Determinants and Perceived Impacts of Biogas Technology among Smallholder Dairy Farmers in Njoro Sub-County, Nakuru, Kenya

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https://doi.org/10.62049/jkncu.v6i2.616

Abstract

The adoption of biogas technology has increasingly been recognized as a sustainable solution for addressing household energy needs, environmental degradation and poor waste management in rural communities. This study assessed the benefits and challenges of biogas adoption and examined the socio-economic drivers of technology uptake among smallholder dairy farmers in Njoro Sub-County, Nakuru County, Kenya. A descriptive research design was employed with a multi-stage sampling method selecting 110 smallholder dairy farmers. Primary data was collected through semi-structured questionnaires and Focus Group Discussions. Data analysis involved descriptive statistics and binary logistic regression using SPSS Version 24. Findings revealed that biogas technology was highly valued for reducing household energy costs (Mean = 4.98), lowering indoor air pollution (Mean = 4.98), reducing dependence on firewood (Mean = 4.97) and improving soil fertility through slurry application (Mean = 4.97). However, the high installation cost emerged as the greatest barrier to adoption (Mean = 4.89), while lack of technical knowledge (Mean = 3.13) also limited effective utilization. Binary logistic regression analysis indicated that age, (B = -1.121, p = 0.047) and monthly income (B = -1.162, p = 0.021) were significantly negatively associated with adoption. In contrast, education level had a strong positive predictor as farmers with medium education level were 33.1 times more likely to adopt ($p < 0.05$). Gender, marital status, household size and land ownership were not statistically significant. The study concludes that while biogas technology offers substantial environmental, economic and health benefits, financial and technical barriers persist. To increase uptake among smallholder dairy farmers, financial support mechanisms and technical extension services need to be strengthened.

Keywords: Clean Energy Adoption, Household Energy Security, Indoor Air Pollution, Socio-Economic Factors, Sustainable Rural Development, Smallholder Dairy Farmers

Introduction

Access to clean and sustainable energy remains a major challenge in many rural areas of developing countries, where households continue to rely heavily on traditional biomass fuels such as firewood, charcoal and agricultural residues for cooking and heating. This dependence contributes to environmental degradation, indoor air pollution, deforestation and various health complications, particularly among women and children who are disproportionately exposed to household air pollution (Kyayesimira & Muheirwe, 2021). In Kenya, the increasing demand for affordable and environmentally friendly energy alternatives has intensified the need for renewable energy technologies that simultaneously support household livelihoods and environmental conservation (Kiprop et al., 2019).

Biogas technology has emerged as a viable renewable energy solution capable of addressing energy poverty while simultaneously contributing to climate change mitigation and sustainable agricultural production. Biogas is produced through the anaerobic digestion of organic materials such as animal manure, crop residues and other biodegradable waste (Atelge et al., 2020). Beyond providing households with a clean source of cooking fuel the process generates nutrient-rich bio-slurry which serves as an effective organic fertilizer to improve soil fertility and crop productivity. In rural dairy farming communities, where livestock manure is readily available, biogas technology presents a practical opportunity to integrate waste management, renewable energy generation and sustainable farming practices (Silva-González et al., 2020).

Despite these numerous environmental, economic and social benefits associated with biogas technology, its adoption among rural households in Kenya remains relatively low compared to its potential (Kimutai et al., 2024). Several factors have been linked to this slow uptake, including high installation costs, inadequate technical knowledge, limited access to credit facilities, insufficient extension services and socio-economic disparities among households. Understanding these challenges is essential for designing effective policies and interventions aimed at promoting the wider adoption of biogas systems among smallholder farmers.

