Intersection Between Household Economics and Community Energy Needs: Case of Biogas Uptake in Kilifi County

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Abstract

As the world strives to transition toward sustainable energy systems, Sustainable Development Goal (SDG) 7 emphasizes universal access to clean, reliable, and affordable energy sources. Biogas technology provides a viable solution by converting organic waste into renewable energy, thus promoting both environmental sustainability and energy efficiency. This aligns with the aspirations of SDG 12, which emphasizes responsible consumption and production through effective waste management. The study sought to assess the intersection between household economics and community energy needs. The study employed a cross-sectional survey research design to collect data from a sample of 133 participants. Data was collected using a semi-structured interview guide. The findings reveal that 78% of respondents were aware of biodigester technology, while 72% had a positive perception of its effectiveness in energy provision and waste management, respectively. Approximately 65% of users reported operational biodigesters that produced sufficient biogas for daily cooking, with 70% confirming a reduction in dependence on firewood. Socially, 82% cited improved household health due to reduced smoke exposure, and 68% highlighted enhanced sanitation and odour control. Economically, 59% of respondents noted cost savings on fuel, while 43% earned a modest income from the sale of bio-slurry. The study found that 34% of households expressed confidence in their long-term financial sustainability, and this finding ($\chi^2 = 18.42$, $p < 0.05$) confirmed a significant relationship between community awareness and technology adoption. The study recommends enhanced awareness and support for biogas use expansion among the residents owing to its socioeconomic value.

Keywords: Biodigester, Biogas Technology, Affordable Energy, Sustainable Energy, Sustainable Development Goals, Waste Management

Introduction

Biogas technology has garnered widespread support as an ecologically sound solution to addressing energy deficits, waste management challenges, and sustainability issues in rural areas (Tagne et al., 2021). Biogas technology transforms waste into energy (Meyer *et al.,* 2021). The generation of biogas via the bioconversion of residual biomass has become recognized as an environmentally friendly technology (Lee et al., 2019).

Globally, various countries have adopted biogas technology, demonstrating its potential to contribute to achieving Sustainable Development Goal (SDG) 7 (Overen *et al.,* 2024). Biodigesters are employed to diminish the amount of pollutants from municipal wastewater, industrial effluent, and domestic operations, with the biogas utilized for electricity and heat generation (Luna-delRisco et al., 2025).

Facilitating energy access in towns and rural areas is crucial for social and economic development, particularly in agriculture and household land utilization (Shahzad, 2012; Rocha-Meneses et al., 2023). Nearly 2.5 billion people worldwide predominantly depend on traditional biomass fuels for cooking, lighting, and heating (Oghu, 2025). By 2030, it is projected that approximately 1.4 billion people will be at risk of insufficient access to modern energy resources (Walters, 2025). Moreover, the global population is expected to rise to approximately 9 billion by 2050, resulting in increased energy demands (Falcon et al., 2022; Güneralp et al., 2017).

Research shows approximately 500 million households in Africa rely on traditional biomass fuel for heating and cooking, lacking access to modern energy sources (Arthur et al., 2011; Bazilian et al., 2010). Therefore, transforming modern biomass fuel usage into cleaner technologies for rural areas would be beneficial in resolving the global energy crisis and improving standards of living, health, and environmental quality (Abdela, 2019; Aiguobarueghian et al, 2024; Savini, 2019).

In Kenya, nearly 68% of the country's energy needs are met by biomass (Gathui & Mugo, 2010; Preble et al., 2020). Thus, the growing pressure on biomass resources underscores the urgent need for alternative, innovative, and sustainable energy solutions that simultaneously address environmental and economic challenges (Singh et al., 2025; Peng & Pivato, 2019). Consequently, biogas technology emerges as a viable innovation, offering both energy security and ecological benefits (Faizi et al., 2025). By utilizing locally available organic materials, biogas provides an affordable and renewable energy source (Czekała, 2022; Kabeyi & Olanrewaju, 2022). Biogas not only eases the burden on forests but also supports cleaner environments and improved livelihoods, especially in rural and peri-urban areas (Abanades et al., 2022; Aultman, 2025; Benti et al., 2021; Rewe et al., 2021).

Despite these clear benefits, biogas technology faces numerous barriers that hinder its widespread adoption (Situmeang et al., 2022). The high upfront cost of constructing digesters remains a significant obstacle for households, particularly those with low or irregular incomes (Gebreegziabher et al., 2021). In Kenya, many rural families are unable to cover the initial costs, despite potential long-term cost savings (World Biogas Association, 2024). Furthermore, a lack of awareness, cultural resistance to waste utilization, technical and maintenance issues, and the absence of supportive policy or regulatory frameworks hinder adoption (Mwirigi et al., 2014; FAO, 2023). These bottlenecks result in low adoption rates of biogas technology, despite its potential to address pressing problems in today's world (Njenga et al., 2019; Situmeang et al., 2022; World Biogas Association, 2024).

