to identify influencing factors. Data were collected through in-depth interviews, observation, and document analysis. The findings reveal that implementation across the three STD dimensions remains suboptimal. Key enabling factors include the added economic value of biogas, the availability of livestock waste, active community participation, and multi-stakeholder collaboration. However, challenges persist, notably there were limited: human resource capacity, appropriate technology, and mechanisms of monitoring and evaluation. The study recommends targeted stakeholder engagement and collaborative strategy development to enhance the sustainability of biogas management and utilization, with an emphasis on environmentally friendly technologies.
Keywords: *biogas, tourism village, environment, green energy, net zero*

1. INTRODUCTION

Dependence on fossil fuels contributes to increased carbon emissions, leading to global climate warming and environmental degradation [1]. The Paris Agreement marked a pivotal moment for countries around the world to commit to developing frameworks and targets aimed at reducing greenhouse gas emissions [2]. The Net Zero emissions scenario, as a follow-up to the Paris Agreement, sets a target for global energy sector CO_2 emissions to be reduced to 23 Gt by 2030 and to reach net zero by 2050 in order to limit the temperature increase to only 1.5°C [3]. Net Zero policies can be implemented through the use of new and renewable energy sources and can result in the production of green products [4]. The use of renewable energy sources serves as a concrete step to reduce reliance on fossil-based fuels, while promoting clean and environmentally friendly energy [5]. The Net Zero concept aligns with the goals of sustainable development, encompassing equity, socio-ecological sustainability, and efforts to improve community economic well-being [6].

Indonesia declared its commitment to achieving a Net Zero emissions target by 2060 during the G20 Summit. The country has set targets for new and renewable energy to account for 23% of the national energy mix by 2025, and at least 31% by 2050 [7]. These targets are being pursued in light of the fact that Indonesia's oil reserves are projected to be depleted within the next 9 to 10 years. According to Statistics Indonesia (BPS), the country's coal reserves can only support energy needs for approximately 62 years, while natural gas reserves are expected to last for about 35 years [8]. Continued exploitation of oil and gas reserves will ultimately lead to their depletion, especially considering that fossil resources require millions of years to form [9]. Therefore, alternative energy sources are urgently needed to replace them. Indonesia possesses substantial renewable energy potential; however, its utilization remains suboptimal, and progress has yet to show significant improvement [10].

The commitment to developing new and renewable energy is also demonstrated by South Africa, which supports actions to prevent environmental degradation and has taken the initiative to invest in a fundamental shift from a fossil fuel-based energy consumption system to renewable energy [11]. The United Kingdom has pursued a similar approach by targeting industrial decarbonization through hydrogen energy to achieve net zero, and has shown interest in adopting hydrogen-fueled equipment for both commercial and household use, despite challenges arising from the dynamics of achieving cross-sectoral economies of scale and public acceptance of renewable energy sources [12]. Yang et al [13] assert that environmentally friendly technological innovation is one of the key drivers of green economic growth through the concept of empowerment. Furthermore, research findings by Ji & Yang [14] indicate that tourism development is causally linked to green economic growth supported by the use of renewable energy sources.

In rural areas, there is a high dependency on firewood and liquefied petroleum gas (LPG) as primary energy sources [15]. This reliance contributes to increased greenhouse gas emissions and leads to significant economic, health, and environmental costs. Clean production technologies apply various production management strategies to generate profit while minimizing environmental impact through energy efficiency, avoidance of hazardous and toxic substances, and waste reduction. Biogas technology offers an efficient alternative energy resource while also empowering local communities. As a multipurpose solution, biogas addresses economic, health, social, and environmental issues simultaneously [16]. The development of biogas enhances the efficient use of environmentally friendly resources, contributing positively to the tourism sector [17]. Biogas systems can be implemented in rural areas through active community participation [18].

