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Improving Community Economic Resilience through Biogas as a Sustainable Alternative Energy

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Abstract

Purpose: The study aims to assess the potential of biogas derived from cow manure to replace LPG in rural households, while strengthening community resilience and improving economic conditions.
Methodology: A descriptive quantitative approach was applied, using statistical analysis of data collected from 39 households in Mundu Village, Tulung District, Klaten Regency that actively use biogas.
Results: The findings show that biogas usage leads to a 75% reduction in LPG consumption and generates monthly savings ranging from IDR250,000 to IDR300,000. The average initial investment of IDR8.6 million indicates strong long-term economic feasibility.
Applications/Originality/Value: This research offers empirical evidence on the viability of biogas as an alternative household energy source in rural Indonesia, highlighting its capacity to decrease dependence on fossil fuels through locally available resources.

Introduction

Indonesia is currently facing a substantial challenge in meeting the growing energy needs of its households. Liquefied Petroleum Gas (LPG) remains the dominant energy source due to its efficient distribution network and ease of use. However, excessive reliance on LPG generates several issues, including price volatility that can burden household finances, supply disruptions during periods of crisis, and a heavy dependence on imports that weakens national energy security (Mustofa et al., 2023). Additionally, such dependence leaves the domestic energy sector vulnerable to fluctuations in global markets. The production and consumption processes associated with LPG also contribute to carbon emissions, intensifying global warming and ecological pressures. These conditions underscore the urgent need to explore energy alternatives that are more sustainable and environmentally responsible. Renewable options such as solar energy and biogas offer promising pathways to reduce LPG dependency while mitigating its environmental impacts (Nugroho et al., 2025).

This research is guided by the Sustainable Livelihood Framework (SLF), which emphasizes the strategic use of local assets such as natural capital, physical infrastructure, and human capital to reinforce community resilience against external vulnerabilities, particularly within the energy sector. This theoretical foundation is highly relevant for initiatives that convert organic waste into renewable energy, such as biogas, which can diversify and strengthen household livelihood strategies. Such efforts align with the principles of sustainability from both economic and ecological standpoints (Purnomo & Yusriadi, 2023). Converting organic waste into energy not only reduces dependence on fossil fuels but also fosters better environmental management. By utilizing locally available resources, communities can lower their exposure to energy price volatility and enhance economic stability. Moreover, the expansion of renewable energy sourced from organic waste supports the long-term goal of establishing an energy system that is both sustainable and environmentally sound (Jaiswal et al., 2022).

Research on biogas as an alternative energy source has been extensive, demonstrating its considerable potential to reduce dependence on fossil fuels such as LPG or firewood. Ningrum et al. (2018) find that biogas utilization in rural areas of Indonesia can reduce household energy expenditures by up to 40%. Biogas also provides additional benefits, as its production byproducts can be used as organic fertilizers that improve agricultural productivity (Elizabeth, 2021). In this regard, biogas not only enhances energy sustainability but also supports food security and contributes to rural economic stability. However, studies by Fitri et al. (2024) indicate that limited public awareness of its benefits, coupled with infrastructural constraints, continues to impede the broader adoption of biogas technologies.

According to data from the BPS, Indonesia's cattle population has suIDRassed 17 million head. Each mature cow produces between 20–30 kilograms of manure per day, which can theoretically generate around 1–2 cubic meters of biogas daily (Mustofa et al., 2023). This substantial potential makes cattle manure an exceptionally valuable renewable energy

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resource. Biogas derived from cow dung can be utilized for various household needs, particularly cooking an essential activity across many regions. Moreover, adopting biogas as an energy source can reduce reliance on increasingly scarce fossil fuels that continue to drive up living expenses.

In Mundu Village, more than 1,200 cattle are owned by local residents; however, much of the manure remains underutilized. Of the 149 cattle farmers in the village, only 70 have successfully converted livestock waste into biogas. With proper management, this waste could be transformed into a renewable energy supply capable of meeting the daily energy needs of approximately 250–300 households. This sizeable potential presents an opportunity not only to reduce dependence on LPG but also to strengthen environmental sustainability through improved waste management practices. Beyond the abundance of raw materials, Mundu Village also faces limited access to LPG due to geographical and distribution challenges (Hidayah & Perwithosuci, 2024). Its relatively remote location from central Klaten and inadequate road infrastructure contribute to high distribution costs and unstable LPG availability. These conditions position biogas as a particularly strategic and locally appropriate alternative. By leveraging readily available resources, the community holds significant potential to build a self-sustaining energy system and enhance household-level energy resilience.

