MERIT RESEARCH JOURNALS
www.meritresearchjournals.org

Merit Research Journal of Agricultural Science and Soil Sciences (ISSN: 2350-2274) Vol. 12(2) pp. 022-030, October, 2024
Available online http://meritresearchjournals.org/asss/index.htm

DOI: 10.5281/zenodo.14055759

Original Research Article

Socio-Economic Factors Influencing Biogas Technology Uptake among Rural Households in Kuresoi South Sub-County, Nakuru County

Gypson Kipkorir Kurere*, Eliud Garry Michura, Sella Kebenei

Kabarak University

Email: gkurere@kabarak.ac.ke

Abstract

Biogas technology presents an alternative sustainable energy source that offers an opportunity to transform energy security, environmental sustainability, and reduction in greenhouse gas emissions. The research study explores the socioeconomic factors affecting biogas technology uptake among rural households in Kuresoi South Sub-County, Nakuru County. This is a descriptive study design based on the use of both primary and secondary data sources. The data collection covered 155 respondents through the use of questionnaires, focus group discussions, key informant interviews and observations. Selection of the respondents was done by using systematic random sampling, while data analysis was done using descriptive statistics, chi-square tests, and cross-tabulation supported by SPSS version 26. Results indicated that despite high levels of awareness, the adoption of biogas technology was low, with firewood remaining the primary source of energy in 68% of the households. Fixed dome and tubular were the biogas digester types in use, since they are relatively cheaper and more durable; however, economic factors, mainly household income, were the main determinant of uptake. The chi-square results indicated that there was a significant relationship between household income and uptake of biogas, $\chi^2 = 9.531$, $p = 0.048$, implying that the poorer a household is, the greater the financial barrier to the technology. Level of education, too had a say in energy adoption; education and energy choice had a strong association-since $\chi^2 = 12.814$, $p = 0.002$-which depicted that more educated households were more likely to adopt the technology. The gender factor is insignificant in influencing energy choices, underlining a proof from the fact that $\chi^2 = 2.119$, $p = 0.346$, where broader socio-economic factors played a much greater role in decisions. This study also revealed out that radio was the effective channel for knowledge sharing and information dissemination related to biogas technology. On the other hand, partial understanding of the technical aspects has acted as a big barrier to the better diffusion of this technology. In conclusion, income levels and education are two main factors affecting the uptake of biogas technology. Enhanced education, targeted financial support and better outreach strategies go toward increasing adoption rates and supporting transitions to sustainable energy in rural areas.

Keywords: Biogas technology, Chi-square analysis Energy adoption, Renewable energy, Rural households, Socio-economic factors

INTRODUCTION

Biogas is a mixture of gases produced through the process of anaerobic digestion, which is the breakdown of organic material by microorganisms in the absence of oxygen. Biogas consists mainly of 50-70% Methane, 30-40% carbon dioxide and low amounts of other gases. Biogas can be produced from a variety of feed stocks, including agricultural waste, food waste, and energy crops. The process of producing biogas involves the breakdown of organic material in a sealed, oxygen-free container or system, such as a biogas digester. The methane produced through this process can be burned to generate heat, electricity, or used as a fuel for transportation. (Igoni et al., 2008)

A report by Aemro, Moura, and de Almeida (2021) revealed that a substantial number of people in developing regions, particularly those in rural areas of sub-Saharan Africa, India, and other parts of Asia, still rely on traditional biomass, coal, or kerosene for cooking. Despite the progress made in economic development and growing awareness of the health hazards associated with using unclean fuels for cooking, the number of individuals without access to clean cooking facilities has continued to rise due to population growth outpacing the increase in households with access to clean energy. At present, approximately 3 billion people, or 41% of the world's population, lack access to clean cooking facilities, which is almost the same number as in 2000. Furthermore, around 1 billion individuals still lack access to electricity, with most residing in sub-Saharan Africa and India, according to the World Bank (2018).

