Journal of Emerging Innovations in Engineering
Volume 1, Number 01, 2025
P-ISSN: xxxx-xxxx E-ISSN : xxxx-xxxx
Open Access: https://jurnal.sutajaya.org

Design and Construction of a Biogas-Fueled Power Generator

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Article Info
Article history:
Received March 12th, 2025
Revised April 20th, 2025
Accepted June 15th, 2025

Keyword:
Biogas; Renewable Energy; Anaerobic Digestion; Rural Electrification; Cow Dung

ABSTRACT (10 PT)
This study explores the design and construction of a household-scale biogas electricity system using Cow dung in Girinata Village, Indonesia, as a practical response to energy access challenges in rural communities. Drawing on anaerobic digestion technology, the system integrates a fiber-based digester, polyethylene gas holder, and a modified dual-fuel generator to produce reliable electricity from cow manure. A qualitative case study and field experiment approach was employed to assess both technical feasibility and social acceptance. Results show the system is technically viable, economically affordable, and socially accepted, with minimal operating costs and high user engagement. Despite initial design challenges affecting gas quality, performance was stable under optimized conditions. This research contributes empirical insights to the literature on decentralized renewable energy, particularly in underrepresented tropical settings, and supports the potential for community-scale replication to promote sustainable energy transitions.

INTRODUCTION

The global energy crisis and climate emergency require all countries to transition their energy systems toward cleaner, renewable, and sustainable sources. In developing nations like Indonesia, the need for affordable and environmentally friendly energy alternatives is urgent, given the limited access to electricity and heavy reliance on expensive and polluting fossil fuels (Mohamed et al. 2024). A particularly promising solution is the utilization of biogas from household and Cow dung as a small-scale electricity source. This system is strategic as it enables decentralized development in rural areas, enhances energy independence, and reduces carbon emissions (Selby, Robinson, and Clifford 2023).

However, household-scale biogas technology still faces structural and technical barriers. Several studies note that the success of biogas programs is often hindered by a lack of technical training, inconsistent digester construction quality, and limited post-installation management (Taherzadeh and Patinvoh 2019). Socioeconomic and cultural aspects such as education level, livestock ownership, and technology perception also significantly influence adoption (Mugagga et al. 2024). In Indonesia, Cow dung remains underutilized despite its potential, especially in rural areas like Girinata Village.

Conceptually, this research is based on a simple yet effective anaerobic digester technology, converting organic waste into energy via enclosed fermentation (Thiruketheeswaranathan and Dharshayini 2021). The resulting biogas is used to power a dual-fuel generator (biogas–gasoline) for household electricity. This approach emphasizes not only technical efficiency but also system adaptability to the local geographic, social, and economic context (Vlasenko and Chernousenko 2024). Furthermore, it references findings on methane gas stability and long-term effectiveness of small-scale biogas systems in developing countries (Dinh et al. 2018).

The primary objective of this study is to design and implement a household-scale biogas power system using Cow dung in Girinata Village as a practical application of sustainable renewable energy. The research addresses how to optimally site and configure the digester near the livestock area, how to efficiently use natural water sources, and to what extent the system can produce electricity reliably in a rural setting. The chosen methodology is a qualitative case study and field experiment, allowing for in-depth exploration of both technical and social dimensions of biogas technology application (Yu et al. 2021).

The academic contribution of this article lies in its integration of field practice with scientific frameworks relevant to renewable energy development at the local level. It provides new insights into the direct application of biogas technology in Indonesian rural communities, which remain underexplored in national and international literature (Montoya and Vargas 2023). Moreover, the experimental field approach adds value in testing the resilience and reliability of the technology in real conditions, something often missing in lab-based or simulation-based studies (Mazur and Gontaruk 2022). This article aims to enhance empirical data for community-based renewable energy policy development and enrich scientific discourse on the integration of technology, environment, and socio-economic empowerment in decentralized energy systems.

Biogas as a renewable energy source is the result of anaerobic fermentation of organic materials, mainly livestock and agricultural waste. Conceptually, biogas technology stems from biomass-to-energy conversion theory via anaerobic digestion, developed systematically in the early 20th century. In practice, household-scale digesters are among the simplest and most relevant implementations in rural areas of developing countries. This model is vital as it addresses energy needs, reduces fossil fuel dependence, and manages waste ecologically (Nethengwe, Uhunamure, and Tinarwo 2021). The "fit-for-purpose" theory underlies the technology adoption framework, emphasizing that systems must be adapted to the local social, technical, and geographic context rather than copying generic models (Van Dung et al. 2021).

