Barriers to the Adoption of Biogas Technology in Smallholder Dairy Farming in Indonesia: A Case Study in Semarang Regency, Central Java

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Abstract. This study aims to identify and analyze the barriers faced by dairy farmers in adopting biogas technology in Manggihan Village, Semarang Regency. This village was selected as a case study due to its significant trend of increasing biogas installations. Farmers in Manggihan Village have a good understanding of biogas potential as an alternative energy source. They are aware of the benefits of biogas in reducing operational costs, preserving the environment, and obtaining an affordable energy source. However, the adoption of biogas technology still faces several challenges, particularly the high initial investment cost. The increased adoption of biogas in Manggihan Village is influenced by several factors, such as government programs, rising conventional energy prices, and growing awareness of environmental importance. Based on the research findings, it can be concluded that with appropriate support, particularly from the government, the potential of biogas as an alternative energy source in the dairy farming sector is very promising. In addition to reducing biogas installation costs, one strategic measure that can be undertaken is reallocating a portion of LPG subsidies to fund biogas installations. This will provide incentives for farmers to switch to biogas and reduce reliance on fossil fuels.

1 Introduction

Energy is one of the basic human needs that plays a crucial role in supporting various life activities. Advances in technology, coupled with population growth, have created a new era of life that drives increased energy demand (Kandpal and Singh, 2022). Biogas holds potential as an alternative energy source for farmers. It is produced through the anaerobic

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digestion of organic materials, such as human and animal waste, organic waste, household waste, and other biodegradable materials (Sahara, 2024). In addition to serving as an energy source, biogas offers several benefits, including reducing greenhouse gas emissions, improving environmental quality, and producing organic fertilizer (Kasap, 2012). Anaerobic digestion is a sustainable method for waste management, providing environmental protection and economic savings by converting organic matter into biogas. This process also recovers resources and energy, reduces pollution from agricultural and industrial operations, and simultaneously offsets fossil fuel usage in operations (Chen, et al., 2008).

Approximately 90% of dairy farming in Indonesia is conducted by smallholder farmers, each owning 3 to 6 dairy cows (Susilorini, et al., 2022). These farms are typically small-scale and rely on simple technology. Smallholder dairy farming is of interest to agricultural policymakers in Indonesia, inspired by its success in South Asian countries, despite facing several major challenges (Remenyi, 2006). The increasing population of dairy cows, predominantly managed in smallholder farms, has intensified the negative impacts of poor manure management, leading to substantial amounts of untreated livestock waste (al Zahra, et al., 2020). It is estimated that 84% of dairy manure is disposed of without any processing, causing environmental pollution (De Vries and Wouters, 2017). The dairy cow population in Indonesia is projected to grow by 16.01% from 2022 (507,075 cows) to 588,280 cows in 2026, with milk production increasing by 15.22% from 824,273 tons in 2022 to 949,733 tons (Pusdatin, 2022).

The potential for biogas development is immense, given the large population of dairy cows. Livestock waste represents an abundant raw material for biogas production, which can serve as an alternative energy source (Sahara, 2024). However, the implementation of biogas technology in smallholder farms in Indonesia remains suboptimal due to resource and knowledge limitations (Sahara, 2024). The adoption of biogas technology in smallholder farming is further hindered by challenges such as high investment costs and perceived complexity (Dyah and Sriharti, 2019).

This study aims to identify and analyze the barriers faced by smallholder dairy farmers in Manggihan Village, Getasan District, Semarang Regency, in adopting biogas technology. The village was selected because it exhibits a growing number of biogas installations and is considered more successful compared to other villages. The findings of this study are expected to represent the challenges faced by smallholder dairy farmers in other regions of Indonesia. Additionally, the study aims to formulate policy recommendations and strategies to address these challenges and enhance biogas utilization in smallholder farming systems.

2 Metodologi

The study was conducted in Manggihan Village, Getasan District, Semarang Regency, Central Java Province, during November and December 2024. This research utilized both primary and secondary data. Primary data collection was carried out through surveys using structured questionnaires, while in-depth interviews were conducted to complement the findings. A total of 32 smallholder dairy farmers from Manggihan Village participated in the study.

Purposive sampling was employed to gather primary data regarding farmers' characteristics and their perceptions of the use and adoption of biogas. Secondary data were also included to support the discussion. These secondary data were obtained from various sources, including the Manggihan Village profile, websites, and various research publications. These sources provided information on (1)The geographical conditions of Manggihan Village, (2) Population data and the number of dairy farmers, (3) The population of dairy cattle, and (3) The number of biogas installations.