These barriers not only slow the diffusion of renewable energy technologies but also reflect deeper socio-economic inequalities within communities (Njenga et al., 2019). Limited access to clean and affordable energy perpetuates cycles of poverty, constrains productivity, and heightens dependence on unsustainable fuels such as firewood and charcoal (Bailis et al., 2015; Kiplagat et al., 2011). Consequently, communities miss out on the multiple co-benefits of biogas adoption and improved health outcomes through reduced indoor air pollution (WHO, 2022), gender equity through reduced drudgery for women (Oparaocha & Dutta, 2011), environmental conservation via reduced deforestation and carbon emissions (IRENA, 2021), and opportunities for local enterprise development through bio-slurry utilization and energy-based entrepreneurship (Njenga et al., 2019; World Biogas Association, 2024).

However, relatively few studies have examined the intersection between household economics and community energy needs in rural counties such as Kilifi, where socio-economic realities strongly shape adoption (Momanyi et al., 2016; Mwirigi et al., 2014; World Biogas Association, 2024; Njenga et al, 2019). There is limited empirical evidence that directly connects biogas adoption to household economic outcomes, such as savings on fuel, fertilizer substitution, or improved health expenditures, in Kilifi County. It is within this intersection of socio-economic realities and community energy needs that the current paper takes a critical stance. Understanding how social and economic factors influence biogas adoption can inform context-sensitive strategies that not only promote clean energy transitions but also enhance livelihoods and community resilience (FAO, 2023; Situmeang et al., 2022). This nexus offers valuable insights for policymakers, development partners, and local innovators seeking to bridge the gap between energy access and socio-economic development in Kenya and similar contexts (Gebreegziabher et al., 2021; IRENA, 2021).

Methodology

This study was conducted in Kilifi County, Kenya, which lies along the Indian Ocean between latitudes 2°20′ and 4°00′ South and longitudes 39°05′ and 40°14′ East (Kenya National Bureau of Statistics, 2019). The region experiences warm temperatures, averaging 27°C, and bimodal rainfall, ranging between 400 mm and 1,300 mm annually (Kilifi County Development Plan, 2023). Agriculture and livestock keeping are the primary sources of livelihood, although deforestation and charcoal burning are common, particularly in mangrove areas, which threaten marine ecosystems. Despite national efforts to promote clean cooking, 67% of Kilifi residents still rely on firewood, 21% on charcoal, while only 2% use LPG and 8% use paraffin (KNBS, 2019). This overdependence on biomass contributes to environmental degradation and public health risks, undermining efforts to promote biogas technology as a clean and sustainable energy alternative in the county.

Due to the ensuing environmental challenges posed by the community's energy needs, a study was commissioned using a cross-sectional survey research design. The researcher contacted the Ministry of Energy and obtained a list of 2,000 farmers who had been trained on biogas. Using Gay (1997) and Mugenda and Mugenda (2003), a sample size of 133 participants was selected. The sample was drawn purposively from known biodigester owners, who were the actual units of observation and analysis for the study. The primary data for the article were collected using a semi-structured interview guide administered to household respondents. Ethical approval was obtained from the Pwani University Ethical Board and the research permit from the National Commission for Science, Technology, and Innovation (NACOSTI).

Results

Socio-demographic Characteristics of Respondents

Table 1: Socio-Demographics

Socio-demographics		Frequency	Percentage
Gender	Male	81	60.9
	Female	52	39.9
Age	26-35	15	11.3
	36-45	78	58.6
	46-55	35	26.3
	Above 55 years	5	3.8
Education level	No formal education	33	24.8
	Primary	40	30.1
	Secondary	32	24.1
	Diploma	13	9.8
	Degree	13	9.8
	Postgraduate	2	1.5

Level of Awareness and Approval of Biogas Technology by the Community

Table 2: Community Awareness and Approval of Biogas Technology

Level of awareness	Percentage	Level of approval	Percentage	Operational capacity	Percentage
Aware	77.4%	Disapproved	12.8%	Operational	89.5%
Not aware	22.6%	Neutral	12.0%	Non-operational	10.5%
		Approved	75.2%		

Setup and Maintenance Cost of Biodigester

Study findings show that nearly one-quarter (24.1%) of the respondents purchased their biodigester units at a cost ranging between KSh 91,000 and KSh 110,000, slightly below one-fifth (20.3%) spent between KSh 151,000 and KSh 170,000, and 19.5% paid between KSh 111,000 and KSh 130,000. Slightly above one-tenth (12.0%) reported spending above KSh 210,000, while 11.3% paid between KSh 71,000 and 90,000. Smaller proportions (6.0%) indicated costs of KSh 51,000 to 70,000, KSh 31,000 to 50,000 (3.8%), and KSh 191,000 to 210,000 (3.0%).