The rate at which access to clean cooking facilities is improving varies significantly across different regions. For instance, China has made significant progress in reducing its reliance on solid fuels for cooking, with the percentage dropping from 52% in 2000 to 33% currently. However, the pace of progress has been slow in sub-Saharan Africa, where population growth has outpaced the progress made in this area. In fact, an estimated 84% of the population in this region still relies on solid biomass, coal, or kerosene for cooking. This is particularly common in rural areas where affordable modern forms of energy are scarce (Osano et al., 2020).

Rural households in Africa depend on solid biomass for cooking (Ravindra, Kaur-Sidhu, Mor & John, 2019). Although the number of people in low- and middle-income countries who have access to clean cooking facilities has increased by 60% since 2000, population growth has outpaced this progress, resulting in around 400 million more people without access to clean cooking today compared to 2000 (UNDESA, 2018). Additionally, some households who have access to clean fuels still use biomass, coal, or kerosene as supplementary fuels, which is known as "fuel stacking."

In Kenya, a significant number of households still rely on solid fuels despite being financially capable of affording the monthly cost of purchasing LPG, which is around USD 15 to 20 (Jürisoo, Lambe & Osborne, 2018). This behavior can be attributed to a range of factors that go beyond income and energy costs. Factors such as availability and reliability of supply, prices of alternative fuels, acquisition costs, safety concerns, lack of awareness of the negative health impacts of traditional stoves, and cultural preferences all play a role in determining fuel usage patterns. Mwirigi et al. (2014) explain that the reasons for this complex behavior are multifaceted.

Kuresoi South sub-county is an area in Nakuru County, Kenya, with a population of predominantly small-scale farmers who rely on agriculture as their main source of income. The area faces a number of socio-economic challenges that limit the adoption of biogas technology, including financial constraints, limited availability of feedstock, and lack of awareness and understanding of the technology. As such, there is a need to assess the socio-economic factors affecting the uptake of biogas technology among rural households in Kuresoi South sub-county in order to develop strategies to promote its adoption and improve rural livelihoods.

Statement of the Problem

According to Otieno, C. 2020, Kuresoi South Sub County has the highest level of firewood use in Nakuru County. The use of firewood for cooking has contributed to uncontrolled harvesting of trees and shrubs as well as exposing users to many health problems especially lung diseases. Every year 21,560 deaths are caused by household air pollution (Clean Cooking Sector Study, 2019). Biogas technology has been regarded as the best alternative to these problems through mitigating green-house gas emissions, improving agricultural sustainability and reducing energy shortage (Mannan et al., 2018).

Wamwea, 2017 records that achievement of biogas technology in rural Kenya has continued to be challenging in spite of the effort from the government and international organizations promoting renewable energy sources. Adoption and sustainability of the technology is still low, presently at 0.03%. Farmers operating on a small scale in the region encounter several obstacles when it comes to implementing biogas technology. These hindrances include limited financial resources, insufficient raw materials for producing biogas, and a lack of knowledge and understanding regarding the technology. As a result, there is a need to identify and understand the socio-economic factors that influence the adoption of biogas in Kuresoi South in order to inform the development of policies and interventions that can support the wider adoption of this technology in the area.

Broad Objective

The broad objective of the study is to assess the socio-economic factors affecting biogas technology adoption among rural households in Kuresoi South Sub County, Nakuru County.

Specific Objectives

The specific objectives of the study include:

1. To determine the percentage of energy mix consumed by households in rural Kuresoi South, Nakuru County.
2. To determine the income level of households heads on biogas technology uptake among rural households in Kuresoi South Sub-County.
3. To assess the level of awareness and knowledge on biogas technology uptake among rural households in Kuresoi South Sub-County.
4. To assess how gender influence decision making processes on uptake of biogas technology among rural households in Kuresoi South Sub-County.

LITERATURE REVIEW

Income

Different studies have managed to draw an inference between the income of the head of a household and the type of fuel they opt for. An analysis by Rahut et al., (2019) on determinants of fuel choice determined that income has a major role in fuel choice. Similarly, Muller and Yan, (2018) also identified managed to draw a correlation between the household income and fuel type. While a majority of the studies have demonstrated a significant influence on the type of fuel a household's income, some studies have also shown that a household income does not influence fuel type.