Renewable energy sources can be found in rural areas through the utilization of livestock waste to produce biogas. The use of biogas derived from agricultural by-products or waste has the potential to reduce greenhouse gas emissions [19]. According to Kaharudin & Sukmawati [20], household-scale biogas systems can be developed using waste from 2 to 4 livestock animals or approximately 25 kg of manure per day to power a reactor with a capacity of 2,500–5,000 liters. This system can produce biogas equivalent to 2 liters of kerosene per day, sufficient to meet the cooking energy needs of a rural household with six family members [21]. From an economic perspective, the use of biogas can reduce household monthly expenses by approximately Rp 50,000 to Rp 60,000 [22].

The study conducted by Batistuta [23] concluded that, based on the Root Mean Square (RMS) values of biogas sustainability, the social, environmental, technological, and institutional dimensions are categorized as moderately sustainable, indicating the need for strategies to improve their status. Hanif [24] found that the energy contained in 1 m^3 of biogas ranges from 2,000 to 4,000 kcal, which is sufficient to meet the cooking needs of a family of 4–5 members for approximately three hours. A study on biogas-based edutourism conducted by Haryanto [25] recommended that the management of livestock waste into biogas be utilized as an educational medium to raise students' awareness of environmental sustainability. Learning activities involving biogas production—whether through direct participation or application-based methods—can serve as valuable role models for future educational practices.

The empowerment-based utilization of biogas, particularly in rural areas, has been explored by Y. Chen et al. [26] who reported that only around 19% of the potential biogas has been utilized in rural China. In a subsequent study, Chen et al. [27] found that dry methane fermentation serves as a model for large-scale biogas production from agricultural waste. Furthermore, Wang et al.[28] highlighted that rural biogas development in China has experienced rapid progress over the past fifteen years, supported by government policies and subsidies. The study also recommended that household biogas usage be continuously encouraged for long-term sustainability. In Indonesia, Roubík & Mazancová [29] have examined the potential for developing small-scale biogas systems and their suitability in rural areas of North Sumatra. The development of renewable energy in small islands such as Karimunjawa and rural areas has shown promise in addressing energy challenges, supporting socio-economic activities, and contributing positively to global efforts in mitigating climate change [30]. However, no research has been found that specifically addresses the sustainability of biogas management as a renewable energy source within ecotourism villages, particularly in Pancoh, Indonesia.

Based on that explanation, the aim of this study is to examine how the application of renewable energy sources, specifically biogas, can be utilized sustainably in accordance with Sustainable Tourism

Development (STD). The concepts used in this research include economic sustainability [31], environmental sustainability [32], and social sustainability [33]. The supporting and inhibiting factors include the availability of livestock waste, community participation, collaboration among stakeholders, human resources, infrastructure and technology [34], as well as the monitoring and evaluation of the sustainability of renewable energy management

2. METHODS

This study employs a descriptive qualitative design, referencing phenomenological research and case study methodologies Klagge & Brocke [35]; Sovacool et al.[36]; Vilkė et al [37]. The research is conducted from April to June 2024. Pancoh Ecotourism has been selected as the research site for the topic of sustainable management of renewable energy sources, as Pancoh is the only tourist village in Sleman Regency, Indonesia, that applies sustainable ecotourism with biogas management as a renewable energy source and tourism attraction [38]. Data collection is conducted through structured interviews with six key informants who are knowledgeable about the concept of sustainable biogas management, including:

Table 1. Demographic Profile of the Informant

No	Code	Status	Occupation
1	INF01	Stakeholders	Biogas Group Coordinator
2	INF02	Stakeholders	Ecotourism Pancoh Advisor
3	INF03	Stakeholders	Environmental Agency
4	INF04	Stakeholders	Tourism Agency
5	INF05	Stakeholders	Homestay Owner
6	INF06	Stakeholders	Tour Guide

Source: *Data Processed by Researchers*

The researcher also conducted observations at the communal biogas site and homestays, as well as gathered supporting data from the ecotourism village and articles discussing the topics of "biogas utilization", "new renewable energy", "Pancoh ecotourism", and "the sustainable management of biogas". The data were tested for reliability and validity before drawing conclusions [39]. The collected data were categorized according to the indicators of economic, environmental, and social sustainability, as well as supporting and inhibiting factors. The validity of the data was then tested through triangulation of theory, methods, and locations. Finally, conclusions and analysis were made based on the findings.