Further, findings show that slightly above two-thirds (66.2%) of the respondents incurred repair costs of between KSh 2,100 and KSh 4,000 for any breakdown or damage to their biodigester system. Of the sample, 21% spent between KSh 1,000 and KSh 2,000, while 12.0% reported costs ranging between KSh 4,100 and KSh 6,000. Additionally, 42.9% of the adopters indicated that they spent between KSh 3,100 and 4,000 on annual servicing or regular checks of their biodigester systems, 30.1% spent between KSh 2,100 and 3,000, and 26.3% reported spending KSh 4,000, while a small fraction (0.8%) incurred costs between KSh 100 and 2,000.

Household Economics of Biodigester Technology

The researcher examined various household economic aspects associated with biodigester use, including the amount of land allocated for installation, the time households dedicate to feeding and maintaining the system, and the amount of water used in daily operations. These factors represent the social costs borne by households, and the results are presented in Table 3.

Table 3: Social Cost of Biodigester

Land use for biodigester	Parentage	Time spent feeding the biodigester	Percentage	Water use for biodigester	Percentage
1-5 M^2	25.6%	Less than 30 mins	19.15%	Below 20 litres	42.55%
6-10 M^2	18.8%	30 mins	61.01%	21-40 litres	19.15%
11-15 M^2	28.6%	30-60 mins	9.20%	41-60 litres	17.02%
16-20 M^2	14.3%	Above 60 min	10.64%	61-80 litres	21.28%
Above 20 M^2	12.7%				

Economic Benefits from the Biodigester

Survey results show that 24.8% of the respondents earned between KES 2,100-3,000 annually from the sale of biogas, 23.3% earned between KES 3,100-4,000 and between KSh 4,100-5,000, while 18.8% reported annual earnings of KES 1,100-2,000 (18.8%) and 9.8% earned below KES 1,000 (9.8%). The majority (77.4%) of the study participants reported generating modest supplementary income from biogas sales, which was substantial enough to contribute to household finances and enhance the perceived economic value of the technology, as well as savings from using other sources of energy for household needs. Furthermore, 16.5% of the respondents earned KES 3,000 annually from the sale of bio-slurry, 22.6% earned between KES 2,100 and 3,000, 33.3% earned between KES 1,100 and 2,000, while 23.3% earned below KES 1,000.

The findings are a testament to the fact that most (63.1%) participants generated moderate supplementary income from biofertilizer sales, reflecting its potential as an added economic benefit alongside biogas production. Additionally, the majority (80.5%) of respondents realized returns from their biodigesters in the range of 0–20%, while only 19.5% of biodigester adopters reported higher returns, reflecting a low return on investment.

Social Benefits from Biodigester Installation

The study explored the social benefits of biodigester adoption, such as job creation during construction and operation, improved accessibility to clean household energy, enhanced health through reduced respiratory problems, increased safety compared to traditional energy sources, and improved agricultural yields resulting from the use of bio-slurry as organic fertilizer.

Table 4: Social Benefits

Employment creation	Percentage	Access to energy	Percentage	Reduced respiratory complications	Percentage	Safety over other sources	Percentage	Improved agricultural yields	Percentage
For installations Yes	89.4%	Very difficult	5.3%	Yes, significantly	44.4%	Very unsafe	3.0%	Improved significantly	47.4%
No	10.6%	Difficult	11.3%	Yes, slightly	31.6%	Unsafe	4.5%	Improved, slightly	25.6%
In operations (Yes)	78.6%	Easy	43.6%	No change	14.3%	Neutral	21.3%	No change	18.0%
No	21.34	Very easy	39.8%	Not sure	9.8%	Safe	38.3%	Not sure	9.0%

The Influence of Household Economics on Biodigester Technology Adoption

Table 5: The influence of household economics on the adoption of biodigester technology

Social cost	χ2	df	P	C
Set-up cost	6.969	7	0.432	0.193
Land use	5.172	1	0.023	0.197
Time spend	0.003	1	0.955	-0.005
Water use	6.58	3	0.086	0.168
Odour	5.452	1	0.020	0.202
Social acceptance	4.199	1	0.040	0.178

The results show that land use (χ^2=5.172, p=0.023, C=0.197), odour (χ^2=5.452, p=0.020, C=0.202), and social acceptance (χ^2=4.199, p=0.040, C=0.178) had a significant influence to the adoption of biodigester technology, suggesting that availability of space, perception of smell, and community approval are important considerations for households deciding whether to adopt the technology.