In Kenya, a study by Baek et al. (2020) indicated the impact of a household income on the type of fuel used. This study concurs with other studies by Ngeno et al., (2018) who in their report indicated that lower-income households tend to go for polluting fuels which are usually cheaper and affordable to them. A household will tend to prefer the most affordable type of fuel and sometimes not pay emphasis to its effects on the users and environment. On the other hand, households will opt to diversify the types of fuel they use as they grow economically (Samson et al., 2015).

Several studies have managed to demonstrate how income can potentially affect biogas adoption in Kenya. For instance, the literature review on the study on factors influencing biogas adoption by Uhunamure et al. (2019), points out the influence of income in biogas adoption in

Kenya. The study shows how a household with higher income can manage to afford more livestock hence be able to install a biogas digester since they have both the raw material and financial power for purchasing the technology. Similarly, Momanyi and Benards, (2016) identified income as one of the prime factors influencing biogas adoption in Kenya. Since individuals with higher income are the ones with better purchasing power, the probability of households with higher than average income to adopt biogas is better than those with lower income.

The study by Mugo, (2017) on factors influencing biogas adoption points out the relationship between income and biogas adoption. The study indicates that the majority (73%) of the respondents in the study who had adopted biogas had an income above Kshs 40,000 while the majority (67.2%) of the non-adopters had an income less than Kshs 20,000. The study further indicates that the cost of installing and running a biogas plant requires a high cost therefore household heads with higher income are best suited to install and run the biogas technology. A similar finding was established by Momanyi & Benards, (2016) who also reiterated the effects of the high cost of biogas installation that can prohibit households with low income from installing the technology. From the data analysis of the study, 70% of respondents who earned less than Kshs 10,000 were unable to afford biogas installation while those who had installed biogas had an income above Kshs 10,000 on average. On the other hand, the availability of other traditional yet deleterious types of fuel such as Kerosene or firewood was much more affordable to the low-income earners.

The main economic activities in Kuresoi South is agriculture and lumbering. Bigger fractions of the farmers are into small-scale informal farming. Considering that the Kuresoi South is mainly a rural area, there is little urbanisation and the economic activities are mainly designated to agriculture (both livestock keeping and plant growing) hence the economy of the area is majorly average. An expanding economy and more people receiving an education means that there is a potential for the economy to grow in the future (GoK, 2018).

The energy ladder theory has been used in the past to depict the idea of an entity where when their income increases; their choice of fuel also changes. If a household happens to grow economically then they will tend to ditch the traditional dirty fuel and go for the cleaner and efficient type of fuel such as LPG gas (Hanna & Oliva, 2015). This has been witnessed in different developing countries. In some cases, however, improvement in the economic capacity of a household would not necessarily mean they change their type of fuel, instead, they will tend to mix whereby they will utilize both the old and new type of fuel (Levine et al., 2018; Muller and Yan, 2018).

RESEARCH DESIGN AND METHODOLOGY

Research Design

This research study adopted a descriptive survey research design. This design was chosen because according to Mugenda and Mugenda (2003), it seeks to answer questions concerning the association between independent and dependent variables of the study. The research is appropriate in determining the relationship between independent variables (socio-economic factors) and dependent variable (adoption of biogas technology).

Location of the Study Area

The research study was carried out in Kuresoi South Constituency, Nakuru County, Kenya. Nakuru County lies within the Great Rift Valley and borders eight other counties namely, Kericho, and Bomet to the West, Baringo and Laikipia to the North, Nyandarua to the East, Narok to the Southwest and Kajiado and Kiambu to the South. The County covers an area of 7,495.1 km2 and is located between longitudes 35^0 28^0 and 35^0 36^0 and latitudes 0^0 13^0 and 1^0 10^0 South (Nakuru County Integrated Development Plan, (2013). Kuresoi South is known for its rolling hills, steep valleys, and high elevations, with the Mau Forest being a major landmark. Kuresoi South lies within longitudes; 35° 31' 18" E, and latitudes 0° 18' 3" S. It covers a total area of 211.7 sq mi (548.2 km^2).