3. RESULT

3.1 Study Area

Pancoh Ecotourism Village is located in Yogyakarta, Indonesia. Its favorable natural conditions and the agricultural activities carried out by the local community are integrated into tourism attractions that generate economic value, uphold socio-cultural values, and promote environmental awareness. In addition to nature-based tourism, Pancoh also has community-managed livestock farming. According to the Village Medium-Term Development Plan, the livestock population includes 123 cattle with 132 workers involved, and 268 goats managed by 284 workers.

Figure 1. Pancoh Ecotourism Village Map

Source: *Data Pancoh Ecotourism Village Manager, 2022*

Figure 1 shows that the potential location of the Pancoh ecotourism village is agriculture (*Pancoh Ecotourism Village Manager, 2022*). In Pancoh, approximately 76.5% of the population is employed in the agriculture and livestock sectors, while the remaining residents work as civil servants, private employees, or entrepreneurs. The agricultural potential and available human resources in Pancoh serve as key strengths in adapting to changing circumstances. The 2010 eruption of Mount Merapi devastated the primary livelihoods of farmers, with volcanic ash severely affecting most of the salak fruit plantations. In response, local NGOs began assisting the community in identifying alternative economic potentials beyond agriculture. Aligned with the development of the ecotourism village, the government, academics, and NGOs supporting ecotourism initiatives discovered that livestock waste in the village had not yet been optimally utilized. Livestock are raised primarily for sale or dairy production. While some residents already use livestock waste as fertilizer, others leave the manure to accumulate in sheds near their homes. Stakeholders have since provided support for managing ecotourism in Pancoh, including the installation of biodigesters to convert livestock waste into biogas.

3.2 *Sustainable Tourism Development (STD) Framework on Biogas Management in Pancoh Ecotourism Village*

Biogas is a potential alternative energy source derived from agricultural and livestock waste, serving as a substitute for non-renewable energy. As a form of renewable energy, biogas can effectively replace fossil fuel consumption. Its raw materials are obtained through the processing of livestock and agricultural waste, which can be utilized by communities as a substitute for natural gas [40]. This study discusses each indicator to identify and analyze the management of biogas as a renewable energy source based on community empowerment in a sustainable manner.

3.2.1 Economic Sustainability

The local economic benefits of biogas management refer to the positive economic impacts generated within a specific community or region. Biogas management can create new economic opportunities, such as the sale of by-products like organic fertilizers, which are marketed to local farmers. It also leads to energy cost savings. Furthermore, previous study shows that the installation of biogas systems reduces the consumption of firewood and liquefied petroleum gas (LPG) [41], and creates employment opportunities for local residents. Community members are actively involved in the processing of livestock waste and the maintenance of biogas installations. In the long term, biogas utilization results in cost efficiency by reducing dependency on fossil-based energy sources and increasing agricultural productivity through land management systems that use more environmentally friendly organic fertilizers. The use of biogas for energy purposes generates positive economic impacts by lowering household fuel expenditures. Additionally, the by-products of biogas, such as liquid and solid fertilizers, have market value. This reduces the need for chemical fertilizers, thereby supporting organic farming and livestock activities [42].

These local economic benefits not only assist individuals but also support sustainable development at the community level. The direct advantages of biogas management for local residents include reduced fuel costs and the sale of biogas by-products such as organic fertilizers. This indicator also encompasses the economic sustainability of biogas projects in contributing to environmentally conscious community income. According to Tumwesige et al.[43], the efficiency of small-scale biogas use is 55% for cooking, 24% for heating engines, and 3% for lighting. Each cubic meter (m^3) of biogas is equivalent to approximately 0.46 kg of LPG. Based on this assumption, a 3-kg gas cylinder can be filled with 6.5 m^3 of biogas, which requires waste from approximately 4.3 cows, while a 12-kg cylinder can be filled with 26 m^3 of biogas from about 17.4 cows [44].