Previous studies have demonstrated both the potential and challenges of developing household-scale biogas systems. In Bangladesh, biogas has proven an effective alternative for rural communities with ample Cow dung but limited electricity access (Amin and Rahman 2018). In China, comparisons between household- and large-scale biogas plants showed household models as more socially and economically efficient, despite lower energy output (Yang et al. 2014). In India, community-based approaches using Deenbandhu digesters have significantly improved quality of life, although technical challenges like temperature fluctuations and waste availability remain (Sisodia 2016). In Cambodia, rural areas without grid electricity were found to have high biogas production potential, with methane content reaching 63.9% (Mustonen, Luukkanen, and Raiko 2013) .

Nevertheless, research gaps persist. There is a lack of integrative approaches that empirically combine system design with local socio-cultural conditions. Most studies are either technical or descriptive surveys, lacking direct field trials to assess full operational feasibility (Petro et al. 2020). Although hybrid biogas systems (e.g., biogas-solar) have been widely discussed, few explore their domestic-scale application in tropical settings like Indonesia (Brar 2018). Most available literature relies on lab simulations, which do not fully reflect real-world conditions in rural communities.

This article occupies a strategic position by bridging these gaps through an experimental field approach and community-based case study in Girinata Village. It focuses on integrating technical digester design with the needs and characteristics of local livestock-rearing communities, while also measuring electricity generation effectiveness. Thus, this research enriches the literature with empirical and contextually grounded findings on sustainable biogas operations in energy-poor rural areas (Tucho and Nonhebel 2017).

Methodologically, most previous studies emphasize quantitative or system engineering analysis. Some employ economic, thermodynamic, or computational simulations, while social studies tend to focus on user perception and technology adoption (Roy et al. 2024). This research bridges both dimensions by combining field observation, technical system design, and real-context feasibility testing. This methodological blend distinguishes the study from prior work that often separates technical and social aspects.

The conceptual synthesis for this methodology includes: (1) anaerobic digestion as a principle for organic waste-to-energy conversion, (2) integration of digester-generator systems for household-scale power, and (3) adaptation to rural environmental and socio-economic conditions. These three elements form a research framework that tests not only the technical design but also the implementation viability in real rural settings (Akram and Jan 2018).

RESEARCH METHODS

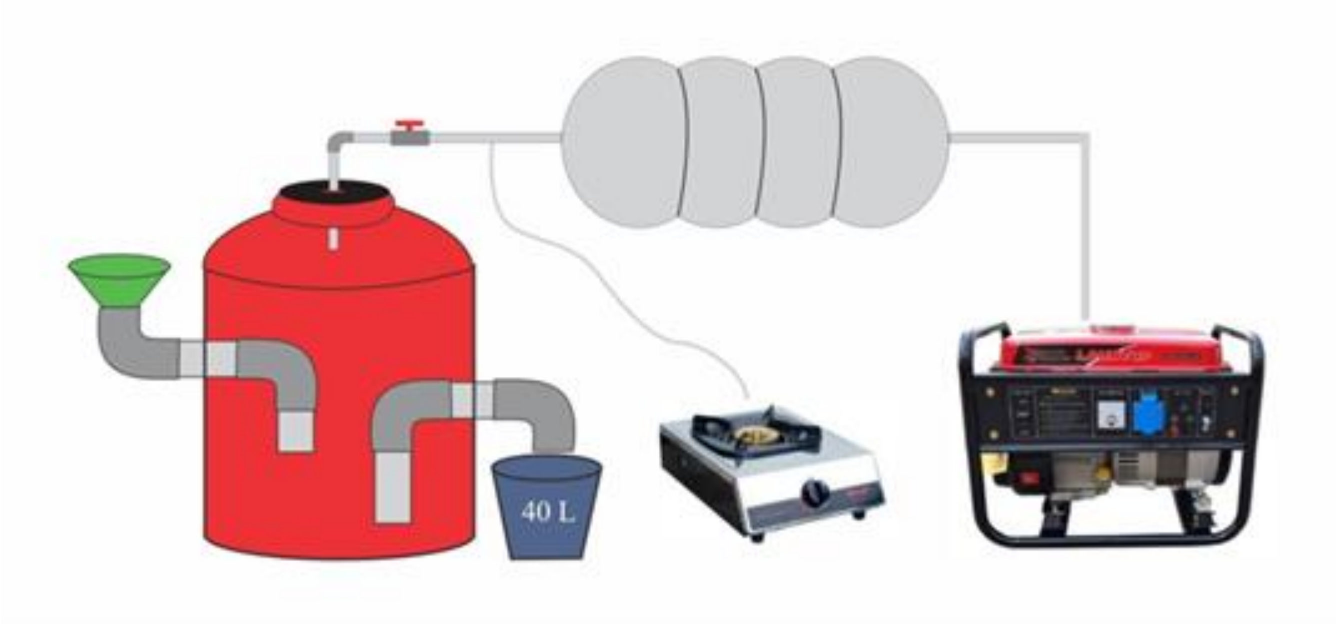
This study adopts a qualitative approach using a case study and experimental design strategy. This approach allows for in-depth investigation of technical and social contexts in applying household-scale biogas electricity systems using Cow dung. The case study enables exploration of unique dynamics in Girinata Village, while the experimental aspect tests technical feasibility and digester-generator system functionality on-site (Bairiganjan 2009a).