The research gap in this field lies in the limited number of studies that systematically measure the contribution of biogas to reducing LPG consumption, its effects on household energy expenditures, and its environmental implications at the village level. Existing research has primarily focused on technical aspects of biogas production and broader efficiency metrics, without empirically assessing its practical application and substitution potential in livestock-rich rural settings (Fitri et al., 2024; Mustofa et al., 2023). Furthermore, studies examining the capacity of cattle manure to generate biogas and its LPG substitution rate in specific local contexts such as Mundu Village in Klaten Regency remain scarce. This study aims to address this gap by assessing the potential of biogas as an alternative household energy source capable of improving energy resilience and promoting environmentally sustainable waste management at the village level.

The objective of this study is to determine the extent to which biogas derived from cow dung can replace LPG in meeting household energy needs. The research focuses on households in Mundu Village, Tulung Subdistrict, Klaten Regency. Specifically, it examines the potential biogas yield based on the existing cattle population, estimates the substitution rate between biogas and LPG, and evaluates the resulting impacts on energy cost savings and environmental sustainability. This study is expected to strengthen the role of biogas in enhancing rural energy resilience and to provide a conceptual foundation for developing locally grounded, environmentally sustainable energy management policies.

Literature Review

Grand Theory

The Sustainable Livelihood Framework (SLF), introduced by Chambers and Conway and referenced in Fitri et al. (Fitri et al., 2024), underscores the importance of leveraging local resources to enhance community well-being, particularly when facing vulnerabilities arising from external pressures. SLF categorizes the assets that shape community livelihoods into five forms of capital: natural, social, human, physical, and financial. This framework highlights the need to optimize these assets sustainably to strengthen household and community resilience. Within this perspective, biogas emerges as a renewable energy solution capable of improving energy security in rural areas that continue to depend on fossil fuels such as LPG and firewood. Utilizing livestock manure for biogas production reduces dependence on imported fuels while expanding access to environmentally friendly energy sources, aligning with core sustainability principles (Awan et al., 2024).

Biogas derived from livestock waste, especially in rural contexts, plays a meaningful role in enhancing both energy resilience and the local economy. SLF emphasizes the sustainable management of natural resources, and biogas as a renewable energy alternative strongly supports this objective. By converting organic waste such as cattle manure into usable energy, communities can produce a resource that is not only environmentally responsible but also capable of lowering household energy expenses, thereby improving overall welfare. Furthermore, biogas utilization contributes to more effective waste management practices, offering ecological benefits such as reducing methane emissions that negatively impact the climate. Thus, biogas development is fully aligned with SLF's principles, which prioritize resource diversification and the strengthening of community resilience through prudent and sustainable natural resource management (Singgih et al., 2024).

Literature Review

Biogas is a gaseous fuel produced through the anaerobic fermentation of organic materials such as livestock manure, agricultural residues, and household waste. The production process consists of four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. During hydrolysis, microorganisms break down complex organic matter into simpler compounds. These compounds are then converted into intermediary substances such as volatile fatty acids, hydrogen, and carbon dioxide during the acidogenesis and acetogenesis phases. The final stage, methanogenesis, involves the transformation of acetic acid and hydrogen into methane, which constitutes the primary combustible component of biogas (Mustofa et al., 2023). This process yields a versatile renewable energy source that can be used for cooking, lighting, and other household needs while simultaneously enabling the productive management of organic waste. As such, biogas development contributes to reducing dependence on fossil fuels and strengthening environmentally sound waste management practices (Said et al., 2025).

One of the principal advantages of biogas lies in its ability to decrease fossil fuel consumption and reduce greenhouse gas emissions, thereby supporting broader efforts to mitigate global warming. As a renewable energy source, biogas produces significantly fewer emissions compared with conventional fossil fuels, positioning it as a more sustainable and environmentally responsible alternative. Furthermore, biogas holds strong potential to replace liquefied petroleum gas (LPG) in household energy use, particularly in rural areas abundant in organic waste resources such as livestock manure and crop residues (Runtuni & Dewanti, 2019). By capitalizing on local materials, biogas not only offers a sustainable source of energy but also strengthens household-level energy resilience. Its adoption can lessen reliance on imported LPG, which is often subject to price instability and supply uncertainties. Consequently, biogas emerges as an important strategy for advancing long-term energy sustainability in rural communities (Gomez et al., 2025).