If dairy farmers on average own four cows [45], then a 3-kg gas cylinder can be filled within 1–2 days, while a 12-kg cylinder can be filled within 4–5 days. If managed properly, farmers could produce 15–30 units of 3-kg gas cylinders or 6–8 units of 12-kg gas cylinders per month. Therefore, livestock waste should be utilized as biogas for household fuel [46];[45]. Based on this technical and economic assessment, biogas technology is considered feasible for development.

The benefits perceived by the Pancoh community are described as follows:

Figure 2 Utilization of Biogas for Cooking

Source: Personal Archive, 2025

Based on Figure 2, biogas is utilized as a substitute for LPG as cooking fuel. An interview with the Sleman Regency Environmental Agency revealed the following statement:

"*The government has been providing assistance for Sustainable Tourism Development (STD) since 2015. The biogas produced in Pancoh has received a high score because the village has been utilizing renewable energy by converting waste or by-products from the area into a potential renewable energy source*." [INF03]

This finding is in line with Alexopoulos [47] which states that biogas is a central component of the farming system that combines waste processing, heat and electricity production, and fertilizer production. The utilization of waste to produce biogas is economically competitive, especially in addressing the rising costs of fuel and inorganic fertilizers. Therefore, livestock waste produced is not a financial burden for farmers, but rather, it holds high economic value while reducing pollution and environmental contamination [48]. With the presence of ecotourism, the process of converting livestock waste into biogas has become one of the educational attractions (as shown in figure 3), making contextual learning about biogas production more meaningful. Students are directly involved, building their knowledge and linking it to real-life situations, which encourages them to apply what they learn in their daily lives. Students are equipped with knowledge, skills, and an environmentally conscious attitude, enabling them to play an active role in solving environmental problems [49].

Figure 3. Education on Biogas Processing

Source: Personal Archive, 2025

The sustainability of utilizing biogas as a substitute for LPG and as an educational tool for the local community and tourism visitors is essential for supporting sustainable tourism. In the long term, the global financial development and the global consumption of renewable energy have a significantly positive impact on environmental conservation. On the other hand, economic growth leads to an increase in carbon emissions worldwide [50]. Renewable energy emerging today is a specific or advanced form of primary energy sources (solar, wind, geothermal, biofuels, biomass, and hydro) or new technologies [51]. The penetration of renewable energy into the energy market has been occurring much faster than anticipated in recent years. By 2030, it is estimated that 15–20% of our primary energy will be sourced from renewable energy Bilgen et al.[52] making the continued management of biogas in Pancoh crucial for its sustainability.

3.2.2 Enviromental Sustainability

Livestock waste is a major source of toxic gases, harmful pathogens, and odors. Therefore, proper management of livestock waste is essential to reduce pollution and protect the environment. The

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appropriate utilization of livestock waste into biogas and compost is highly beneficial for improving crop yields and ensuring sustainability [53]. The term "biogas" generally refers to the gas produced through the biological decomposition of organic materials in the absence of oxygen. Biogas is one of the products formed during the anaerobic digestion process and consists of CO2, CH4, H2S, H2, H2O, and several trace compounds depending on the composition of the substrate [54]. Biogas is estimated to be 20% lighter than air. It has a combustion temperature range of 650-750°C, with a calorific value ranging from 4,800 to 6,700 kcal/m3, which is lower than that of pure methane, which reaches 8,900 kcal/m3 [55].

The formation of biogas through an anaerobic system involves three main stages: 1) Hydrolysis, which is the breakdown of easily soluble organic materials and the digestion of complex organic substances into simpler forms; 2) Acidogenesis, where simple sugars formed during the hydrolysis stage serve as food for acid-forming bacteria; and 3) Methanogenesis, the process of methane gas formation [56]. The advantage of anaerobic fermentation over aerobic fermentation is its high reduction of organic materials, making it an effective method for waste treatment [28]. The biogas and fertilizer produced at the end of the anaerobic process can be used for cooking, lighting, and electricity generation.