The research utilized primary data collected directly from the livestock areas in Girinata. This includes site condition observations, documentation of raw Cow dung materials, construction and testing of the digester-generator system, and technical performance logs during the trial period. Relevant secondary data such as technical design reports, prior implementation records, and academic findings were also used to support the analysis (Teferra and Wubu 2018).

Data collection involved participatory observation, visual and narrative documentation of system construction, and live recording of system testing. Instruments included technical observation sheets, field notes, cameras, and tools for measuring gas pressure, fermentation temperature, and generator electrical output. Observations were conducted continuously during the construction and early operation stages, focusing on equipment reliability, energy conversion efficiency, and user-friendliness (Alessio et al. 2019).

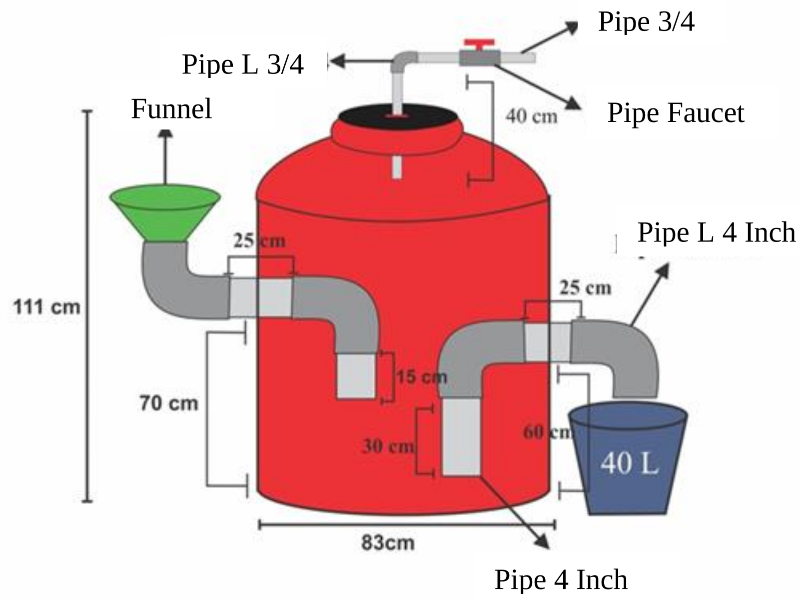
Inclusion criteria involved all directly obtained information from the biogas system construction and testing processes relevant to the Girinata context. Data from areas with dissimilar geographical, social, or technical characteristics—such as urban or industrial-scale biogas systems—were excluded to maintain contextual validity. Supporting literature was selected based on its relevance to domestic digester practices and rural renewable energy case studies (Isha et al. 2022a).

The unit of analysis is the household-scale biogas electricity system installed in Girinata's livestock area. The main subjects are the digester design, the manure-to-biogas conversion process, and the generator integration. Additionally, livestock owners and locals involved in the implementation process provided critical insights into system usability and social acceptance (Matambo et al. 2017a).



Picture 1. Biogas Digester Layout

The balloon-type digester, as illustrated in Picture 2, is designed for household-scale applications.