Population of the Study

The target population in this study are rural households from Kuresoi South Sub-county. Kuresoi South consists of a population size of 154,998 people and a total number of 34,627 households according to the Kenya National Bureau of Statistics, 2019.

Sampling Procedure and Sample Size

Sampling means selecting a given number of subjects from a defined population as representative of that population. According to Creswell (2015), any statements made about the sample should also be true of the community. The following formula by Creswell (2015) was used to determine sample size.

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

Where: n = Sample size, N = Population, C = Coefficient of variation, e = Standard error. C=25% is acceptable according to Creswell (2015) e = 0.02 and N=34,627

n= [34,627*0.25^2] / [0.25^2 +(34,627-1)0.02^2]

=2164.19/13.91

=155

The study adopted stratified random sampling using the administrative unit called “ward” as strata to proportionally distribute the 155 households in the 4 wards of Kuresoi South Sub -county based on the total number of households in each ward. For example, the number of households to be selected from Kiptagich Ward was computed as follows: 7,853/34,627* 155=35 households

Stratified random sample applied by the study

The actual households surveyed from each Ward was selected from a randomized sampling frame using systematic random sampling based on a predetermined sampling interval. Purposive sampling was used to identify the key informants in the area of study based on the fact that they are knowledgeable on socio-economic and biogas issues affecting the residents of Kuresoi South.

DATA ANALYSIS, PRESENTATION, AND DISCUSSION

Income Levels

The studysought to identify the income levels of the respondents to determine any relationship with the uptake of biogas technology in the study area.

The table shows the distribution of monthly household income in KES. As shown, almost half of the households, 49.7 percent, earn below KES 10,000, while one-third, 34.8 percent, earn between KES 10,000 and 20,000. Only 10.3 percent earn between KES 20,000 and 30,000 and 3.2 percent between KES 30,000 and 40,000, while 1.9 percent earn above KES 40,000. This means that a significant proportion of the population falls within the lower level of income, further hurling problems in the adaptation of clean energy solutions. Lower-income homes may lack the financial capacity to invest in clean energy technologies due to up-front cost.

According to a study conducted by Chiteculo et al. in 2018 in Kenya, while these experiences brought about long-term savings and environmental benefits, the probability of a low-income household adopting a solar energy system was still low since this involved very high upfront costs. This supports the broader literature indicating that up-front capital requirements are one of the main barriers to adopting clean energy for economically disadvantaged groups.

In a connected study, Sovacool et al. (2018) assessed the use of clean energy technologies in Tanzania and found one significant barrier to be financial constraints. According to the findings, lower-income families are likelier to spend their money on basic beneficial needs such as food and education rather than on long-lasting but highly costly energy infrastructure. This can be quite understandable, having undergone daily economic struggles.

A study by Khandker et al. (2018) in Bangladesh showed, however, that the presence of credit and financial support mechanisms increased considerably the adoption rate of solar home systems among lower-income households. This means that new financing innovations; microloans or, particularly, pay-as-you-go

Table 1. Stratified Random Sampling

	Targeted sample size		
Ward	**No. of Households**	**Sample size**	**%**
Kiptagich	7,853	35	23
Keringet	8,882	40	26
Amalo	5,990	27	17
Tinet	11,902	53	34
Total	**34,627**	**155**	**100**

Source: (Kenya National Bureau of Statistics, 2019)

Table 2. Income

	Frequency	Percent	Valid Percent	Cumulative Percent
Below 10,000	77	49.7	49.7	49.7
10,000-20,000	54	34.8	34.8	84.5
20,000-30,000	16	10.3	10.3	94.8
30,000-40,000	5	3.2	3.2	98.1
Above 40,000	3	1.9	1.9	100.0
Total	155	100.0	100.0	