The management of biogas has several significant environmental impacts, including the reduction of greenhouse gas emissions such as methane and carbon dioxide, which are typically released from organic waste decaying in landfills or agricultural lands [57]. The management of organic waste by converting it into a useful energy source, along with the utilization of by-products from the biogas production process, known as digestate or nutrient-rich organic fertilizer, helps improve soil fertility and reduce reliance on chemical fertilizers. Additionally, the process contributes to the reduction of sulfur dioxide, nitrogen oxides, and other harmful particles that affect human health and the environment. Furthermore, it decreases dependence on fossil fuel sources, thus contributing to energy sustainability.

"*The general rules in Pancoh include: no littering, no defecating in the river, and no damaging the surrounding natural environment*." [INF02]The researcher also conducted observations at the cattle shed (as shown in figure 4 and 5) and found a significant amount of livestock waste scattered around the area.

Figure 4. Signboard of the Communal Cattle Barn

Source: Personal Archive, 2025

Figure 5. Piles of Cattle Manure

Source: Personal Archive, 2025

Livestock waste is often left piled up or abandoned, creating an eyesore, emitting unpleasant odors, and making the barns appear unclean. This unhygienic condition can attract disease vectors such as flies and mosquitoes, compromise the health of the cattle—some of which suffer from injuries—and contribute to air pollution. According to Holcomb et al. [58] improperly managed livestock manure can have detrimental effects on the surrounding environment through contamination of soil and surface water, as well as methane gas emissions into the atmosphere. The technical requirements for a clean, hygienic, and healthy environment have not been met in the communal barn, which poses negative environmental consequences [53].

The utilization of biogas energy offers several advantages, including the reduction of unpleasant livestock manure odors, the prevention of disease transmission, the mitigation of greenhouse gas emissions, the generation of heat and mechanical/electrical power, and the production of valuable by-products such as solid and liquid fertilizers [59],[60], [61], [46]. Biogas can be used primarily for cooking, lighting, and powering water pumps at the individual level, as well as for electricity, heat, power generation, and even fuel for vehicles at the industrial level [62]. Additionally, biogas helps address environmental issues such as soil degradation, deforestation, CO_2 emissions, indoor air pollution Bond & Templeton [54] organic pollution, and social problems such as dependence on firewood and fossil fuels.

Dianawati and Mulijanti [46] stated that 1 m^3 of biogas is equivalent to powering a 60–100 watt lamp fr 6 hours, cooking three meals for 5–6 people, 0.7 kg of gasoline, operating a 1 HP motor for 2 hours, or producing 1.25 kWh of electricity. According to Susilaningsih et al. [45], the annual cost of biogas fuel is approximately IDR 400,000, which is significantly lower than firewood (IDR 900,000), LPG (IDR 2,520,000), and kerosene (IDR 1,980,000). Thus, the use of biogas as a fuel source is more economical compared to other energy sources. However, the poor condition of cattle sheds, the lack of maintenance of biodigesters, and the tendency of homestay operators not to utilize biogas hinder the optimal achievement of environmental sustainability.

3.2.3 Social Sustainability

Social sustainability in biogas management refers to how biogas projects can provide long-term social benefits to the community. This includes several aspects, such as: improving community welfare by providing affordable and environmentally friendly energy sources; creating new job opportunities across various stages, from raw material collection, biogas plant operation, to distribution and maintenance; enhancing public health; empowering communities to manage the systems; and reducing the potential for social conflict arising from competition over limited energy resources [55]. This indicator assesses how biogas management contributes to improving the quality of life, including access to clean energy and better health outcomes due to reduced reliance on traditional fuels such as firewood.