Njoro Sub-County is predominantly am agricultural area characterized by intensive dairy farming activities, making it highly suitable for biogas production due to the continued availability of substrate. However, despite this ecological suitability, many farmers continue to depend on conventional energy sources. Consequently, there is a need to assess the perceived benefits and challenges associated with biogas technology adoption in the area, as well as the socio-economic factors influencing adoption decisions among smallholder dairy farmers. This study therefore sought to evaluate the benefits associated with the use of biogas technology and identify the challenges hindering its adoption in Njoro Sub-County, Kenya. Additionally, the study examined the relationship between selected socio-economic factors and the adoption of biogas technology among smallholder dairy farmers. The findings of this study are expected to contribute to policy formulation, renewable energy promotion and sustainable rural development initiatives aimed at improving household energy security and environmental sustainability in agricultural catchments.

Methodology

Study Area

This study was conducted in Njoro Sub-County, Nakuru County, Kenya (Figure. 1). The Sub-County is situated approximately 180 km northwest of Nairobi and approximately 20km southwest of Nakuru town in Kenya's Rift Valley region covering a total area of about 713.3 km². Geographically, it lies between latitude 0.3333°S and longitude 35.9500°E (Masara et al., 2026; Ogola et al., 2023). The Sub-County is situated at an average altitude of 1,800 m above sea level (Kenya National Bureau of Statistic (KNBS, 2019). The area receives bimodal rainfall, with the long rains occurring between March and May, and the short rains between October and December. Annual rainfall varies across the region, typically ranging between 900 mm and 1,200 mm, supporting both crop and livestock farming (Koskey et al., 2021).

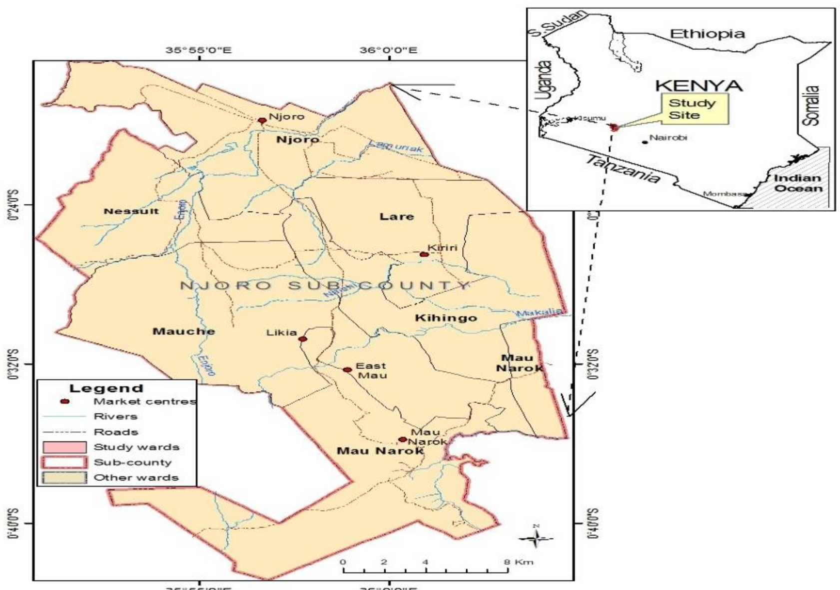

Figure 1: Map of Kenya showing the study area
Source: By Author, adapted from Environmental Systems Research Institute (2026)

Research Design and Target Population

In this study, a descriptive research design was employed to explore the perceptions, advantages, challenges and daily life of smallholder dairy farmers associated with adoption of biogas technology. The target population was the smallholder dairy farmers in the six administrative wards of Njoro Sub-County. The inclusion criteria were that respondents should have at least three cows to ensure technical relevance. Table 1 indicates the distribution of farmers in the study area by ward indicating the geographical spread of farmers.