Anaerobic fermentation technology plays a crucial role in improving biogas production efficiency. Numerous studies have shown that optimized use of anaerobic reactors combined with careful regulation of environmental factors such as temperature and pH can significantly increase biogas output. Through the implementation of advanced fermentation techniques, the conversion of organic matter into biogas becomes more efficient, reducing energy losses and lowering operational costs (Liang et al., 2022). These technological innovations enhance the economic feasibility of biogas systems, particularly in rural regions with substantial potential for organic waste utilization. Proper technological interventions can improve both the quantity and quality of biogas produced, making it a more accessible and affordable energy alternative for rural households. Investments in efficient fermentation technology can therefore stimulate the sustainable expansion of renewable energy while reinforcing the resilience of local energy systems (Rafdi & Surnati, 2023).

Biogas

The economic benefits of biogas utilization in household settings are substantial, particularly in reducing liquefied petroleum gas (LPG) consumption and associated energy expenditures. Pokhrel & Pokhrel (2023) report that biogas can replace up to 50% of domestic LPG usage, depending on the production capacity and size of the digester. This substitution reduces reliance on fossil fuels and directly decreases household spending on energy. Similarly, a study by Geddafa et al. (2023) in Ethiopia demonstrates that 6 m^3 biogas systems are capable of fully meeting rural cooking needs, highlighting their potential to significantly lower household energy costs. Such findings are highly relevant for rural areas in Indonesia, where organic waste resources are abundant. By reducing dependence on LPG an increasingly scarce and costly fuel biogas adoption can strengthen household financial resilience and improve overall economic well-being.

Beyond financial savings, biogas adoption yields additional economic and environmental benefits for households. By lowering LPG consumption, biogas helps reduce one of the most significant spending categories for many rural families. Moreover, biogas supports environmentally responsible waste management by utilizing organic waste that would otherwise be burned or disposed of improperly (Meegoda et al., 2025). This process not only reduces greenhouse gas emissions but also minimizes air and soil pollution. Furthermore, the development of biogas systems can stimulate new economic opportunities in rural areas, including employment in waste collection, digester construction, and maintenance. Such initiatives promote community empowerment and strengthen local economic resilience, aligning with Sustainable Livelihood Framework (SLF) principles that emphasize the strategic use of local resources and community capabilities (Al Zahra et al., 2024).

Biogas also offers major economic advantages through reduced energy costs and decreased dependency on LPG. Pokhrel & Pokhrel (2023) found that biogas can substitute up to half of a household's LPG consumption, depending on digester size and feedstock availability. Supporting this, Geddafa et al. (2023) observed that household-scale biogas investments in Ethiopia are not only technically viable but also economically attractive, significantly lowering household energy expenditures. Bhatt & Tao (2020) argue that small-scale anaerobic digestion systems demonstrate strong economic efficiency, with promising returns on investment. Similarly, Kusz et al. (2024) note that biogas investments in the livestock sector can enhance business profitability by reducing operational costs. In the Indonesian context, Rianawati et al. (2021) emphasize that biogas plays a vital role in advancing the national energy transition by enabling the productive use of organic waste at the village level an approach consistent with SLF principles that advocate strengthening local economies through renewable resource utilization.

Methodology

Research Design

This study aims to examine the effect of biogas utilization on reducing liquefied petroleum gas (LPG) consumption in Mundu Village. Using a descriptive quantitative approach, the research analyzes patterns of LPG use before and after the adoption of biogas systems, while also assessing key variables such as digester capital investment, digester capacity, and the resulting economic benefits. The central focus is to evaluate the viability of biogas as an alternative energy source for the community. Descriptive statistical techniques were employed to compile and analyze data related to digester capacity, initial investment costs, and the monthly reduction in LPG consumption. In addition, exploratory qualitative elements particularly interviews were incoIDRorated to provide contextual depth and to clarify the quantitative results. Overall, this research offers a comprehensive assessment of the effectiveness of biogas in reducing LPG dependency in Mundu Village, situated in the Tulung Subdistrict of Klaten Regency.