Analysis of Farmers' perception terhadap Biogas

Farmers' perceptions of biogas were analyzed based on multiple attributes, encompassing both attributes of biogas usage as a product and farmers' willingness to adopt biogas. The multi-attributes of biogas usage as a product include: (i) the use of biogas as a substitute for LPG, (ii) the ease of biogas production technology, (iii) consumer availability (market share), (iv) the affordability of the product for consumers, and (v) the ease of marketing bioethanol products.

Meanwhile, the multi-attributes of farmers' willingness to adopt biogas include: (i) community acceptance of biogas technology, (ii) affordability of technology adoption costs, (iii) dissatisfaction with existing practices, (iv) input limitations, (v) land availability, (vi) sufficiency of technological information, and (vii) availability of additional workforce.

Perception data were initially qualitative ordinal data, which were then converted into quantitative data through a scoring (scaling) technique and subsequently averaged [Chikuta, 2014; Widodo, 2022]. Farmers' perceptions of the attributes of biogas usage and adoption levels were categorized into four scales, ranging from 1 to 4, with categories of very poor, poor, good, and very good, as shown in Equation 1 [Milkias, 2019].

$$Score = \frac{n_i.s_i}{N_i}$$

Where n_i is the number of respondents in column $_i$ ($_{i=1,2,3}$), s_i is the score of statement $_i$ ($_{i=1,2,3}$), and N_i is the number of respondents in row $_i$ ($_{i=1,2,3}$).

Subsequently, the performance score for the multi-attributes is determined within a 4-scale interval, as shown in Equation 2.

:

$$Interval\ scale = \frac{highest\ score - lowest\ score}{number\ o\ f\ interval\ scale}$$

Attributes with higher scores are perceived as good, while those with lower scores are perceived as poor. The assessment of farmers' perception categories is based on the mean of attributes, which are mapped into four perception categories, as follows: 1)Very low perception with a mean score of 1.00–1.75, 2) Low perception with a mean score of 1.76–2.50, 3) High perception with a mean score of 2.51–3.25, and 4) Very high perception with a mean score of 3.26–4.00.

Farmers' views on these four products are illustrated using perceptual mapping through radar charts [Gigauri, 2019].

3 Results and Discussion

3.1 Farmers Caracteristics

Manggihan Village, located in Getasan District, Semarang Regency, is one of the villages in Semarang Regency. It is situated at coordinates 110°14'54.75" – 110°39'3" East Longitude and 7°3'57" – 7°30'0" South Latitude. The elevation of Manggihan Village is 800 meters above sea level (masl), with the lowest elevation in Seturun Hamlet and the highest in Sengon Hamlet (Manggihan, 2024). Manggihan Village consists of 599 households, 246 of which are dairy farmers. Among these dairy farmers, 62 households (or 25.20%) have installed biogas systems. Of all the dairy farmers, 85.16% (218) are smallholders, with an average ownership of 3.7 dairy cows per farmer. According to Matondang and Rusdiana, (2013), more than 90% of farmers in Indonesia are smallholder farmers characterized by relatively small-scale operations, typically ranging from 1 to 5 cows. The characteristics of smallholder farmers in Manggihan Village are presented in Table 1.

Tabel 1. Farmers Characteristics of Manggihan village.

No	Parameter's	
1	Farmer's age (years)	49.41 ± 13.29
2	Farming Experience (years)	25.97 ± 14.93
3	Education	
	Elementary school,	50.00%
	Junior high school	18.75%
	Senior high school	28.13%
	University	3.13%
4	Family income (USD)	155,22 ± 60,73
5	Primary Job	
	Farmer	50.00%
	Employee	15.38%
	Livestock farmer	23.08%
	Trader	11.54%
6	LPG requirement (kg/month)	9

Source: Research results, 2024

The average age of dairy farmers in Manggihan Village is slightly higher than that of farmers in Lembang, West Bandung Regency (44.86 years) (Sudrajat, et. al., 2022) and the overall average age in West Java, which is around 46 years (Akzar et al., 2022). The average age of farmers in Manggihan, reaching 49 years, indicates that their physical capacity tends to decline, which often results in suboptimal livestock maintenance (Sudrajat, et. al., 2022).

The experience of dairy farmers in Manggihan Village is similar with Fadillah, et al., (2023) reported that the average farming experience of dairy farmers in West Java is 19.1 years. Research by Satiti, et al., (2022) stated that farmers in Samiran Village, Boyolali Regency, predominantly have more than 15 years of farming experience.