Table 1: Distribution of Smallholder Dairy Farmers by Wards

Ward	Number of Farmers	Ward Population Census	Proportion (%)	Sample Size
Mau Narok	3,258	46,540	19.16	21
Mauche	3,131	44,724	18.42	20
Kihingo	2,447	34,955	14.40	16
Nessuit	1,240	17,720	7.29	8
Lare	1,643	23,466	9.66	11
Njoro	5,281	75,446	31.10	34
Total	17,000	242,851	100	110

Sampling Procedure and Sample Size

Multi-stage sampling technique was employed in the research. Purposive sampling was used to select all six wards in the study area because of the high dairy potential. Proportional sampling was used to select the respondents per ward, and systematic random sampling was applied in the selection of the individual farmers within the sampling frame. To achieve a representative and unbiased dataset from an accessible population of 17,000 smallholder dairy farmers, the study utilized Nassiuma's (2000) formula as shown below;

$$n = \frac{NC^2}{c^2 + (N-1)e^2}$$

Where n=sample size, N=population (accessible population of 17,000 smallholder dairy farmers), C=coefficients of variation (0.21) and e=standard error (0.02)

$$n = \frac{17{,}000x0.0441}{0.0441 + (16999x0.0004)}$$

$$n = 110$$

Based on the parameters, the formula generated a sample size of 110 respondents. Kathuri and Pals (1993) note that samples above 100 are adequate for survey studies; therefore, this sample size was deemed sufficient. To improve representativeness, stratified random sampling was used, with the population divided into strata based on geographical location, ensuring a comprehensive and balanced representation of the Sub-County's dairy farming community.

Data Collection and Quality Control

Primary data was collected through semi-structured questionnaires and Focus Group Discussions (FGDs), which had 6 participants each in each ward. The questionnaires included both closed- and open-ended questions to obtain comprehensive household information. Triangulation was done to increase the validity and reliability by combining the quantitative survey results with the qualitative thematic results from the FGDs (Song et al., 2022). To enhance the research instrument, it was further validated by experts from Environmental and Biological Sciences who refined the instrument for clarity, technical accuracy and relevance. The instrument was pre-tested in a pilot study with 30 randomly selected households in Molo Sub-County (Molo, Turi and Elburgon wards) one month prior to the main data collection. The Cronbach's alpha reliability coefficient was 0.72, which is greater than the 0.70 threshold, indicating acceptable internal consistency (Izah et al., 2023). All 110 questionnaires for households were manually checked for completeness and consistency before analysis.

Data Management and Statistical Analysis

The data management and analysis process were carried out carefully, ensuring the reliability of the results on biogas technology adoption. A complete and consistent manual check of each of the 110 household surveys was conducted before the data were processed. The verified data was then systematically entered into SPSS (Version 24) for analysis. Both descriptive statistics involving means, and standard deviations were used utilizing a 5-point Likert scale to measure the intensity of agreement, to rank the perceived benefits and operational challenges of biogas technology. A binary logistic regression analysis was also performed to assess the effect of different socio-economic factors on the probability of adopting biogas technology. The model reliability was validated using the Omnibus Tests of Model Coefficients ($p = 0.001$) and Hosmer-Lemeshow test ($p = 0.605$) to achieve a good model fit.

Results and Discussion

Demographic Characteristics

Age and Gender of the Respondents

The study achieved a 100% response rate, reflecting a high level of community engagement. Demographic profile (Figure 2) revealed a comparison of the study's participants, categorizing the by gender across four distinct age intervals. The data indicates a progressive increase in participation as age increases for both genders, with a more considerable representation of respondents found in the 'above 60' category. In the younger and middle-age brackets (18-35, 36-45 and 46-60), female respondents consistently outnumber their male counterparts, most notably in the 36-45 group where there are three times as many women as men. However, this trend shifts in favour of males in the oldest demographic population.

