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Biogas Technology for Strengthening Soil and Water Conservation: A Case Study in Leksana Village, Merawu Subwatershed

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Abstract Soil and water conservation is one of the keys to preserving natural resources. Livestock development can optimize the use of grass for soil and water conservation. However, livestock manure waste is a problem for the environment and health. This study aimed to explore the role of biogas technology in supporting the strengthening of soil and water conservation in the Merawu Subwatershed. Through a community empowerment approach, this research included educational programs, implementation of biogas technology, and evaluation of impacts on the environment and economic welfare of the community. After implementing the education program, the results showed a significant increase in public awareness related to environmental conservation. Biogas technology has been successfully installed in households as a pilot project and can operate the biogas system independently. It found positive environmental impacts, including improved soil quality and decreased organic waste load in local water sources. Increased economic welfare is also recorded through a decrease in costs for cooking fuel by 75%; moreover, there is a potential decrease in farming costs with organic fertilizers. The successful implementation of this biogas can be an inspiring model for households and other regions, demonstrating the potential of biogas technology as a holistic solution to soil and water conservation challenges. Although successful, the study identified several challenges, including the resilience of biogas systems to weather fluctuations and the program's expansion to a broader region. Recommendations were given to expand community education, improve technical sustainability, and strengthen stakeholder cooperation. In conclusion, this research makes significant contributions to the literature and practices of community empowerment and natural resource conservation, affirming that biogas technology can be a motor of sustainable positive change at the local level.

1. INTRODUCTION

The Merawu Subwatershed is an area rich in natural resources. However, the increasing human activity in the region, especially in the agricultural sector, is causing severe soil and water conservation challenges. The increasing rates of soil erosion and water quality degradation are significant issues that must be addressed

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immediately (Ngadisih et al., 2020). Livestock development can optimize the use of grass for soil and water conservation (Hani & Geraldine, 2019), apart from being a farmer's savings and income. Nevertheless, livestock manure waste becomes a problem for the environment and health if not managed properly (Gusti et al., 2022). Amidst these challenges, biogas technology is emerging as a sustainable solution that can meet people's energy needs and support the strengthening of soil and water conservation.

The use of biogas as an alternative energy source in the Merawu Subwatershed has excellent potential to reduce pressure on the environment and reduce methane (CH_4) emissions (Alhassan et al., 2019; Arshad et al., 2021; Tasmaganbetov et al., 2020). Biogas benefits areas with minimal conventional energy sources (Smirnov et al., 2021). By utilizing organic waste from the agricultural and livestock sectors, biogas technology can convert organic matter into clean, environmentally friendly, and sustainable energy sources (Akyürek, 2023; Kabeyi & Olanrewaju, 2022; Rafiee et al., 2021; Rahmat, 2023). In addition, this biogas can be an additional source of income for local communities, improving their welfare.

In addition to economic benefits, implementing biogas technology is also expected to positively impact soil and water conservation in the Merawu Subwatershed. The anaerobic process in biogas production produces nutrient-rich waste, which can be used as organic fertilizer to improve soil fertility. Thus, using biogas waste as organic fertilizer can help reduce the use of chemical fertilizers that tend to damage soil and water.

This study explores the role of biogas technology in supporting the strengthening of soil and water conservation in the Merawu Subwatershed. Through this research, we strive to explore the full potential of biogas technology in supporting soil and water conservation in the Merawu Subwatershed. By understanding local challenges and applying participatory approaches, it is expected that the implementation of this technology can facilitate a successful and sustainable model for community empowerment and environmental preservation in the region. This holistic approach lays the foundation for our research in formulating strategies that can have a long-term positive impact on the Merawu Subwatershed ecosystem and the well-being of local communities.

2. METHOD

2.1 Study site

Leksana Village is one of the villages located in Karangkobar District, Banjarnegara Regency, Central Java Province. The topography is in the form of mountains with a more than 40 degrees slope. The land cover in Leksana Village is dominated by moors and gardens. There are two distinct farming systems in this area, i.e., agroforestry and intensive crop production systems. The relative position of the study site is presented in Figure 1.

Most of the people in Leksana Village make a living as farmers. They use the land to plant cabbage, potatoes, corn, and beans by applying planting patterns in agroforestry and intensive agriculture. Erosion that occurs on agricultural land causes reduced soil fertility, thereby reducing the productivity of land affected by erosion. For this reason, planting grass and terraces is expected to reduce the erosion rate. Farmers use grass for animal feed, especially cows and goats. Livestock is a form of farmer savings that guarantees the family economy. Livestock maintenance will release livestock manure, which, if not appropriately managed, can pollute the environment and interfere with health.