Below is an excerpt from the interview with the Sleman District Tourism Office:

"*The sustainability of biogas management still requires assistance from the Sleman District Tourism Office. We have observed that there have been initiatives for waste processing and biogas utilization, but these efforts are still carried out individually and have not yet been implemented comprehensively*." [INF04]

Opportunities to utilize biogas and generate marketable value are still facing several obstacles and challenges. The results of an interview with the Biogas Group Coordinator revealed the following:

"*Currently, I am the only one processing livestock waste for the tourism attraction. I find it difficult to encourage the community to participate because not everyone can tolerate the smell of the waste, and the technology is still manual*." [INF01]

The sustainability of biogas in creating job opportunities and reducing environmental impacts is still suboptimal. The number of individuals involved is limited, with a lack of understanding, consistency, and inadequate management. These findings are in line with research Ajieh et al.[63] which suggests that there is a significant knowledge gap within the community, thus requiring increased awareness, policy formulation, and sustainable management regarding the importance of biogas production. Several surveys indicate that the utilization of household biogas has decreased significantly, and more digesters are being discontinued [28]. This condition was also found in research, which showed that public trust has an impact on the sustainability of the program Mancini & Raggi [64] and research X. Yang et al.[65] indicating that the adoption of biogas production is strongly influenced by economic incentives, particularly those aimed at diversifying income sources for farmers by combining livestock and biogas production, leading to a reduction in agricultural land.

3.3 Biogas Management Supporting Factors

3.3.1 Value Added

The value added of biogas aims at the economic, environmental, and social benefits derived from its production. This concept includes enhancing the quality of biogas by increasing its methane content as a substitute for fossil fuels, environmental sustainability through the utilization of organic waste, and the broader impact on sustainability and economic development with the availability of renewable energy sources and job creation [66]. According to the homestay owner, the value added obtained is as follows.

"*The value added from managing livestock waste into biogas, in addition to producing gas for cooking, is that the resultin waste can be used as fertilizer for vegetables*." [INF05]

From the informant statement, it can concluded the added value derived from biogas management, includes economic, environmental, and cultural benefits. These benefits stem from the use of biogas as a substitute for LPG fuel and as an environmentally friendly fertilizer for farmers and the community. This statement aligns with findings from studies H. Chen et al.[67], Xiong et al.[68] which suggest that small farmers benefit economically, with an income increase of 15–20% from the sale of electricity and fertilizer. Environmentally, the reduction in methane emissions is equivalent to 2.1 tons of CO_2eq per year per reactor.

3.3.2 Availability of Livestock Waste

The availability of livestock waste refers to the quantity, continuity, and physical-chemical characteristics of livestock waste that can be utilized for biogas production, organic fertilizer, or industrial raw materials. The number of cattle in Kalurahan Girikerto is 1,055. Each cow produces 10–15 kg of manure per day, so 15-20 cows are needed to generate biogas on a household scale. Reactor tanks with capacities of 2,500–5,000 liters are used to process the manure into biogas, which is equivalent to 2 liters of kerosene per day and can meet the cooking energy needs of a rural household with 6 family members Heriyanti et al.[69], Rahmat et al.[21]. Therefore, the potential of livestock waste can meet the gas needs for 70 households, or more than half of the 182 Heads of Families in Pancoh. This finding complements the results of a study Roubík & Mazancová,[29] which indicates that the potential for developing small-scale biogas systems in rural areas is supported by a sufficient amount of animal waste as raw material and biogas digester design.

3.3.3 Community Participation

Community participation in biogas management in rural areas involves the active involvement of local residents in all stages of the biogas process, from planning and construction to the maintenance of the biogas system. This includes contributing labor, utilizing organic waste from households or agriculture as raw materials, and using the generated energy for daily needs [70]. Biogas management in rural areas requires the community's role to ensure the sustainability of the program. Active participation needed may include providing raw materials such as livestock manure, food waste, or agricultural waste, participating in socialization and training activities to understand how biogas installations work, including the maintenance and management of post-process waste, utilizing the products for cooking, lighting, or other energy needs, and being involved in maintaining and caring for biogas installations to keep them functioning optimally, such as cleaning the biodigesters regularly or acquiring skills to fix minor repairs. Community participation was expressed by the biogas group coordinator and Homestay Owner, as follows:

"*The utilization of biogas came almost simultaneously with ecotourism, where NGOs offered the locals training in biogas processing at the group's cattle pens. Eventually, the locals were invited to provide land for a communal biogas project, and I received training and support*." [INF01]

"*The biogas produced in Pancoh is a pilot project. The community is encouraged to use the waste or trash available in their area as a potential source of renewable energy*." [INF05]

Based on the statements from the informants, community participation is encouraged by NGOs and the government to manage waste and trash into biogas. The community's participation in managing methane gas into biogas can enhance the community's welfare [70]. This finding aligns with research Sari et al.[71], which indicates that community participation has a significant impact on biogas utilization, especially in the stages of extension services, and needs to be enhanced in terms of the number of livestock providing biogas raw materials and direct assistance.

3.3.4 Collaboration Among Stakeholders

Collaboration among stakeholders in the sustainable management of biogas refers to the synergy between government, private sector, communities, academics, NGOs (Non-Government Organizations), and media in designing, implementing, and monitoring an economic, environmentally friendly, and socially inclusive biogas system. This collaboration involves role distribution, knowledge exchange, fundraising, and monitoring the sustainability of social, economic, and environmental impacts.

Figure 6. Training on Livestock Waste Management

Source: Personal Archive, 2025

Figure 6. illustrates that the livestock waste management training in Pancoh involves various stakeholders, including social organizations such as the Scout Movement. The development of village potential is carried out by the Village Government through the Village-Owned Enterprises (BUMDes) and the Micro, Small, and Medium Enterprises (MSME) Forum, in collaboration with academics, innovators, and relevant government agencies in Sleman Regency. The forms of guidance and assistance include support for creative industries such as batik, recycled crafts, and tourism development. This aligns with the findings of Sari et al.[71], which emphasize that the involvement of government bodies, local communities, investors, non-governmental organizations, and farmers in biogas projects—guided by clean energy transition principles such as accountability, transparency, equity, and responsibility—is essential to overcoming barriers and ensuring the success of biogas initiatives.

3.4Biogas Management Inhibiting Factor

3.4.1 Limited Human Resources

The limitation of human resources in biogas management refers to the shortage of skilled personnel in technical areas such as digester repair and optimization, insufficient knowledge in governance, and limited managerial capacity that hinders the planning, development, operation, and sustainable maintenance of biogas systems. The shortage of labor involved in biogas management is illustrated by the following statement:

"*Pancoh Wetan is not involved; many of the young people have become migrant workers. In fact, if managed properly, this (biogas) could be more profitable than working abroad*." [INF06]

The lack of interest among the younger generation and the broader community in biogas management is evident from field observations at the communal livestock facilities, where member participation in cleaning activities remains minimal. There is a limited sense of ownership over the infrastructure, and active involvement in digester maintenance has yet to emerge.

This finding complements previous studies indicating that community participation in biogas initiatives is often limited to attending training sessions and providing labor during construction, while long-term engagement tends to rely on individual efforts, thereby impeding optimal management [71]. Moreover, new energy projects may also give rise to significant issues of recognition and procedural injustice, such as the lack of acknowledgment of farmers' and community members' lived experiences, livelihood needs, and voices of Indigenous peoples. These include historical rights to land, natural resources, and autonomous governance, all of which can trigger prolonged intra- and inter-community conflicts (Romero-Lankao et al., 2023).

3.4.2 Limited Infrastructure and Technology

Indicators of infrastructure and technological availability include the presence of physical facilities and technological tools that support the production, processing, and distribution of biogas as a renewable energy source. Infrastructure components consist of biodigesters, storage tanks, gas distribution networks, and waste treatment equipment. Technology, on the other hand, encompasses both software and hardware used to enhance efficiency, control emissions, and optimize biogas production processes. Sustainability can be achieved when the infrastructure is durable, requires minimal maintenance, and is manageable by the local community [72].