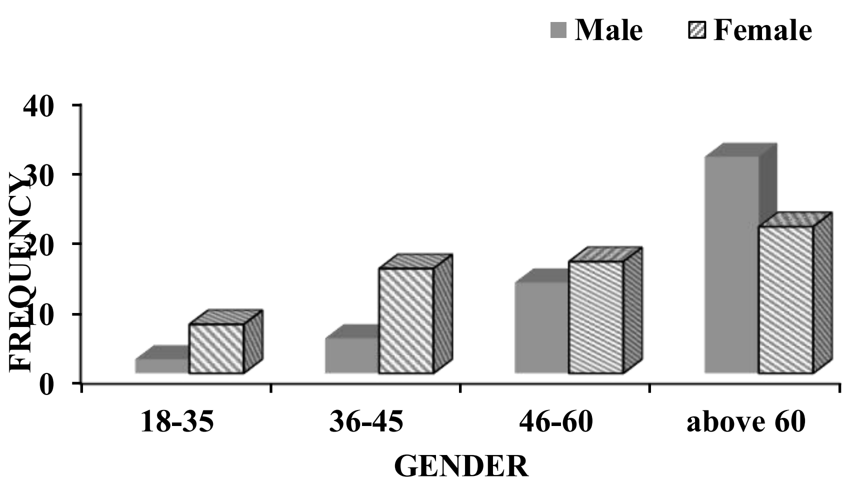

Figure 2: Age and Gender of the Respondent

This distribution is particularly significant for a study on biogas technology, as it reflects the perspectives of those most directly involved in household energy management. In many rural and peri-urban contexts, women are the primary users of cooking fuels and managers of organic waste; therefore, their higher representation suggests that the data captures the insights of the primary beneficiaries of clean energy transitions. This gender-inclusive data set ensures that the findings on adoption levels are representative of both the labour providers and the decision-makers within the community. Unlike Kitheka et al. (2022) who argued that cultural roles and biased resource ownership remain significant barriers to gender-balanced participation in Kenya, this study found a relatively equitable distribution of respondents (53.6% female verses 46.4% male). In this specific case, the traditional barriers mentioned do not result in the exclusion of women, rather their majority representation suggests a high level of active participation and interest among those most affected by household energy poverty. This augurs well for biogas technology adoption if the public and private sector provide the much needed financial and technical support.

Education Levels of the Respondents

The educational attainment of the group in Figure 3, illustrate the attainment across different age groups within the study population. The data demonstrates that formal education is widespread among participants, with only a marginal number, exclusively in the older age brackets of 46-60 and above 60 years, reporting no formal schooling. Across the categories of primary, secondary and post-secondary education, there is a consistent trend where participants aged above 60 represent the highest frequency, peaking at 18 individuals in the primary education group. Conversely, the youngest demographic (18-35) shows the lowest representation across all formal education levels, maintaining a relatively flat distribution with 3 to 4 participants in each category. While the older cohorts dominate the total count in every education tier, the data highlights that a significant portion of the above 60 group has successfully attained secondary (16) and post-secondary (14) qualifications, suggesting that higher education is well represented even among the senior members pf the surveyed group.