Picture 2. The Balloon-Type Digester

Data were analyzed using content analysis to interpret observation results and technical notes from the experiment. Thematic coding was applied to field data, categorizing findings into technical (energy efficiency, system stability, gas yield) and social aspects (community involvement, usability, technology perception), and interpreting interrelationships in system sustainability. Results were validated through data triangulation across technical documentation, direct observation, and informal interviews with local users (Roldán-Porta et al. 2023). No statistical or qualitative software tools were employed due to the descriptive nature of the field data.

RESULTS AND DISCUSSION

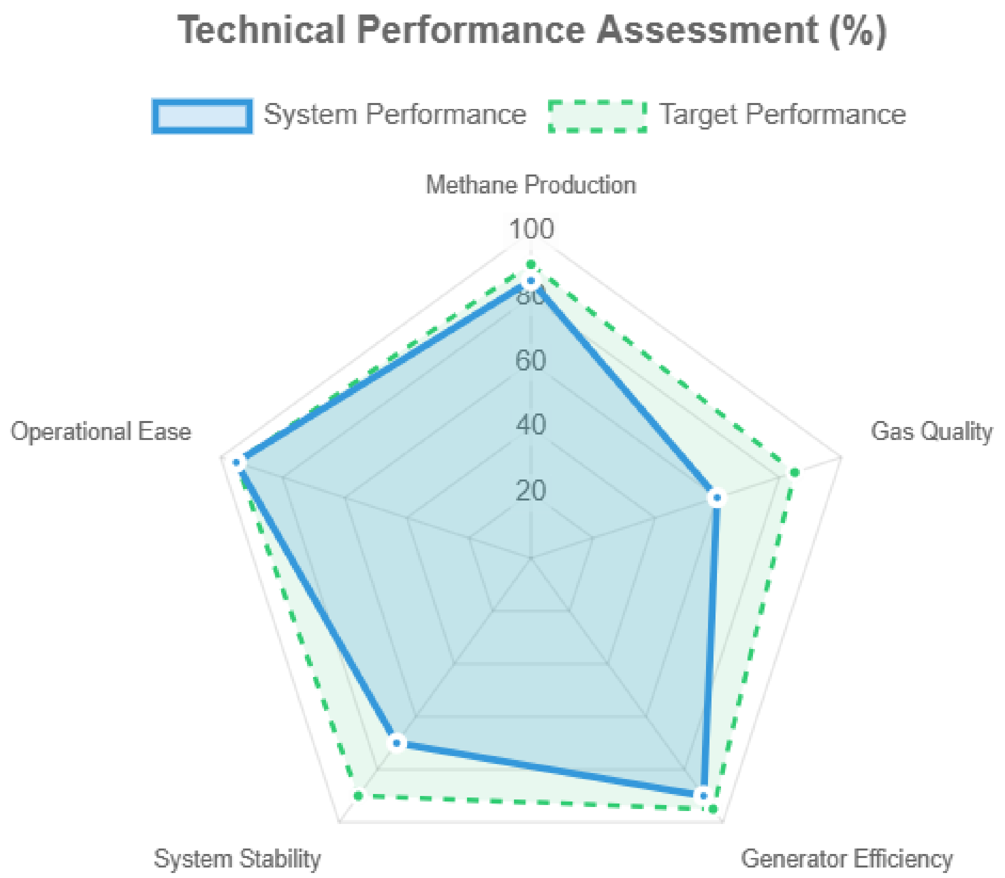
Results

This research successfully developed a contextually tailored prototype of a household-scale biogas electricity system for rural livestock-rich areas. The system comprises three main components: a fiber-based biogas digester, a polyethylene gas holder, and a 1500-watt generator with a modified carburetor, demonstrating promising results in equipment construction, technical performance, and economic viability. The system components of the prototype development are presented in Table 1.

Table 1. Syistem Component

Component	Specification	Material	Key Advantage
Digester	520 Liters	Fiber	Corrosion resistance, thermal stability
Gas Holder	Tubular, 2 outlets	Polyethylene (PE)	Flexibility, chemical resistance
Generator	1500 Watt	Modified carburetor	Enhanced biogas combustion
Piping	¾ inch	Plastic	Airtight, durable joints

The 520-liter biogas digester is made of fiber material, offering excellent corrosion resistance and thermal stability, making it suitable for anaerobic fermentation in tropical regions. The gas holder is a tubular-shaped PE plastic container with two ¾-inch outlet pipes, selected for its flexibility and chemical resistance. The 1500 W generator is equipped with a specially modified carburetor for biogas, replacing the standard float chamber and gasoline jet.