Source: *Research Data (2024).*

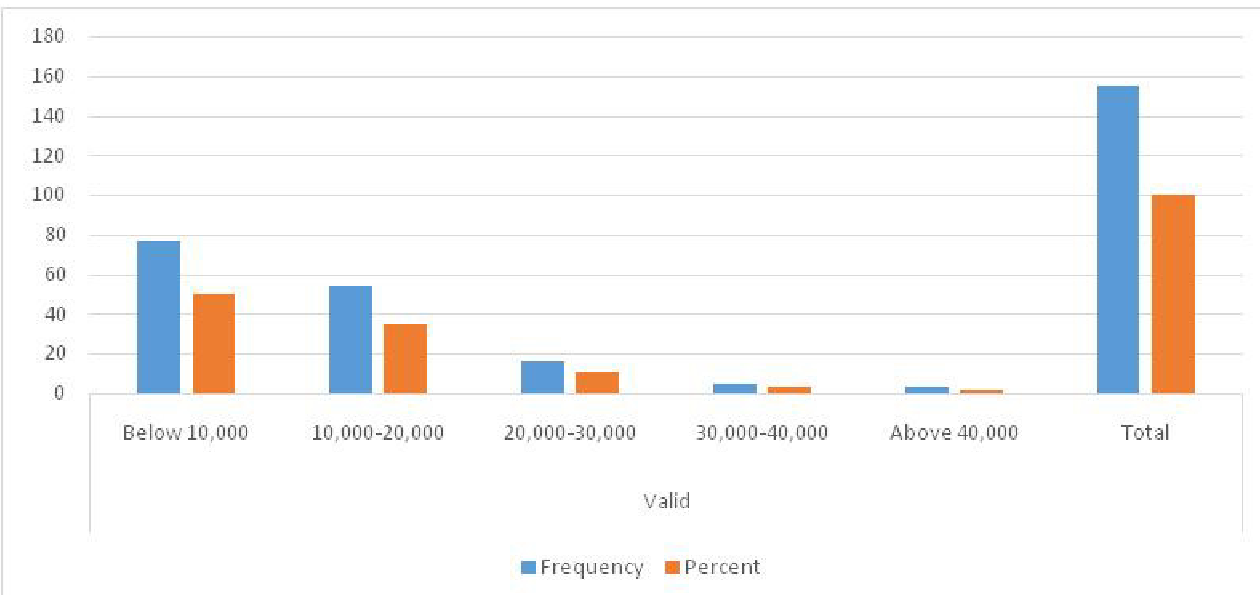

Figure 1: Income

Source: *Research Data (2024).*

models, would be significant enablers for the low-income population shifting into clean energy.

Furthermore, in 2018, research in India by Rahut et al. showed that as income increased, modern energy source usage increased substantially. Still, the presence of subsidies and government support programs was of paramount importance to be able to enable the shifting away from traditional biomass use toward cleaner forms of energy for the lower-income households. This shows that policy interventions are highly deterministic in dictating the clean energy adoption rate.

Establishing the Relationship between Income and household's Primary Energy

The table 3 displays various Chi-Square test statistics testing the relationship of household income to household

Table 3. Household Primary Energy*Income Cross tabulation

			Energy		Total
			1.00	3.00	
Income	**1.00**	**Count**	5	72	77
		Expected Count	8.9	68.1	77.0
	2.00	Count	13	65	78
		Expected Count	9.1	68.9	78.0
Total		Count	18	137	155
		Expected Count	18.0	137.0	155.0

Table 4. Chi-Square Tests Between Household Income and Household Primary Energy

	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	3.907	1	.048		
Continuity Correction	2.979	1	.084		
Likelihood Ratio	4.034	1	.045		
Fisher's Exact Test				.077	.041
Linear-by-Linear Association	3.882	1	.049		
N of Valid Cases	155				

Source: *Research Data (2024).*

primary energy type. The Pearson Chi-Square test has a value of 3.907 with 1 degree of freedom and an asymptotic significance or p-value of 0.048, which is significant at the 5% significance level. The Likelihood Ratio Chi-Square also confirms this conclusion with a value of 4.034 and a p-value of 0.045. The p-value, however, from the Continuity Correction applied to the 2 x 2 table was not significant at 0.084. Fisher's Exact Test yields a p-value of 0.077 (2-sided) and 0.041 for the 1-sided test; thus, under this latter approach, there would be an association. Linear-by-Linear Association value is 3.882 with a p-value of 0.049, indicating significance. The analysis produces a significant relationship between Household Income and Primary Energy Sources. Only tests of Continuity Correction and Fisher's exact test (2-sided) are non-significant, but only marginally so. There were 155 valid cases with no expected counts less than 5.