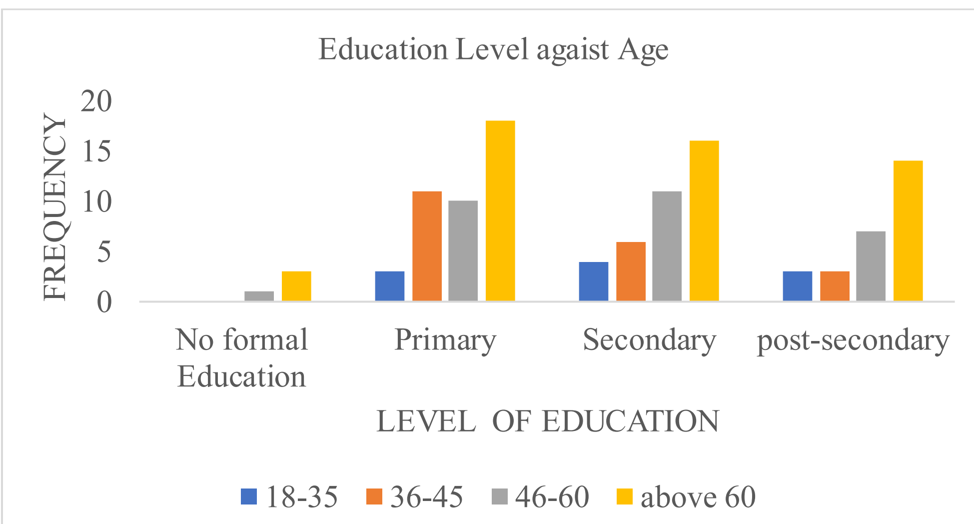

Figure 3: Education Level against the Age of the Respondents

When viewed together, these statistics indicate a mature respondent base with a solid foundation in basic and intermediate education. A significant relationship was established in that, higher education levels significantly enhance a household's ability to process technical information and understand the long-term economic benefits of transitioning from traditional biomass to biogas (Kimori et al., 2024). These findings differ from those of Katuwal (2022), whose research suggests that even functional literacy (primary school) is sufficient to drive adoption if the extension services are high-quality. However, it is noted that as households move from primary to secondary education, the motivation shifts from basic energy need to economic and environmental awareness.

Benefits And Challenges Associated with the Use of Biogas in Njoro Sub-County

The use of descriptive statistics to rank biogas drivers and barriers provides a quantifiable weight of perception that simple binary surveys lack. By calculating the mean and ranking variables, this study identifies the precise hierarchy of factors influencing the energy transition in Njoro. This methodology is supported by Albin & Foley (2021), who argue that in rural agricultural clusters, the ranking of means is essential for distinguishing between nuisance challenges (low means) and adoption-blocking barriers (high mean). Their research suggests that when economic barriers consistently rank highest, it indicates a market failure that education alone cannot solve.

Furthermore, the calculation of Standard Deviation (SD) serves as a measure of social cohesion regarding the technology. According to Miller et al. (2022), a high mean paired with a low SD for a benefit, such as reduction in fuel collection time, demonstrates a universal success of the technology across different household types. Conversely, a high SD in the technical challenges category often points to uneven access to skilled technicians or varying qualities of digester construction within the community. This statistical depth ensures that the findings from Njoro are not just anecdotal but represent a reliable trend.

The ranking of environmental benefits versus economic barriers allows for the identification of the incentive gap. As noted by Le Treut et al. (2021), using a Likert-based hierarchy reveals that while farmers may Strongly Agree with the health benefits of biogas, their strong agreement with the burden of installation costs often remains the dominant influence of their final decision. This statistical evidence is vital for shifting the focus from raising awareness to implementing the financial de-risking strategies required for widespread adoption.

Benefits Associated with Using Biogas

The analysis results in Table 2 presents the descriptive statistics for the perceived benefits of biogas technology. Overall, the results indicate an exceptionally high level of satisfaction and perceived value across all measured variables, with mean scores consistently approaching the maximum possible value of 5.00.

The primary benefits identified by the respondents' centre on environmental and economic efficiency. Specifically, the statements regarding biogas use lowers energy costs and biogas helps reduce indoor air pollution both achieved a remarkably high mean score of 4.98. These findings are supported by very low standard deviations of 0.134, suggesting a strong consensus among households that the technology is highly effective in improving air quality and reducing financial burdens. Similarly, the roles of biogas in providing a cleaner cooking environment, improving soil fertility through slurry, and reducing dependence on traditional firewood all recorded identical mean scores of 4.97. For these three variables, the standard deviation was recorded at 0.164, further reinforcing the uniformity of positive experiences among the adopters.

A study conducted by Michael et al. (2025) aligns with my findings. They found that clean energy adoption, particularly biogas, significantly improves household well-being by lowering energy costs, reducing indoor air pollution and providing a cleaner cooking environment. Furthermore, it supports environmental and agricultural sustainability by decreasing dependence on firewood and producing high-quality slurry that enhances soil fertility.