Data Source

The dataset used in this study was obtained through direct observation, in-depth interviews with households in Mundu Village, and secondary data drawn from household records related to energy consumption and energy-related expenditures. The primary data consisted of interviews with biogas users residing in Mundu Village, Tulung District, Klaten Regency. Each interview lasting approximately 15–30 minutes was conducted between November 4 and 7, 2024. Respondents were selected using a puIDRosive sampling technique, targeting households that had utilized biogas for at least one year and had not received any form of external assistance. The data collected encompassed three key variables: (1) capital investment for digester construction (IDR), (2) digester capacity (m^3), and (3) monthly reductions in LPG consumption (kg or cylinders). The interviews also included questions regarding average monthly LPG expenditures before and after the adoption of biogas technology.

Data analysis was conducted using descriptive statistical methods, including the calculation of minimum and maximum values, means, and standard deviations. Interview results were systematically processed to determine the average monthly reduction in LPG usage and the corresponding financial savings for households. Additionally, the relationship between digester volume and the rate of LPG reduction was examined to evaluate the efficiency of biogas utilization. The processed data are presented in tables and graphs to improve clarity and support inteIDRretation.

Descriptive Analysis

To systematically analyze the collected data, descriptive statistical methods were employed to provide a comprehensive overview of data distribution, mean values, standard deviations, and the identification of potential outliers (Jogiyanto, 2013). This analytical approach is essential for understanding household energy consumption patterns and clarifying differences in LPG usage before and after the adoption of biogas technology.

Data Analysis

The descriptive analysis conducted in this study utilizes basic statistical tools to identify patterns, distributions, and key characteristics within the dataset. The analytical techniques applied include the calculation of mode, minimum and maximum values, mean, and standard deviation for each primary variable. The quantitative variables examined comprise digester volume (m^3), digester construction cost (IDR), year of construction, reduction in LPG consumption (tube/month), and household energy expenditure (IDR).

The mode is used to identify the most frequently occurring values in the dataset, such as the most common year of construction or the dominant digester size installed. The mean reflects the central tendency of each variable, while minimum and maximum values illustrate the overall range of the observed data (Jogiyanto, 2013). Standard deviation is applied to measure the degree of dispersion or variability relative to the mean value, providing insight into the consistency of household experiences across variables.

Data Visualization

Graphical representations were incoIDRorated to enhance the clarity and inteIDRretability of the findings (Jogiyanto, 2013). In this study, scatter plots and bar charts were utilized as visualization tools to explore patterns, investigate relationships between variables, and compare values across categories. Scatter plots are used to demonstrate relationships between pairs of quantitative variables. For example, the scatter plot comparing digester volume (m^3) and monthly LPG reduction (tubes/month) enables the assessment of whether a correlation exists between digester size and the degree of LPG savings achieved. The plotted points represent individual households, facilitating the identification of trends, deviations, and the potential strength of relationships.

Bar charts, on the other hand, are used to compare average or total values across different categories, such as LPG reductions grouped by year of digester construction or construction costs categorized by digester size. Bar charts provide a clear and direct visual comparison, making differences between groups easy to observe. Together, these visualization techniques offer an intuitive understanding of the data and strengthen the overall descriptive analysis by presenting quantitative findings in a more structured and informative manner.

Result

The primary objective of the research was undertaken in Mundu Village, located in the Tulung District of Klaten Regency, which is characterized by a substantial population of cattle, yet exhibits restricted access to liquefied petroleum gas (LPG). Mundu Village was selected due to its representative nature in illustrating the energy-related challenges prevalent in rural areas, in addition to the significant yet underutilized local resources. The application of bovine manure for biogas generation presents a viable resolution to the issue of reliance on fossil fuels, while simultaneously enhancing energy resilience at the community level. The methodological framework employed in this study is a descriptive statistical approach, which facilitates the organized presentation of data concerning the volume of processed bovine manure, the quantity of biogas generated, and the rate of substitution for LPG.