However, water use (χ^2 = 6.58, p = 0.086, C = 0.168) was not statistically significant at the 5% level of confidence for the study. Similarly, time spent in feeding biodigester (χ^2=0.003, p=0.955) were also shown not to be statistical significant with adoption, implying that perceived time investment and set up cost were not a deciding factor for households in this study.

The Influence of Socio-Economic Benefit on Biodigester Adoption

Table 6: Table Influence of social benefit on biodigester adoption

Socio-Economic Benefit	χ2	df	P	C
Income from byproducts	3.522	4	0.047	0.163
Return on investment	0.699	2	0.705	0.019
Employment creation	1.375	1	0.241	-0.102
Energy access	4.572	1	0.032	0.182
Reduced respiratory complications	0.209	1	0.648	-0.040
Safety over other energy sources	5.172	1	0.023	0.197
Improved agricultural yields	0.836	1	0.361	0.079

Findings in Table 4 show that income from byproducts (χ^2=3.522, p=0.047, c=0.163), energy access (χ^2=4.572, p=0.032, C=0.182) and safety over other energy sources (χ^2=5.172, p=0.023, C=0.197) had a significant influence on the adoption of biodigester technology, indicating that households' value improved access to clean energy and enhanced safety conditions when making adoption decisions.

Conversely, return on investment (χ^2=0.699, p=0.705, c=0.019), employment creation (χ^2=1.375, p=0.241, C-0.102), reduced respiratory complications of users (χ^2=0.209, p=0.648, C=-0.040), and improvement of agricultural yields (χ^2=0.836, p=0.361, C=0.079) were not statistically significant. Thus, although these are potential benefits of biodigester technology, they were not decisive factors influencing adoption in the current context.

Discussion

The study results in Table 1 demonstrate that the representation of men and women incorporates balanced perspectives, which is adequate and meets the threshold set by the Kenyan Constitution (2010), stipulating that no single gender should comprise more than two-thirds in appointive and by extension operational engagements. Furthermore, Table 2 shows that 77.4% of the respondents stated their community was aware of biodigester technology and its benefits, while 75.2% of the community members approved and supported biogas technology, indicating a broad social acceptance which was in line with those reported by Walekhwa *et al.,* (2019) and Cheng *et al.* (2020) in Uganda, who found that community-level awareness and social approval played a central role in shaping long-term adoption of renewable energy innovations, including biodigesters which was informed by awareness campaigns and perceived benefits.

Majority (75.9%) of the biodigester owners incurred moderate to high investment costs, which influence access, affordability, adoption rates, and the perceived economic viability of the technology within different income segments, as observed by Walekhwa et al. (2009) in Uganda that high upfront costs remain a major barrier to biogas adoption in East Africa. Findings by Chisika et al. (2021) revealed that most rural households in Kenya prefer medium-capacity biodigesters due to affordability and manageable feedstock requirements. Similarly, Karanja *et al.* (2021) reported that household-level adoption is often skewed toward small- to medium-scale digesters, as larger systems require substantial capital and consistent feedstock supply. On the contrary, Gebremedhin et al. (2019) highlighted that in Ethiopia, larger biodigester units were more prevalent among farming households with higher livestock populations and land availability.

Survey results in Table 3 indicate that the majority (80.26%) of respondents reported taking approximately 30 minutes to feed the biodigester, which was determined by the distances and biodigester capacity, as well as the integration into daily routines. As observed by Bensah et al., (2020), the average biodigester feeding time in smallholder households typically ranges between 20 to 40 minutes. Karanja and Wekesa (2022) found that in rural Kenyan households, most users spent approximately 30 minutes on biodigester feeding routines, suggesting that the practice integrates well into daily farm schedules. While Osei et al., (2023) observed that in Ghana, households with larger biodigesters often required over an hour for feeding and slurry handling, showing how system size and management practices influence time requirements.

According to Nnaji et al., (2012), in Nigeria, small-scale biogas adopters often attained only marginal savings, with the technology remaining economically unappealing without external support or subsidies. Similarly, Ghosh and Sahu (2019) observed in rural India that while households reported some reduction in fuel expenditure, the returns were modest due to high input costs and inefficiencies in system operation. The findings of this study were consistent with those of previous studies. On the contrary, Parawira (2009) in Zimbabwe established higher returns at community or institutional levels of adoption; thus, larger-scale systems have greater potential to generate meaningful economic benefits. Bond and Templeton (2011), noted that proximity to households not only ensures regular feeding and monitoring of the biodigester but also enhances its integration into daily domestic energy and waste management practices.