While all categories were viewed favourably, biogas maintenance costs are manageable received the lowest relative mean score of 4.50. Although this still represents strong agreement, the higher standard deviation of 0.751 and a wider range of responses with a minimum score of 3 (Neutral) compared to the minimum of 4 (Agree) seen in other categories, indicates that opinions on maintenance affordability are slightly more varied than the opinions on the direct benefits of usage. Despite this slight variance, the overall data suggests that biogas technology is perceived as a highly beneficial intervention for the surveyed households. A research done in Kenya aligns with these findings, whereby it shows that 87% of women reported improved respiratory health and 72% noted improved children's health after installing a biogas system due to the elimination of toxic smoke from solid fuels (Dohoo et al., 2012).

Table 2: Benefits Associated with Using Biogas

	N	Min	Max	Mean		SD	Variance
	statistic	Statistic	Statistic	Statistic	SE	Statistic	Statistic
Biogas use lowers energy costs.	110	4	5	4.98	0.013	0.134	0.018
Biogas helps reduce indoor air pollution.	110	4	5	4.98	0.013	0.134	0.018
Biogas reduces household's dependence on firewood.	110	4	5	4.97	0.016	0.164	0.027
Biogas provides a cleaner cooking environment.	110	4	5	4.97	0.016	0.164	0.027
Biogas slurry improves soil fertility.	110	4	5	4.97	0.016	0.164	0.027
Biogas maintenance costs are manageable	110	3	5	4.50	0.072	0.751	0.564
Valid N	110						

Challenges Hindering the Adoption of Biogas Technology

Despite high satisfaction, structural barriers persist. Table 3 highlights installation cost as the most formidable barrier. This factor recorded a mean of 4.89, with respondents providing scores ranging from 2 to 5. The relatively low standard deviation of 0.476 indicates that the high cost of entry is a widely recognized deterrent that discourages broader adoption. In contrast, the lack of technical knowledge as a limiting factor for effective use showed much more divided results. This variable produced a mean score of 3.13, which sits just above the neutral point on the Likert scale. However, the high standard deviation of 1.868 and the full range of responses (from 1 to 5) indicate a lack of consensus.

Table 3: Challenges Hindering Adoption of Biogas Technology

	N	Min	Max	Mean		SD	Variance
	Statistic	Statistic	Statistic	Statistic	SE	Statistic	Statistic
The cost of installation discourages adoption.	110	2	5	4.89	0.045	0.476	0.227
Lack of technical knowledge limits effective use.	110	1	5	3.13	0.178	1.868	3.488
Valid N	110						

This suggests that while some users feel their technical knowledge is a major hurdle, others feel completely confident in their ability to operate the technology, pointing towards a need for targeted rather than universal technical training. These results are consistent with those of Kulugomba et al. (2024), who indicates that the primary barrier of biogas adoption is the high initial installation cost, which acts as a formidable financial deterrent for many potential users. Additionally, adoption is hindered by a lack of consistent technical knowledge, inadequate access to reliable water and feedstock and a shortage of post-installation support services.

Relationship Between Socioeconomic Factors and Adoption of Biogas Technology in Njoro Sub-County

A binary logistic regression analysis (Table 4) was conducted to determine how various socio-economic factors influence the probability of biogas technology adoption in Njoro Sub-County. The "Omnibus Tests of Model Coefficients" confirmed that the overall regression model is statistically significant, with a Chi-square value of 48.745 and a p-value of 0.001. This significance indicates that the predictors included in the model significantly improve our ability to predict biogas adoption compared to a model with no predictors.

Furthermore, the model's explanatory power is reflected in the Cox & Snell R Square (0.358) and the Nagelkerke R Square (0.584), suggesting that the model explains between 35.8% and 58.4% of the variance in biogas adoption. The reliability of these results is supported by the Hosmer-Lemeshow Test, which yielded a *p*-value of 0.605; since this is greater than 0.05, the null hypothesis of a good model fit is not rejected, proving that the predicted probabilities do not significantly differ from the observed outcomes.