2.2 Process and methods of research

The biogas implementation process was carried out in three main stages, i.e.: 1) pre-development; 2) development; and 3) post-development. The pre-development stage was the stage of planning activities and designing the implementation of biogas technology. This stage included preliminary surveys, community discussions, and socialization. An initial survey was conducted to understand the community characteristics in the Leksana Village. We worked in focus group discussions (FGD) to convey our goals and gather aspirations from the local

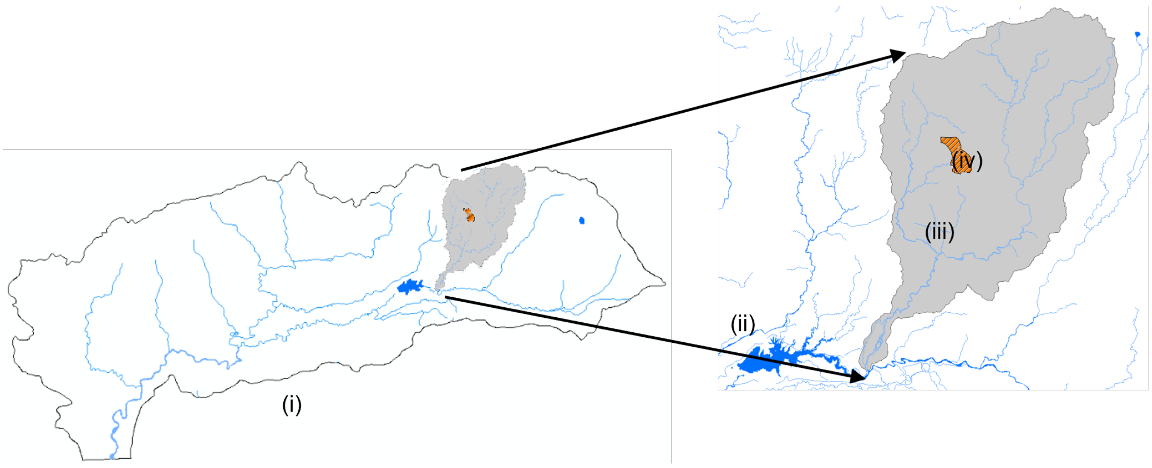

Figure 1 . Location of Leksana Village (i) Serayu Watershed; (ii) Mrica Reservoir; (iii) Merawu Subwatershed; (iv) Leksana Village

stakeholders. We selected participants based on purposive sampling techniques, a non-probability sampling that relies on the researcher's judgment (Creswell, 2014).

The plan prepared in the first stage was then implemented in the second stage, i.e., the development phase. The development phase involved preparing the area, procuring tools and materials, as well as the construction, training, and assistance in making bioreactors or biodigesters. The final stage was the post-development phase, in which the dissemination of information and evaluation after completing the construction and regulation of biogas were conducted. This phase assessed performance and determined the community's response to the program. Biogas technology development actively involves the community with space, ideas, and energy contributions.

3. RESULT AND DISCUSSION

3.1 The implementation of biogas technology

Before the implementation of biogas, an introduction and discussion with the community was carried out. The results of observations showed that the community is interested in biogas development. In addition, there was a significant increase in public awareness related to environmental conservation after implementing the education/extension program. A pilot project for biogas installations was carried out to ensure further biogas implementation. After in-depth discussions with the community, it was decided to build fiber-based biogas. The main reason for choosing this material is to minimize potential damage due to slope movement or landslides (Satriagasa et al., 2020) because Laksana Village is an area that is prone to landslides (Hutomo & Maryono, 2016; Mudasih, 2019).

Biodigester technology is applied to produce methane (CH_4) gas, an alternative renewable fuel source using raw materials derived from livestock manure (de Souza Guimarães & da Silva Maia, 2023), which can used by residents as energy for cooking at the household scale (Hasanudin et al., 2021). In addition, using biodigesters improves environmental sanitation, reduces the odor pollution of livestock manure waste, and produces biogas dregs as fertilizer (Aji & Bambang, 2019). Indirectly, biodigesters were used to improve economic structure, create new job opportunities, and decrease energy dependence on foreign bioenergy investment (Dinçer et al., 2023). Biodigester technology can be an alternative fuel that replaces firewood, liquefied petroleum gas (LPG), and kerosene to support people's daily lives (GeethaThanuja et al., 2023). With a volume specification of 4 m3 made from fiber, this biodigester is used as a pilot unit in the study site for one family with 2-3 cows (Figure 2).