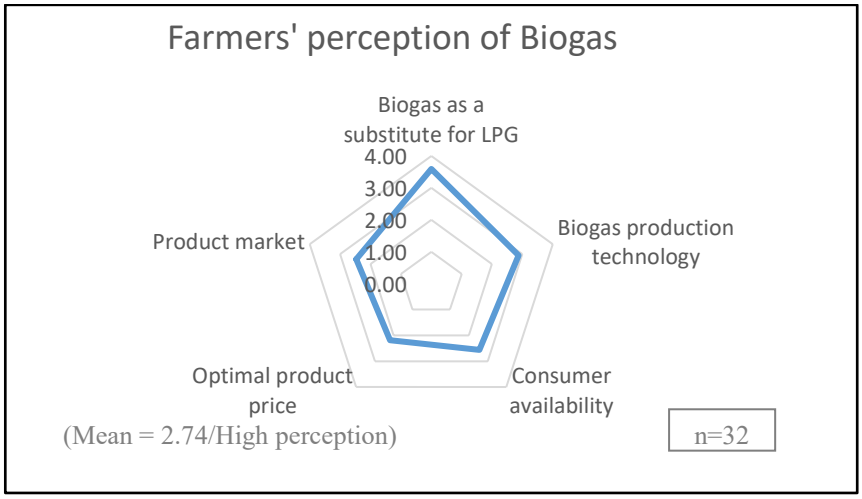
The education level of farmers in Manggihan Village is dominated by primary education. This finding is consistent with research conducted in the same regency by Haloho et al., (2013), where 51.3% of farmers were primary school graduates. However, it differs from findings in other regions by Satiti, et al., (2022) and Nurdiyansah, et al., (2020), where farmers' education levels were dominated by high school graduates at 77.27% and 40%, respectively. Education and farming experience influence awareness and the adoption of technology (Takanjanji and Kaka, 2022). Farmers with longer experience and higher education levels tend to exhibit greater awareness and higher rates of technology adoption (Akzar, et al., 2022).

The primary occupation of most farmers in Manggihan Village is farming, while only 23.08% are primarily livestock farmers. This aligns with Satiti, et al., (2022) findings, which reported that 45.45% of farmers are primarily crop farmers, while 31.82% are primarily livestock farmers. Most small-scale dairy farming operations are managed as secondary businesses, leading to suboptimal attention to their management (Haloho et al., 2013).

This is reflected in the average income of farmers, which remains below the 2024 Semarang Regency Minimum Wage of USD 159.20 (Central Java Province, 2024). Low income has driven many young people in Manggihan Village to work in factories around Semarang and Salatiga. Parents play a crucial role in educating and raising awareness among the younger generation about the potential of dairy farming and the utilization of by-products to support family income (Firman et al., 2018). This is essential to ensure the sustainability of the

livestock sector in Manggihan Village, so it does not rely solely on factory jobs in the Semarang and Salatiga areas.

3.2 Farmer's Perception on Biogas



Source: Primary data 2024 (processed)

Note: scala/category:
a. 1,00-1,75 = Very low perception
b. 1,76-2,50 = low perception
c. 2,51-3,25 = High perception
d. 3,26-4,00 = Very high perception

Figure 1. Farmers' perceptions of biogas

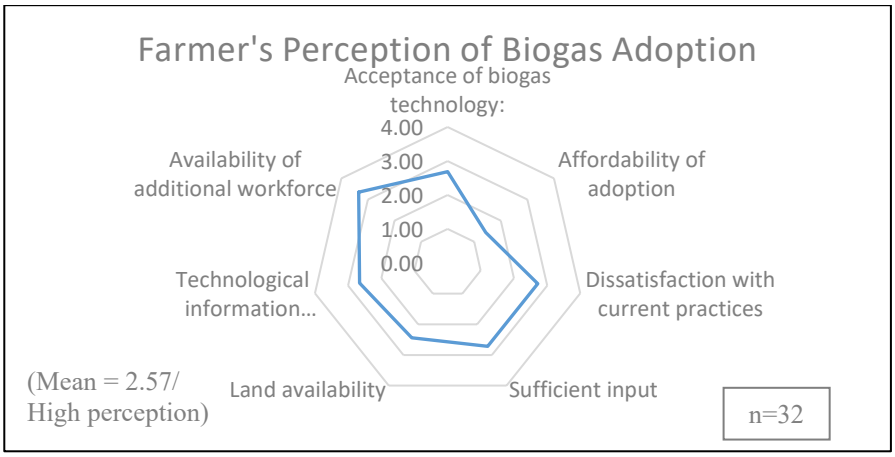
Farmers have a high perception of biogas, primarily driven by the benefits they perceive from its use in daily life. One of the main factors contributing to this perception is the potential of biogas as a substitute for LPG. Farmers are consumers of subsidized LPG from the government, and there are certain moments when LPG gas becomes scarce (Kompas, 2023). In such situations, biogas significantly helps meet the energy needs of farmers. The use of biogas can save on expenses and provide long-term positive impacts on household economics (Savitri, et al., 2024). Circular economy principles in biogas can optimize the use of biomass resources (Situmeang, et al., 2022). Biogas is seen as a more cost-effective, environmentally friendly, and easily accessible alternative energy source for farmers, especially in rural areas. These factors contribute to the increasingly positive perception of biogas, both in terms of its attributes as an LPG substitute and its consumer availability.