Table 4: Tests of Model Coefficients

Step 1		Chi-square	df	Sig.
	Step	48.745	22	0.001
	Block	48.745	22	0.001
	Model	48.745	22	0.001

Table 5: Model Summary

Step 2	Log Likelihood	Cox & Snell R Square	Nagelkerke R Square
1	55.566[a]	0.358	0.584

Table 6: Hosmer–Lemeshow Test

Step 3	Chi-square	df	Sig.
1	6.378	8	0.605

A detailed analysis of the variables in the equation identified some socio-economic factors that are significantly related to adoption: age, education level, and monthly income. Age was found to have a significant negative effect on adoption (B = -1.121, $p = 0.047$), implying that younger household heads are more likely to adopt the technology than older ones. Education level emerged as a powerful positive predictor, particularly for respondents in categories 2 and 3; specifically, those in education category 2 were found to be 33.1 times more likely to adopt biogas ($p = 0.004$), while those in category 3 were 11.1 times more likely ($p = 0.016$) compared to the reference group. Conversely, monthly income showed a negative relationship with adoption B = -1.162, $p = 0.021$), suggesting a unique economic trend where adoption may be driven by a need for cost-saving among specific income brackets rather than mere wealth. Other factors such as gender, marital status, household size, and landownership type did not reach statistical significance in this specific model, indicating that while they may play a descriptive role, they are not the primary drivers of adoption in this study area. A study conducted by Jan (2021) corroborates to the findings of this study, with socioeconomic factors such as education, total landholdings, cost of energy consumption, occurrence of smoke-related diseases and possession had a significant relationship with adoption of biogas technology.

Conclusion

The study established that biogas technology provides significant environmental, economic and health benefits to households in Njoro Sub-County, particularly through reduced energy costs, lower indoor air pollution and improved soil fertility. However, high installation costs and limited technical knowledge remain major barriers hindering wider adoption among smallholder dairy farmers. Additionally, socio-economic factors such as age, education level and monthly income significantly influence the likelihood of adopting biogas technology in the study area.

Recommendations

- Financial support measures, including subsidies, low-interest loans, and flexible payment schemes, should be put in place by the government and relevant financiers to ease the high initial costs for smallholder farmers to install biogas systems.
- The County Government of Nakuru should incorporate the maintenance of the biogas units and the management of bio-slurry into current agricultural extension services. This would shift the emphasis from simply installing it to sustainability in its operation.
- Promotion strategies should target youth and farmer field schools through digital platforms, by emphasizing biogas technology as a climate smart rather than only a waste management solution.
- Further studies should examine the long-term sustainability and performance of biogas systems among smallholder farmers, with particular focus on maintenance practices, user satisfaction and the continued use of biogas technology over time.

Disclosure of Conflict of Interest

There is no conflict of interest declared by the authors in regard to the findings of this research.

Funding

This research was funded by the MasterCard Foundation through RUFORUM and TAGDev Scholarship Program.

Acknowledgements

The authors would like to express their gratitude to the MasterCard Foundation, RUFORUM and TAGDev Scholarship Program for their financial assistance for this research. We would like to express our gratitude to the fraternity at Egerton University for its support in our academic pursuits during this study. It is our great pleasure to have the guidance, constructive feedback and constant support from our supervisors. Special appreciation is also extended to Njoro Sub-County Livestock Officer and the Agricultural Extension Officers of the various wards for their cooperation in the process of data collection. Finally, we thank our classmates, parents, and guardians for their encouragement, prayers, and unwavering support.

Ethical Approval

The study was carried out in accordance with Egerton University Ethics Committee prior to the start of data collection Approval no *EUISERC/APP/504/2025*. Research permits were also obtained from National Council for Science, Technology and Innovation, reference number *NACOSTI/P/25/4178452*. Permission was also sought from the County Secretary of Nakuru and Head of Public Service ref *MOH/NJR/ATTACH/RESEARCH/VOL.II/309*. Informed consent was obtained from all respondents prior to their participation in the study. Participation was voluntary, and all data collected were kept confidential and used exclusively for research purposes.

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