Descriptive Statistics

At the preliminary phase of the analysis, descriptive statistical computations are executed to furnish a comprehensive overview of the attributes of the amassed data. The derived descriptive statistics encompass the mean, median, minimum (min), maximum, and standard deviation of the subsequent variables:

Table 1. Descriptive Statistic

Variable	Modus	Mean	Min	Max	Std Dev
Digester Volume (m^3)	6	6.62	6	8	0.94
Digester Cost (IDR)	8,000,000	8,666,666	7,000,000	12,000,000	12,265,341
Years	2015	2015	2013	2017	0.96
Monthly Gas Reduction	396	369	192	576	81.46

(Source: Author, 2025)

According to the information presented in Table 1, the average digester volume is 6.62 m^3, with a modal value of 6 m^3, a minimum of 6 m^3, and a maximum of 8 m^3. The standard deviation of 0.94 indicates relatively low variation in digester size across the sampled households, suggesting that most units were constructed within a similar capacity range. The construction cost of the digesters shows an average expenditure of IDR 8,666,666, with a mode of IDR 8,000,000 and a cost range from IDR 7,000,000 to IDR 12,000,000. The relatively large standard deviation of IDR 12,265,341 indicates considerable variation in construction costs, which may stem from differences in digester size, technology used, material quality, or the geographical conditions of the installation site.

For the year of construction, both the mean and the mode fall in 2015, with a temporal span ranging from 2013 to 2017 and a standard deviation of 0.96 years. This suggests that most digesters were built within a similar period, reflecting a concentrated phase of biogas adoption in the village. In contrast, the monthly reduction in liquefied petroleum gas (LPG) consumption exhibits greater variability. The average reduction is 369 tubes per month, with a modal value of 396 tubes, a minimum of 192 tubes, and a maximum of 576 tubes. The standard deviation of 81.46 reflects substantial differences in LPG savings across households, likely influenced by household size, cooking frequency, digester performance, and overall energy needs. Taken together, these findings illustrate notable diversity in both the level of investment and the outcomes achieved from biogas utilization, highlighting that household-specific factors play an important role in determining the economic and energy benefits derived from the technology.

Findings

Table 2. Estimated Savings in Biogas Use

Years	LPG Costs/Year	Biogas Cost	Savings	Percentage Difference
1	IDR 756,000	IDR 8,666,666	-IDR 7,910,666	-1,046.4%
2	IDR 1,587,600	IDR 8,716,666	-IDR 7,129,066	-449%
3	IDR 2,502,360	IDR 8,766,666	-IDR 6,264,306	-250.3%
4	IDR 3,508,596	IDR 8,816,666	-IDR 5,308,070	-151.3%
5	IDR 4,615,455	IDR 8,866,666	-IDR 4,251,211	-92.1%
6	IDR 5,833,001	IDR 8,916,666	-IDR 3,083,665	-52.9%
7	IDR 7,172,301	IDR 8,966,666	-IDR 1,794,365	-25%
8	IDR 8,645,531	IDR 9,016,666	-IDR 371,135	-4.3%
9	IDR 10,266,084	IDR 11,943,588	-IDR 1,677,504	-16.3%
10	IDR 12,048,693	IDR 11,993,588	IDR 55,104	0.5%
11	IDR 14,009,562	IDR 12,043,588	IDR 1,965,973	14%

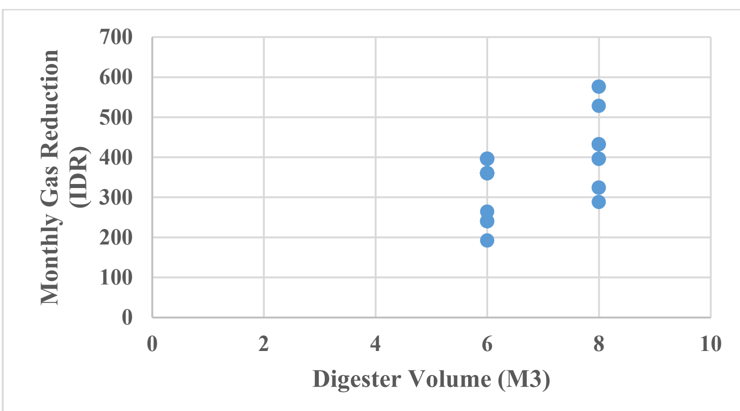
12	IDR 16,166,518	IDR 12,093,588	IDR 4,072,929	25.2%
13	IDR 18,539,170	IDR 12,143,588	IDR 6,395,581	34.5%
14	IDR 21,149,087	IDR 12,193,588	IDR 8,955,498	42.3%
15	IDR 24, 019,996	IDR 12,243,588	IDR 11,776,407	49%
16	IDR 27,177,995	IDR 12,293,588	IDR 14,884,407	54.8%
17	IDR 30,651,795	IDR 12,343,588	IDR 18,308,206	59.7%
18	IDR 34,472,974	IDR 12,393,588	IDR 22,079,386	64%
19	IDR 38,676,272	IDR 12,443,588	IDR 26,232,683	67.8%
20	IDR 43,299,899	IDR 12,493,588	IDR 30,806,310	71.1%