According to Li et al. (2018), within the rural areas of China, the adoption of cleaner energy sources is highly driven by the level of income at the household level; that means more affluent households use electricity and natural gas, while poorer ones stick to the traditional use of biomass. Similarly, Ahmad and Puppim de Oliveira (2018) found in Bangladesh that higher-income households tend to use LPG as a modern form of energy, whereas, for poor families, firewood and other traditional fuels are usually the only way.

This is further supported by a study conducted in India by Khandker et al. (2020), where they found that income remains one of the most critical determinants of switching from traditional to modern sources of energy; therefore, with the help of subsidies and financial support, it could play a vital role in making cleaner sources of energy more accessible to the low-income groups. In sub-Saharan Africa, similar trends were recorded, with the choice of which energy to use directly being dictated by the income level, in that more affluent households chose to use electricity and poorer households stuck to kerosene and wood (Uhunamure et al., 2019). Table 5

The data provided above on the adoption of biogas technology describes a precise scenario of the barriers and motivations that exist among households. Item 1 shows a high perception that the initial cost of biogas technology is a significant barrier, thus indicating that financial constriction is a primary concern. This concern is further underpinned by Item 2, where the low perception indicates that majorities feel their income is not sufficient to invest in biogas technology. It simply means that one of the significant obstacles is a huge capital upfront requirement, which deters many from considering biogas as a sustainable energy.

In contrast, items 3, 4, and 5 generally favor the biogas technology. Item 3 is highly perceived, which means that, in general, households could see the long-term value or even the benefits reaped from biogas technology; it seems to be something good to invest in. Item 4 shows a high perception, thus emphasizing that without access to financing options, this need cannot be met. If accessible financial aids such as loans or subsidies are made available, then biogas technology will be easily adopted by these households. On the last note,

Table 5. Households Head Perception Towards Income as A Factor affecting Biogas Uptake

Items	SD (%)	D(%)	N (%)	A(%)	SA(%)	Mean	Standard Deviation	Decision
1. The initial cost of biogas technology is a significant barrier for me.	0 (0)	0 (0)	3 (1.9)	25 (16.1)	127 (81.9)	4.80	.447	High Perception
2. My household's income allows for investment in biogas technology.	135 (87.1)	6 (3.9)	2 (1.3)	9 (5.8)	3 (1.9)	1.32	.910	Low Perception
3. I believe biogas technology is a worthwhile investment for our household.	4 (2.6)	15 (9.7)	9 (5.8)	18 (11.6)	109 (70.3)	4.37	1.117	High Perception
4. Access to financing options would facilitate biogas technology adoption.	8 (5.2)	7 (4.5)	5 (3.2)	14 (9.0)	121 (78.1)	4.50	1.101	High Perception
5. Biogas technology offers long-term cost savings compared to other fuels.	6 (3.9)	14 (9.0)	9 (5.8)	23 (14.8)	103 (66.5)	4.31	1.160	High Perception

Note: N=155; SA=Strongly Agree; A=Agree; N=Neutral; D=Disagree; SD=Strongly Disagree; Weighted Average=3.86
Source: *Research Data (2024).*

an understanding of the long-term cost savings is highlighted by high perception in Item 5, which biogas offers over other fuels, thereby showing that households recognize the economic benefit once the initial cost barrier is overcome. According to Ulsrud et al. (2018), in Tanzania, it was reported that the high initial cost of biogas technology demotivates most households from investing in this sustainable gas. Precisely, it is noted that even though the use of biogas brings clear long-term benefits, which include cost savings and environmental advantages, many prospective users are scared off by the high upfront investment. This agrees well with the high perception of the initial cost as a barrier indicated in Item 1 of the provided data.

Furthermore, Item 2 from findings in earlier work in Kenya by Mwirigi et al. (2018) supports a low perception of the ability of households to invest in biogas technology. The study showed that income levels among a majority of the households rarely suffice to finance upfront costs for biogas systems; instead, there is a call for financial support. To such results, the research finds weak financial capacity among low-income households as one major constraint to adopting biogas technology.