Biogas technology has been successfully installed in one household as a pilot project, and the biogas system can be operated independently. It found positive environmental impacts, including improved soil quality and decreased organic waste load in local water sources. Increased economic welfare is also recorded through a decrease in costs for cooking fuel by 75%; besides, there is a potential decrease in farming costs with organic fertilizers.

The application of biodigester technology provides several benefits, including 1) reducing environmental pollution due to accumulated livestock manure (Sujono & Kusuma, 2022); 2) can be used as an alternative fuel to support people's daily activities, for example, cooking; 3) the by-products have been successfully processed into

Figure 2 . Biogas installation process: (a) Agroforestry; (b) Discussion; (c) Biodigester installation; (d) Biogas for cooking

organic fertilizers so that people can save costs for fertilizer purchases and increase their income; 4) can reduce production prices in farming activities; and 5) biodigester technology is one form of conservative effort to divert from and reduce the dependence of community member on intensive agricultural activities. It is expected that with these conservative efforts, upstream communities can become successful farmers with equal sources of income and realize independence in disaster-resilient villages.

The successful implementation of this biogas can be an inspiring model for other households and regions, demonstrating biogas technology's potential as a holistic solution to soil and water conservation challenges. Although successful, the study identified several challenges, including the resilience of biogas systems to weather fluctuations and the program's expansion to a broader region. Recommendations were given to expand community education, improve technical sustainability, and strengthen cooperation among stakeholders (Al Batistuta et al., 2021).

The farmer stated that the biogas technology is simple, easy to implement, and easy to maintain. The perception of biogas users regarding environmental impact was that the biogas technology can reduce pollution, reduce sources of disease, and improve environmental quality. Biogas technology can relatively save fuel costs and is cheaper than other fuels but it is less sufficient as cooking fuel. The limited availability and the disadvantage of biogas in meeting the cooking fuel needs. Discussions with the community showed that they agreed to process manure into biogas and support the government's program in biogas processing.

3.2 Advantages and disadvantages of biogas

The utilization of livestock and organic waste in biogas has several advantages, including: A renewable energy source that is cheap to operate and environmentally friendly (Nasution, 2020) helps in organic waste management; biogas creates independent local energy sources up to the household level, reduces dependence on outside energy sources, and allows energy diversification, leading to energy transition to clean energy. In addition, biogas will reduce the use of fossil fuels that cause climate change. Economically, biogas will improve welfare by lowering costs and increasing income. Cost reduction includes farming costs by replacing inorganic fertilizers with organic fertilizers from the biogas process. It has reduced energy costs by reducing electricity and LPG energy used by households with biogas energy. The observations showed a 75% reduction in energy costs for cooking from previous energy use. In addition, there is potential income from the sale of organic fertilizers and slurry from the biogas process. On the other hand, there is a possible decrease in livestock waste processing costs, which also means reducing health costs and environmental pollution from livestock waste.

In addition to the advantages of biogas technology, the community has encountered several weaknesses. Biogas installations require a relatively high initial investment, so it is necessary to find a solution, especially if the price of fossil energy is still too low and subsidized. Moreover, the biogas process requires the availability of organic raw materials and manure that continues to be available. The availability of these raw materials varies depending on seasonal factors that can affect the performance of the biogas system. Besides raw materials, it also requires sufficient availability of clean water for the anaerobic process. Although biogas can be a sustainable energy source, small-scale biogas production has not been able to meet household energy needs due to limited energy produced. Biogas systems also require good maintenance and management to operate efficiently, such as monitoring pH, temperature, and methane gas content and ensuring that leakage does not occur and the biogas process continues. The anaerobic fermentation process in biogas production can be influenced by temperature and weather factors that will affect the efficiency of biogas production (Fauziah & Hidayatullah, 2023). Although biogas is a clean energy source, the process produces by-products such as hydrogen sulfide and liquid waste that need to be addressed according to environmental standards (Ahmad et al., 2021; Angkat et al., 2020). The sustainability of the biogas system also depends on the availability of supporting infrastructure, such as gas distribution networks, appropriate biodigesters, and other equipment that may not be available in certain areas.

4. CONCLUSION

The development of biogas technology is one of the efforts to strengthen soil and water conservation, accelerate the energy transition, improve welfare, and improve environmental conditions. The community welcomes and enthusiastically develops the biogas program, which is realized by the community's desire to participate in development activities from the planning stage to implementation and management. The positive impact has been felt, and the potential is developed in a broader range. However, high initial investment, community education to improve its sustainability, and continuous community empowerment are still needed, along with creating sustainable conservation markets.

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CONFLICT OF INTERESTS

The authors declare there is no conflict of interest.

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