(Source: Author, 2025)

Based on Table 2, the economic benefits of biogas begin to materialize gradually, particularly when compared with the steadily rising cost of liquefied petroleum gas (LPG) driven by inflationary pressures. The analysis is grounded in several key assumptions: an initial LPG price of IDR 21,000 per kilogram with an annual increase of 10%, monthly biogas maintenance costs of IDR 50,000, and the annualization of biogas investment costs through depreciation. Under the assumption of proper digester management and the availability of cow manure as feedstock, additional operating costs remain minimal, ensuring that biogas remains financially stable over time. The results show that LPG expenditures grow exponentially from IDR 756,000 in the first year to IDR 43,299,899 by the twentieth year reflecting the compounded impact of the assumed 10% annual price increase. This pattern illustrates that although LPG may appear affordable in the early years, it becomes progressively less viable as long-term inflation erodes household purchasing power. The financial burden becomes particularly pronounced in the second decade, posing severe challenges for low-income households as rising LPG prices significantly strain budgetary capacity. In contrast, biogas costs are initially higher due to investment depreciation and routine maintenance needs (Dianawati & Mulijanti, 2015), but remain relatively stable over time.

In the first year, the total annual cost of biogas amounted to IDR 8,666,666, with modest increases in subsequent years, consistently ranging between IDR 8–12 million per year. A critical turning point occurs in the tenth year, when annual biogas expenses (IDR 11,993,588) fall below the annual cost of LPG (IDR 12,048,693). Although the initial difference is small, the gap widens shaIDRly in the following years due to the accelerating inflation-driven rise in LPG prices. The relative stability of biogas expenditures demonstrates its long-term cost efficiency, as it is not influenced by inflation or fluctuations in global fossil fuel markets. These findings reinforce the conclusions drawn by Dianawati & Mulijanti (2015), who highlight the strong potential of biogas in dairy-based communities to reduce long-term household energy expenses. Similarly, Harun & Sokku (2021) argue that converting household organic waste into renewable energy promotes both economic efficiency and environmental sustainability. For example, by the fifteenth year, households achieve savings of IDR 11,776,070 (49%) compared with LPG, rising dramatically to IDR 30,806,310 by the twentieth year. These figures firmly position biogas as a sustainable and economically advantageous alternative that can meaningfully reduce dependence on fossil-based energy sources.

Graph 1. Digaster Volume to LPG Gas Reduction per Month

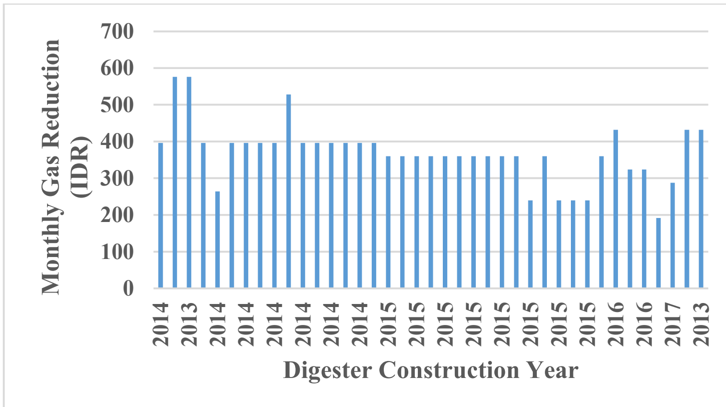


(Source: Author, 2025)

Graph 1 illustrates the relationship between digester volume and the corresponding reduction in monthly LPG expenditures (measured in Rupiah). A clear pattern emerges, showing that financial savings increase as digester volume becomes larger. At a capacity of 6 m³, the reduction in LPG costs ranges from IDR190,000 to IDR400,000 per month, whereas at a capacity of 8 m³, the savings range expands to IDR290,000–IDR580,000 per month. This indicates that larger digesters are capable of producing greater volumes of biomethane, thereby enabling a more substantial substitution of LPG.