The technology for biogas production is also an important factor that supports the positive perception. Farmers believe that the technology for producing biogas has become easier to implement, thanks to the available training and technical guidance. This perception differs from the research by Ariyanti, el at., (2024), which mentioned that beef cattle farmers in Karanganyar Regency perceived biogas technology as difficult to replicate. The positive perception in Manggihan Village is due to the active role of village officials and agricultural extension workers in socializing and educating farmers about biogas technology. The interaction between farmers and information sources, such as extension workers, plays a crucial role in the process of biogas technology transfer, helping farmers obtain sufficient information and knowledge to enhance their understanding of the technology (Putra. et al., 2019).

However, there are some factors that contribute to a lower perception of biogas among farmers, such as the price of biogas products and market access. These results align with the

research by Arianti, et al., (2024), which found that farmers still consider biogas to be relatively expensive and difficult to market. Biogas technology is often perceived as requiring high initial investment and maintenance costs (Tigabu, et al., 2015), leading farmers to perceive the price of biogas as high and its marketing as challenging.

3.3 Farmers Perception of Biogas Adoption



Source: Primary data 2024 (processed)

Note: scala/category:
a. 1,00-1,75 = Very low perception
b. 1,76-2,50 = low perception
c. 2,51-3,25 = High perception
d. 3,26-4,00 = Very high perception

Figure 2: Dairy Farmers' Perception of Biogas Adoption in Manggihan Village

Farmers have a high perception of biogas adoption. Factors such as acceptance of biogas technology, dissatisfaction with current practices, sufficient raw materials, ease of technological information, and availability of additional labor contribute significantly to this perception. A study in Paser Belengkong found a significant positive relationship between farmers' perceptions and the implementation of biogas technology (Tohri, et al., 2019). This perception is important because individuals' views on relative advantages and their experiences with biogas installations significantly contribute to the acceleration of technology adoption among farmers (Putra, et al., 2019). According to Ahmad, et al., (2023), the decision to adopt biogas in rural households is significantly influenced by relative advantages, trialability, and observability. Regarding the availability of labor, some previous biogas users were former firewood users, and the labor required for biogas operations is less than the labor required to gather firewood.

However, land availability contributes only slightly, while the affordability of adoption costs has a very low contribution to farmers' perception of biogas adoption. Smallholder households are characterized by low incomes with limited assets and resources, including small land (Purwantini, et al., 2021). Farmers in Manggihan typically keep cattle behind their homes, and some farmers live in densely populated areas with limited land, making it difficult to install biogas systems.

The upfront costs of biogas installations are substantial, which is a primary impediment to widespread adoption, especially among small-scale farmers (Diouf and Miezan, 2019). It should be noted that all biogas installations in Manggihan Village are provided by the government, and dairy farmers do not incur any costs for installation. There are several reasons why dairy farmers generally struggle to finance biogas installations independently:

A) High initial investment costs, according to Wahyudi (2017), the investment required to build a biogas digester is quite high, and some farmers believe it is more profitable to use the funds to increase livestock numbers or purchase land than to invest in building a biogas digester. B) Long payback period, the payback period for a biogas digester compared to LPG as a cooking energy source, calculated without subsidies and without commercial interest loans, shows that the investment in a biogas digester will be recovered in about 6 years (Atmaja, et al., 2014). C). Limited access to capital: Many farmers, especially small-scale farmers, have limited access to funding sources such as bank loans (Purwantini, et al., 2021). One potential solution is to create more affordable biogas installation packages. Currently, the biogas package installed in Manggihan Village costs about 1,000-1,200 USD. Farmers hope that the price of one biogas installation package can be reduced to around 300-400 USD. Currently, the Indonesian government provides a substantial amount of funding for energy subsidies, including the subsidy for LPG purchases. The LPG subsidy for 3 kg gas in Indonesia in 2024 is 4.915 million USD. The actual price of a 3 kg LPG gas is 2.62 USD, with a subsidy of 1.84 USD, allowing the community to purchase it for 0.78 USD (Antaranews, 2025). Farmers who do not use biogas typically consume an average of 3 cylinders of 3 kg LPG gas per month. If this subsidy were redirected to support biogas installation, it would only be needed once over several years, and the LPG subsidy for farmers in the coming years could be eliminated. There are currently cheap biogas installation alternatives with prices around 300 USD, which would be equivalent to the subsidy for 4 to 5 years.