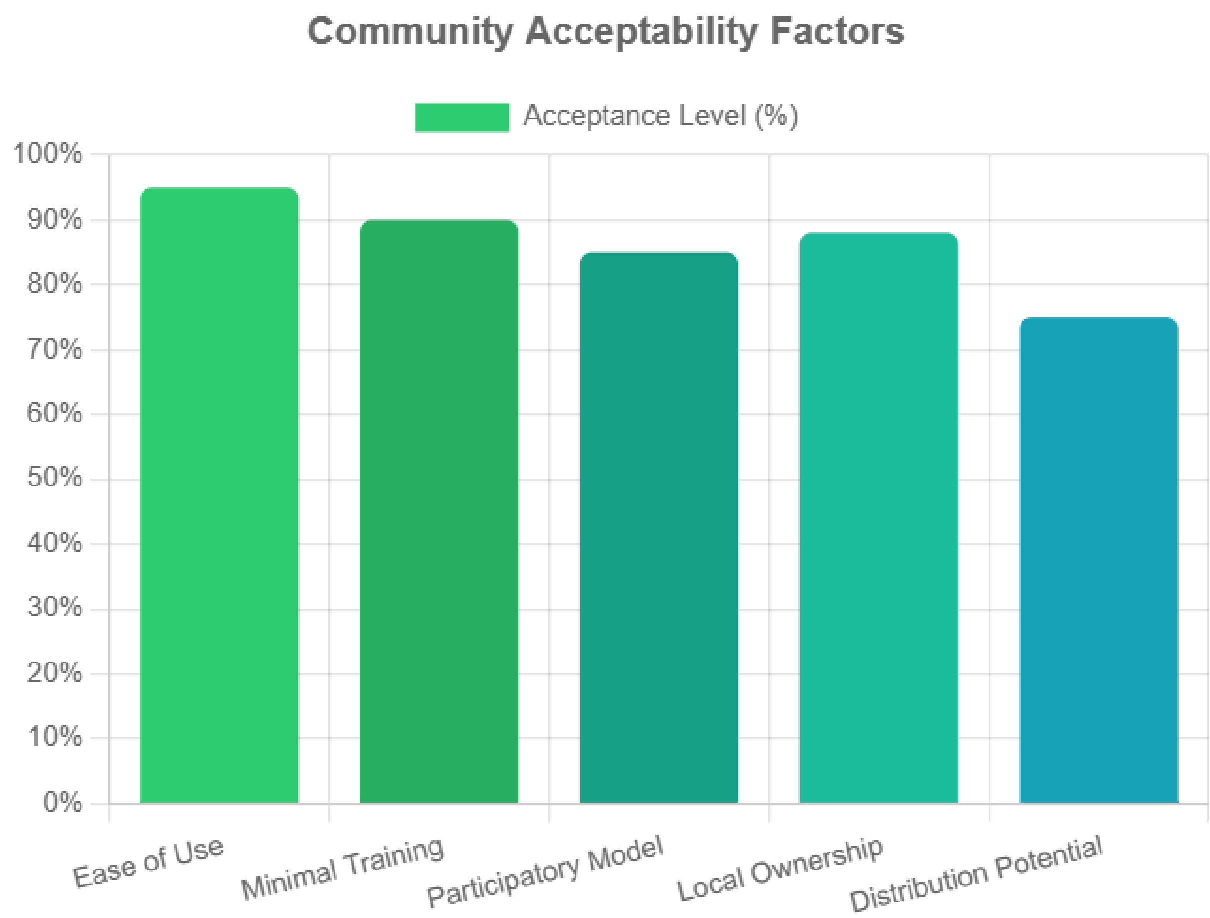
Picture 2. Technical Performance Assesment

Based on Picture 2, the technical profermance can be classified for successful, needs improvmnet, peak under stable flow and high performance and detailed presented at Table 2.

Table 2. Syistem Component

Performance Aspect	Status	Details	Supporting Research
Methane Production	Successful	Semi-continuous fermentation of cow dung	-
Gas Quality	Needs Improvement	Residual fermentation matter mixing with fresh inputs	Rasimphi, Tinarwo, and Gitari 2019
Generator Performance	Peak under stable flow	Optimal performance with consistent gas supply	Saxena, Mishra, and Sen 2020
System Sensitivity	High	Sensitive to pressure variations and air mixing	Confirmed by biogas engine studies

Community acceptability falls into the very good category. The factors influencing community acceptability are explained in the Picture 3.