Items 3, 4, and 5, on the flip side, appear to have positive perceptions about the value and actual benefits of biogas technology. This agrees with several studies that claim that biogas has the potential for long-term savings and environmental benefits.

The study by Surendra et al. (2018) for instance revealed that households in Nepal using biogas reported high savings from fuel expenditure and improved health through reduced indoor air pollution. This supports the typical perception of this biogas technology as a worthwhile investment about its long-term cost-saving potential. This awareness about the importance of financing options is supported by the results of a study conducted in South Africa by Amigun and Blottnitz, 2018, where access to financing and credit schemes was established as one of the most dominant drivers for the increased adoption of biogas technology. In that regard, their study demonstrated that innovative solutions such as pay-as-you-go and micro-loans mechanisms help to scale up the adoption of biogas by minimizing this barrier of upfront costs for low-income households.

CONCLUSION

The study highlights the critical influence of income on the adoption of biogas technology among rural households in Kuresoi South Sub-County. Despite widespread awareness of the benefits of biogas, including long-term cost savings and environmental sustainability, financial barriers continue to inhibit its uptake. Most households in the region fall into the lower-income category, with nearly 85% earning less than KES 20,000 per month. This low income level restricts their ability to afford the high upfront costs associated with biogas technology installation. Subsequently, many households continue to rely on cheaper, traditional fuels such as firewood, which are more accessible but pose environmental and health risks. Furthermore, the study confirms a significant relationship between household income and energy choices as lower-income households are more likely to stick with affordable yet polluting fuel sources. The financial constraints that these households face highlight the need for interventions that can address the affordability barrier to biogas technology adoption.

RECOMMENDATIONS

1. The government, in partnership with NGOs and financial institutions, should introduce subsidies or grants to reduce the upfront cost of biogas installations for low-income households. This could make the technology more accessible to a broader section of the population.
2. Introducing flexible financing solutions such as microloans or pay-as-you-go models would enable low-income households to adopt biogas technology without the burden of high upfront costs. This strategy has proven successful in other regions and could be adapted for Kuresoi South.
3. Although awareness of biogas exists, further educational initiatives should focus on the long-term financial and health benefits of biogas technology. Increasing awareness of financing options could also motivate households to make the transition.
4. The government should consider introducing policies that incentivize the adoption of clean energy technologies, such as tax breaks for biogas adopters or promoting public-private partnerships aimed at supporting sustainable energy adoption in rural areas.

REFERENCES

Aemro YB, Moura P, de Almeida AT (2021). Inefficient cooking systems a challenge for sustainable development: a case of rural areas of Sub-Saharan Africa. *Environment, Development and Sustainability*, 1-25. biogas dissemination in Rwanda: AHP approach. *Renewable Energy*, *163*, 1127-1137.

Fisher S, Bellinger DC, Cropper ML, Kumar P, Binagwaho A, Koudenoukpo JB, Landrigan PJ (2021). Air pollution and development in Africa: impacts on health, the economy, and human capital. *The Lancet Planetary Health*, *5*(10), e681-e688.

Flotats X (2019). Biogas: perspectives of an old technology. In *Biorefinery* (pp. 313-349). Springer, Cham.

Franceschinis C, Thiene M, Scarpa R, Rose J, Moretto M, Cavalli R (2017). Adoption of renewable heating systems: An empirical test of the diffusion of innovation theory. *Energy*, *125*, 313-326.

Hasan AM, Kabir MA, Hoq MT, Johansson MT, Thollander P (2022). Drivers and barriers to the implementation of biogas technologies in Bangladesh. Biofuels, 13(5), 643-655.

Igoni AH, Ayotamuno MJ, Eze CL, Ogaji SOT, Probert SD (2008). Designs of anaerobic digesters for producing biogas from municipal solid-waste. *Applied energy*, *85*(6), 430-438

Iqbal S, Anwar S, Akram W, Irfan M (2013). Factors leading to adoption of biogas technology: a case study of District Faisalabad, Punjab, Pakistan. Int. J. Acad. Res. Bus. Soc. Sci. 3(11), 2222-6990.