Biogas has a positive impact on improving environmental quality and generating direct economic savings in rural areas (Atmaja, et al., 2014). Manggihan Village is one of the areas contributing to livestock waste runoff into Rawa Pening Lake. This lake, located in Semarang Regency, is the confluence of 14 tributaries, a volume of 48.15 million m3, and a sedimentation rate of 778.93 tons per year (Jatengprov, 2024), with revitalization costs from the Ministry of Public Works and Housing in 2024 amounting to 4.4 million USD (LKPP, 2023). It is time for efforts to stop sedimentation and the growth of water hyacinth upstream to begin. The costs of cleaning Rawa Pening Lake from water hyacinth and dredging sedimentation are very high. It would be more practical to redirect those funds for biogas development in upstream villages like Manggihan and the surrounding villages.

3.4 Biogas Adoption

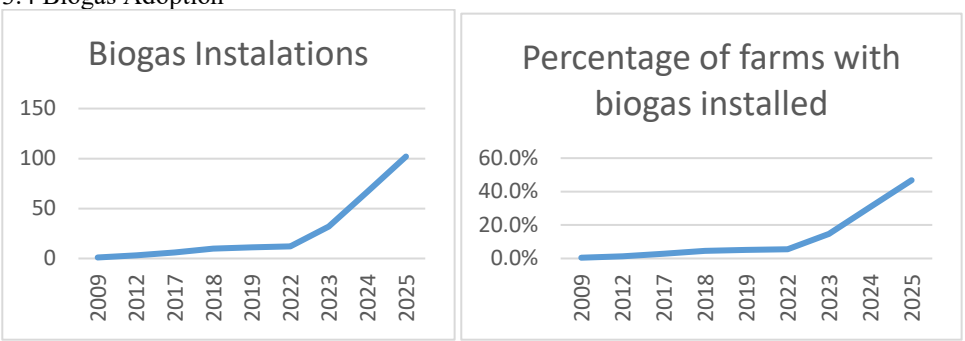


Figure 3: Trend of Biogas Installation Growth and Percentage of farms with biogas installed in Manggihan Village

Based on Figures 3, the adoption of biogas technology continues to increase. The growing number of biogas installations indicates that more dairy farmers in Manggihan Village are adopting this technology. This may be due to increased awareness among farmers about the benefits of biogas, such as cost savings, clean energy, and better waste management. Factors influencing biogas adoption among smallholder farmers in Indonesia include education,

female involvement, livestock ownership, income, availability of funds, and engagement with stakeholders (Putra, et al., 2019). The sharp increase in 2022 and 2024 suggests that there were factors driving the acceleration of biogas adoption during these periods.
Factors that may have contributed include: a. Increased biogas productivity, with the addition of a desulfurizer tool, making farmers more satisfied with the biogas equipment they have. b. Government programs. Biogas from agricultural waste can play a role in the energy transition, but it requires state incentives (Kabeyi and Olanrewaju, 2021). c. Rising conventional energy prices: The increasing cost of conventional energy such as LPG may have encouraged farmers to seek more affordable alternatives like biogas. d. Increased environmental awareness: Growing awareness of the importance of the environment and clean energy may also be a driving factor.
Potential for further growth: The continued upward trend through 2024 indicates that there is still significant potential for the growth of biogas installations in Manggihan Village. In 2025, it is expected that a proposal for the installation of 35 biogas units will be submitted. Currently, Manggihan Village has just introduced a new biogas system made of rubber, with an installation cost of 300 USD. The response from farmers is still unknown as the installation is limited to 5 farmers in December 2024. Hopefully, with the reduction in installation costs, this will encourage more farmers to adopt biogas technology in Manggihan and other regions in Indonesia.

4 Conclusion

Small Holder Farmers in Manggihan Village, Semarang District, has high perception on biogas as a product and willingnes to biogas adoption, reflecting a relatively high level of acceptance. However, some farmers face challenges due to limited land availability. The primary barrier to adopting biogas technology is the inability of farmers to afford the necessary biogas equipment. The government should recognize biogas as an opportunity to promote renewable energy while achieve long-term savings on 3 kg LPG subsidies. In addition to efforts to reduce biogas installation costs, government subsidies could provide significant support to small-scale farmers.

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