These findings are consistent with Afrian et al. (2017), who observed that increases in digester capacity and optimized organic feedstock mixtures (such as cow manure combined with elephant grass) directly enhance biogas production. Similarly, Yakin et al. (2019) highlight the importance of operational stability such as maintaining optimal temperature and performing routine maintenance to ensure consistent gas generation. The variation in savings among households with digesters of the same size further suggests that biogas production efficiency is strongly influenced by feedstock quality, environmental conditions, and the technical proficiency of the operator. Overall, the graph strengthens the argument that investing in larger-capacity digesters constitutes an effective and economically advantageous strategy for households and rural communities seeking to reduce energy expenditures and increase energy self-sufficiency.

Graph 2. Monthly LPG Gas Reduction based on Year of Construction

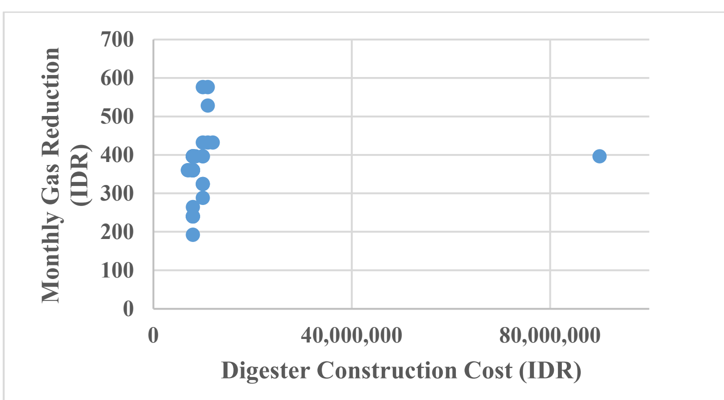


(Source: Author, 2025)

Graph 2 illustrates the monthly reduction in LPG consumption relative to the year in which each digester was constructed. Overall, the patterns presented in the graph do not show a linear relationship between digester age and the magnitude of savings. Several digesters built between 2013 and 2014 achieved monthly reductions exceeding IDR500,000, while others constructed more recently (2015–2017) generated savings of less than IDR300,000. This divergence indicates that efficiency is influenced not solely by the year of construction but also by a range of technical and managerial factors.

These observations align with findings from Mustofa et al. (2023), who highlight the critical role of operational and maintenance management in sustaining optimal biogas conversion performance over time. Likewise, Purnomo & Yusriadi (2023) emphasize that the effectiveness of biogas systems is shaped by the reliability of feedstock supply and the quality of digester construction. As a result, even older digesters may continue to operate effectively, while the actual amount of LPG savings depends primarily on routine maintenance, consistency in raw material input, and user practices in gas consumption. This evidence reinforces the notion that the long-term economic benefits of biogas are determined more by proper management and operational practices than by the chronological age of the digester itself.

Graph 3. Digaster Cost Against Monthly LPG Gas Reduction



(Source: Author, 2025)

Graph 3 illustrates the relationship between capital investment in digester construction and the corresponding monthly reduction in liquefied petroleum gas (LPG) consumption. The majority of observations show that digesters built with capital expenditures ranging from IDR 5,000,000 to IDR 15,000,000 are capable of generating monthly LPG savings between IDR 200,000 and IDR 600,000. Interestingly, one outlier appears in the dataset: a digester constructed with a capital investment nearing IDR 90,000,000 yields savings of only around IDR 390,000 per month an outcome not substantially different from systems built at far lower costs. This pattern suggests that investment magnitude does not necessarily correlate directly with energy-saving efficiency.

These findings are consistent with Harun & Sokku (2021), who emphasize that the effectiveness of household-scale alternative energy technologies is more strongly influenced by user competence, operational practices, and routine maintenance than by the size of the initial investment. Similarly, Oktavia & Firmansyah (2016) argue that biogas technologies designed to meet local needs characterized by simpler construction, lower costs, and reduced technical complexity often exhibit greater efficiency and reliability compared with more expensive, highly sophisticated systems. From an economic perspective, these insights highlight that moderate capital investments, when accompanied by appropriate system design and effective management, tend to produce a higher benefit–cost ratio. This solidifies biogas as a prudent, economically sound, and sustainable energy option for rural households seeking long-term reductions in fossil fuel dependency.