In the Pancoh ecotourism area, two communal biogas units are located near residential areas, designed to meet the energy needs of approximately ten households. The construction cost of a 4–5 m^3 digester in Yogyakarta in 2011 was approximately IDR 2 million, with a projected return on investment by the sixth year [73]. The size of the biogas reactors varies between 1 and 150 m^3, and common designs include fixed-dome, floating-drum, and plug-flow types. The following figure shows the location of the communal biogas units.

The condition of the digester, which has been in use for over ten years, was described by an informant as follows:

"*This biogas digester was built in 2015 and is currently not functioning well; there is a significant buildup of sediment that should have been cleaned. We do not know how to resolve the technical issues—there used to be monitoring, but now it is no longer in place*." [INF01]

"*The limitations of communal biogas systems are also attributed to insufficient land availability. The close proximity between residential houses does not meet the spatial requirements for proper digester installation*." [INF05]

Previous biogas management efforts were supported by both government agencies and non-governmental organizations. The assistance provided included the construction of two digesters; however, only one remains operational. This limitation is attributed to restricted land availability, the close proximity of residential buildings, and the continued use of traditional technologies. These findings are consistent with Patinvoh & Taherzadeh [74] which state that infrastructural limitations pose significant barriers to policy implementation. In developing countries, biogas technology still requires advancements at all levels—from small-scale (household/domestic use) to large-scale applications such as energy generation, electricity production, and transportation.

This result also aligns with the findings of Roopnarain & Adeleke [75] who, in a case study conducted in Africa, identified key barriers to biogas technology adoption, including cost implications, lack of communication, and limited sense of ownership. Therefore, government-supported capital investment and the development of policies to facilitate biogas technology implementation are necessary to promote community prosperity.

3.4.3 Limited Monitoring and Evaluation of Renewable Energy Programs

Monitoring is defined as a systematic process to observe and track the implementation of renewable energy programs. This includes monitoring progress, usage, challenges encountered, resource use efficiency, infrastructure maintenance, and the associated socio-economic impacts [76]. Evaluation, on the other hand, involves in-depth analysis based on sustainability indicators of renewable energy sources, such as biogas production efficiency, reactor durability, operational and maintenance costs, emission reduction levels, and the degree of community adoption of the program in both the short and long term [77]. Observational findings related to one of the monitoring devices located at the communal livestock facility are presented in the figure 7.

Figure 7. Group Livestock Facility Monitoring Station
Source: Personal Archive, 2025

Observations at the site indicated that the monitoring device is no longer functional. When this condition was inquired about, the informant provided the following statement:

"*Currently, there is no more monitoring, so the damage to the equipment and the cleanliness of the digester are not being monitored.*" [INF01]

Based on the results of observations and interviews, it can be concluded that monitoring and evaluation of the program have not been carried out sustainably since the conclusion of the pilot project on the utilization of livestock waste as a renewable energy source in the ecotourism village. This study reveals barriers that differ from previous research, which stated that community empowerment in biogas utilization had been successful and resulted in the long-term adoption of biogas by the community [71].

4. CONCLUSION

The commitment of the Pancoh Ecotourism Village to manage tourism with an environmentally sustainable concept is evident. As a pilot project for ecotourism, Pancoh has made efforts toward the sustainability of renewable energy sources. Economic sustainability is achieved through the utilization of cattle waste, which is processed into biogas that can replace LPG gas. Biogas is used for cooking activities in homestays and as an educational tool for visitors. Social sustainability is reflected in the involvement of the local community in biogas management. However, environmental sustainability in management has not been fully optimized, as there are still significant amounts of livestock waste accumulating, and there is a tendency for the community to continue using firewood.

There are both supporting and inhibiting factors in the sustainable management of biogas. This study encourages the government to provide incentives for ecotourism villages committed to environmental sustainability, including support for mentoring and equipment. The community should be involved in management from the production, marketing, and maintenance of the biodigester. Academics are expected to provide guidance in terms of skills and knowledge regarding the production of environmentally friendly fuel sources. The private sector should be involved in providing capital assistance and mentoring through CSR initiatives, especially in the development of innovations, including renewable energy in ecotourism villages.

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