J. Cleaner Prod. 193, 300-314.

Jürisoo M, Lambe F, Osborne M (2018). Beyond buying: The application of service design methodology to understand adoption of clean cookstoves in Kenya and Zambia. *Energy Research & Social Science*, *39*, 164-176.

Karjalainen S, Ahvenniemi H (2019). Pleasure is the profit-the adoption of solar PV systems by households in Finland. *Renewable energy*, *133*, 44-52.

Mannan M, Al-Ansari T, Mackey HR, Al-Ghamdi SG (2018). Quantifying the energy, water and food nexus: A review of the latest developments based on life-cycle assessment.

Manzano RM, Pérez JE (2023). Theoretical framework and methods for the analysis of the adoption-diffusion of innovations in agriculture: a bibliometric review. *Boletín de la Asociación de Geógrafos Españoles*, (96), 4.

Marie, M., Yirga, F., Alemu, G., & Azadi, H. (2021). Status of energy utilization and factors affecting rural households' adoption of biogas technology in north-western Ethiopia. Heliyon, 7(3), e06487.

Mugenda, O.M. and Mugenda, A.G. (2003) Research Methods, Quantitative and Qualitative Approaches.

Mukeshimana, M. C., Zhao, Z. Y., Ahmad, M., & Irfan, M. (2021). Analysis on barriers to

Mwirigi J, Balana BB, Mugisha J, Walekhwa P, Melamu R, Nakami S, Makenzi P (2014). Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. biomass and bioenergy, 70, 17-25.

Mwirigi JW, Makenzi PM, Ochola WO (2009). Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy for Sustainable Development, 13(2), 106-115.

Mwirigi JW, Makenzi PM, Ochola WO (2009). Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. *Energy for Sustainable Development*, *13*(2), 106-115.

Nevzorova T, Kutcherov V (2019). Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. *Energy Strategy Reviews*, *26*, 100414.

Nyonje RO, Njoroge WR, Gakuu MC (2013). Adoption of Biogas Technology Projects among Rural Household of Lanet Location-Nakuru County.

O'Connor S, Ehimen E, Pillai SC, Black A, Tormey D, Bartlett J (2021). Biogas production from small-scale anaerobic digestion plants on European farms. *Renewable and Sustainable Energy Reviews*, *139*, 110580.

Ogejo JA, Wen Z, Ignosh J, Bendfeldt ES, Collins Jr, ER (2009). Biomethane technology.

Osano A, Maghanga J, Munyeza CF, Chaka B, Olal W, Forbes PBC (2020). Insights into household fuel use in Kenyan communities. *Sustainable Cities and Society*, *55*, 102039.

Otieno C (2020). THE URBAN INVISIBLES. *THE JUST CITY*, 40

Roopnarain A, Adeleke R (2017). Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renewable and Sustainable Energy Reviews*, *67*, 1162-1179.

Samali JE (2018). *Livestock derived biogas and woodfuel for climate change mitigation: comparative analysis in Nakuru county, Kenya* (Doctoral dissertation, University of Nairobi).

Taherdoost H (2018). A review of technology acceptance and adoption models and theories. *Procedia manufacturing*, *22*, 960-967.

Uhunamure SE, Nethengwe NS, Tinarwo D (2019). Correlating the factors influencing household decisions on adoption and utilisation of biogas technology in South Africa. Renewable and Sustainable Energy Reviews, 107, 264-273.

Wahyudi J (2017). The Determinant Factors of Biogas Technology Adoption in Cattle Farming: Evidences from Pati, Indonesia. International Journal of Renewable Energy Development, 6(3).

Wamwea SN (2017). *Success and failure of biogas technology systems in rural Kenya: an analysis of the factors influencing uptake and the success rate in Kiambu and Embu counties* (Master's thesis, Norwegian University of Life Sciences, Ås).

Zheng X, Wei C, Qin P, Guo J, Yu Y, Song F, Chen Z (2014). Characteristics of residential energy consumption in China: Findings from a household survey. *Energy Policy*, *75*, 126-135.