Discussion

This study demonstrates that biogas serves as a highly viable substitute for most household LPG needs in Mundu Village, reducing LPG consumption by approximately 75% on average. The adoption of biogas generates monthly financial savings ranging from IDR 250,000 to IDR 300,000, while simultaneously lowering dependence on fossil fuels and reducing carbon emissions associated with LPG combustion. These outcomes are consistent with development economics principles, which emphasize the importance of locally sourced energy diversification to strengthen energy autonomy and enhance rural community welfare (Susana & Suartika, 2017). Beyond its economic benefits, biogas also yields notable environmental advantages, including the reduction of livestock-related odors and the creation of cleaner and more hygienic living environments. With an initial digester investment averaging IDR 8,666,667.67, the technology has proven capable of generating long-term financial returns for households. The savings accumulated from reduced energy expenditures can be redirected toward essential needs such as children's education, healthcare, or small business development, thereby increasing household purchasing power and contributing to sustainable local economic growth (Dianawati & Mulijanti, 2015).

From a sociological standpoint, the use of biogas significantly enhances household energy security and helps reduce disparities in access to clean energy between urban and rural populations. However, the successful implementation of this technology depends heavily on the community's readiness in terms of knowledge, operational understanding, and management capacity. Limited awareness of biogas benefits, combined with restricted access to information and technical training, presents substantial barriers to wider adoption (Oktavia & Firmansyah, 2016). Therefore, government intervention and institutional support play a crucial role. Such support may include providing accessible financing schemes, facilitating training programs, and offering sustained guidance to ensure proper maintenance and long-term functionality. These efforts are essential not only for maintaining biogas program continuity but also for strengthening community participation in environmental stewardship and advancing autonomous, sustainable rural development (Harun & Sokku, 2021).

Although biogas has been shown to deliver significant economic and environmental benefits, its implementation in Mundu Village still faces a number of challenges that merit careful examination. One of the main obstacles is the substantial initial capital required for digester construction, which averages more than IDR 8 million. This cost presents a considerable barrier for low-income households, who are often compelled to prioritize immediate necessities over long-term energy investments (Afrian et al., 2017). Additionally, low levels of technological literacy and limited public understanding of the benefits and operational processes of biogas contribute to slow adoption rates. Many residents remain skeptical about the reliability and long-term sustainability of biogas systems. The lack of adequate outreach, education, and technical training further exacerbates this issue, resulting in insufficient operational and maintenance skills among potential users. Thus, a more holistic approach is needed one that focuses not only on the provision of technology but also on strengthening community capacity and social readiness (Nigrum et al., 2023).

Strong, coordinated support from various stakeholders including government agencies, non-governmental organizations, and financial institutions is essential to improve access to affordable financing, provide continuous training, and ensure sustained technical assistance. Such support is necessary not only to position community members as users but also to empower them as capable operators and long-term maintainers of the technology. The successful implementation of biogas systems depends on the alignment of appropriate technology with adequate social preparedness. If these challenges can be systematically addressed, biogas holds considerable potential as an alternative energy solution capable of fostering household energy self-sufficiency and advancing sustainable economic development within the village context (Singgih et al., 2024).

Conclusion

The findings of this research indicate that the implementation of biogas in Mundu Village has significantly reduced household dependence on liquefied petroleum gas (LPG), with an average decline in consumption of approximately 75%. Although the initial investment required for constructing biogas digesters is relatively high, the long-term savings generated from reduced monthly energy expenditures demonstrate strong potential for cost recovery. These financial savings positively affect household economic conditions by enabling the reallocation of resources toward productive puIDRoses such as education, healthcare, and small-scale economic activities.

From an environmental standpoint, biogas contributes to lowering carbon emissions and supports cleaner living conditions through improved management of organic waste. These ecological advantages underscore the broader sustainability benefits of biogas within rural contexts. Therefore, cross-sectoral support remains essential to ensure the continuity and expansion of biogas adoption. With the backing of appropriate policy frameworks and active community participation, biogas can evolve into a viable sustainable energy alternative, strengthening household energy resilience and contributing to the development of a more robust local economy.

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