Accessibility of biogas systems significantly influences technology acceptance and long-term sustainability (Kabir et al., 2018; Smith et al., 2019). These results were supported by those of the current study. Moreover, Kimani (2020) reported that biogas projects in East Africa generate significant local employment through construction and maintenance activities. Similarly, Mwirigi *et al.,* (2021) found that the introduction of small-scale biodigester systems in Kenya created diverse job opportunities across construction, maintenance, and waste management, thereby strengthening rural economies. Smith *et al.,* (2014) found that households adopting clean cooking solutions, including biogas, experienced significant reductions in household air pollution, thereby lowering risks of smoke-related illnesses. The adoption of biogas in rural Kenya has contributed to improved respiratory health, particularly among women and children, who are most exposed to indoor cooking smoke (Mwirigi et al., 2014). The current study aligns with this finding.

A large proportion (72.1%) of the community viewed biogas as a safe energy option, which is supported by Gautam et al., (2019), who noted the same for communities in Nepal. Moreover, in Kenya, Mwirigi *et al.,* (2014) observed that while many rural households associated biogas with cleaner and safer energy, limited technical knowledge and inadequate user training often created doubts about safety. Osei-Marfo *et al.,* (2018) highlighted that digestate from biogas systems significantly enhances soil fertility and crop yields when applied appropriately, which is in line with the current findings. Similarly, Arthur et al., (2011) noted in Ghana that farmers who integrated bio-slurry into their farming systems experienced reduced dependence on chemical fertilizers and improved soil health. Thus, the majority (72.1%) of the respondents indicated that the application of bio-fertilizer was perceived to boost crop productivity, which can enhance food security and generate greater economic returns for farming households. Similarly, Mwirigi *et al.,* (2014) reported that farmers using bio-slurry in Kenya recorded higher crop yields and reduced expenditure on inorganic fertilizers. Moreover, Kabir *et al.,* (2013) highlighted in Bangladesh that the integration of bio-slurry into farm systems improved both soil structure and crop output.

Mwirigi et al., (2009) highlighted land availability as a key determinant of biogas uptake in Kenya, and align with studies noting the importance of odour management and social acceptance in influencing adoption. Nevertheless, Mengistu et al., (2016) identified water availability as a significant predictor of biogas adoption in Ethiopia, suggesting that in the current study area, water may be less critical due to contextual factors such as access to piped or nearby water sources. Katuwal and Bohara (2009), observed that the promise of reliable and renewable household energy is a major motivator for biogas adoption in Nepal. Similarly, the role of safety is consistent with Surendra et al., (2014), who documented that reducing indoor smoke and firewood handling risks contributes to the willingness of households to invest in biogas systems. However, the non-significance of health benefits contrasts with Surendra et al., (2014), who emphasized improved household health as a primary driver of biogas adoption in developing countries.

The study concludes that adoption of biodigester technology in Kilifi County is characterized by strong community awareness, a positive perception, and moderate economic viability. Most households were aware of and approved of the technology, with a majority reporting operational biodigester that provide tangible social and economic benefits. The adoption process is largely supported by affordable maintenance costs and the ability to integrate biodigester operations into routine household activities.

Furthermore, the use of bio-slurry enhanced soil fertility and crop productivity, while the technology reduced exposure to smoke and harmful fumes, improving household health and safety conditions. Employment creation during installation and operation further highlighted the socio-economic value of the technology. However, the relatively low returns on investment and moderate-income generation from byproducts suggest that while biodigesters offer social and environmental benefits, their direct financial profitability remains limited at the household level.

The paper emphasizes the need for the government, NGOs, and technology providers to enhance capacity-building programs that equip users with the technical knowledge necessary for biodigester installation, operation, and maintenance. This will minimize system failures and improve long-term functionality, especially in rural settings where technical expertise is limited. Additionally, the survey found that high setup costs remain a significant barrier to widespread adoption. It is recommended that stakeholders introduce flexible financing models such as low-interest loans, subsidies, or cooperative-based credit systems. These mechanisms can make biodigester technology more affordable to low- and middle-income households while encouraging investment in renewable energy solutions.

The adoption rates were found to be low, and there is a quest to increase awareness campaigns to sensitize communities about the social, environmental, and health benefits of biodigester technology. Promoting community success stories and demonstrating the positive impact of biogas and bio-slurry use can improve social acceptance and foster peer-driven adoption.

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