Picture 3. Community Acceptability

Success factors for community adoption: (a) System ease of use and operation, (b) Minimal technical training requirements, (c) Participatory development model, (d) Local ownership and capacity building, (e) Potential for gas distribution networks, (f) Alignment with successful CDM biogas projects..

Tabale 3. Economic Analysis

Cost Catagory	Amount (IDR)	Amount (USD)	Percentage	Status
Initial Capital	4,072,000	260	100%	On-Time
Fuel Cost	0	0	0%	Ongoing
Operating Cost	Minimal	Minimal	<5%	Ongoing
Maintenance Cost	Minimal	Minimal	<5%	Periodic

Based on Table 3 can explained tahat capital Cost IDR 4,072,000 approximately USD 260, with generator and biogas carburetor being the most expensive components. Fuel costs negligible utilizes on-site livestock manure, eliminating fuel procurement costs. Operating and maintenance costs minimal system simplicity and component durability ensure low maintenance requirements. Profitability Mid-term based on electricity savings and energy sale potential; ROI and payback period under evaluation

Discussions

This research produced a contextually tailored prototype of a household-scale biogas electricity system for rural livestock-rich areas like Girinata. The outcomes span three aspects: equipment construction, technical performance, and economic viability. The system includes three main components—a fiber-based biogas digester, a polyethylene gas holder, and a 1500-watt generator with a modified carburetor. The 520-liter fiber digester was selected for its corrosion resistance and thermal stability, consistent with findings that fiber materials effectively maintain anaerobic fermentation temperatures in tropical regions (Getaneh, Tucho, and Eba 2024).

The gas holder, built from PE plastic in a tubular shape with two ¾-inch pipe outlets, was selected for its flexibility, chemical resistance, and temperature durability. PE's effectiveness in rural gas storage has also been documented in Brazil (Dias et al. 2020). Pipe-plastic joints were sealed securely using strong adhesives to ensure airtightness.

The generator employed a modified carburetor replacing standard gasoline float chambers and jets with biogas-specific inlets. Plastic piping delivered gas through the venturi chamber, a technique previously validated in South African dual-fuel generator trials for enhanced biogas combustion (Matambo et al. 2017).

Technically, the system successfully produced methane from semi-continuous fermentation of cow dung. However, early-stage design weaknesses caused residual fermentation matter to mix with fresh inputs, lowering gas quality. This supports prior recommendations for tighter control over input-output cycling in semi-continuous systems (Rasimphi, Tinarwo, and Gitari 2019). Generator performance peaked under stable gas flow, confirming studies highlighting the sensitivity of biogas engines to pressure and air mixing (Saxena, Mishra, and Sen 2020).

Economic analysis indicated a capital cost of IDR 4,072,000 (approx. USD 260), with the generator and biogas carburetor being the most expensive components. Fuel costs were negligible, using on-site livestock manure. Operating and maintenance costs were also minimal due to the simplicity and durability of the system, aligning with Ethiopian studies on low-cost rural biogas deployment (Isha et al. 2022). The system offers mid-term profitability based on electricity savings and energy sale potential. Indicators such as ROI and payback period are under continued evaluation.

Community acceptability was high due to the system's ease of use and minimal technical training requirements. The participatory development model mirrors successful CDM biogas projects in India (Bairiganjan 2009b), enhancing long-term sustainability prospects through local ownership, training, and potential gas distribution networks.

Future research directions continued to evaluation of ROI and payback period indicators, development of gas distribution network infrastructure, and scaling up for broader rural deployment while maintaining the participatory development model that ensures long-term sustainability through local ownership and training

CONCLUSION

Based on the research objectives, problems, and results, this study concludes that the household-scale biogas electricity system designed and implemented in Girinata Village is technically feasible, economically sound, and context-sensitive. Locating the digester near manure sources and using natural water effectively supported anaerobic fermentation without external resources.

The system met its goals of reducing fossil energy use, mitigating Cow dung impacts, and generating alternative energy. It produced adequate electricity for household use and added value to previously unused organic waste.

Field trials confirmed the synergistic and efficient performance of the digester, gas holder, and modified generator. With an investment of IDR 4,072,000 and minimal operating costs, the system holds long-term economic potential for community-scale replication. This research significantly contributes to renewable energy development using Cow dung in rural Indonesia and supports inclusive and sustainable energy transitions.

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