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Insights into home biogas technology adoption dynamics through the lens of the diffusion of innovation theory in Uganda

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ABSTRACT

Ensuring sustainable development and enhancing socioeconomic conditions hinge on clean energy accessibility. To effectively promote and expedite the adoption of biogas technology, providing current information on crucial elements is vital. Our study delved into biodigester adopter typologies and assessed socioeconomic influencers on small-scale biodigester uptake in homes of Mpigi in Uganda. Employing a cross-sectional research design, we integrated quantitative and qualitative methods by conducting household surveys and key informant interviews coupled with field observations. Utilizing SPSS version 23, descriptive statistics and regression analysis characterized household features and evaluated adoption factors, revealing innovators (17.8 %), early adopters (25.7 %), early majority (33.7 %), late majority (15.8 %), and laggards (6.9 %). Biogas use increased from 2009 to 2017, declining by 2020. Education, income, subsidies, and farm proximity were key adoption predictors. Expanding subsidy access is crucial to accelerating biogas technology use, considering significant socioeconomic aspects. Study results inform ongoing discussions on formulating distinct policies for biogas adoption across developing countries.

Introduction

The huge biogas potential in sub-Saharan Africa is envisaged to solve energy poverty and environmental problems under different designs and types (Lwiza et al., 2017; Moli et al., 2021; Ortiz et al., 2017). A biodigester is a system that biologically digests organic materials through anaerobic processes. Biogas is a methane-rich gas produced by the anaerobic fermentation of organic material. It is produced after feeding the biodigesters with either kitchen or animal wastes (Kelebe, Ayimut, et al., 2017). Unlike other forms of renewable energy, biogas production systems are relatively simple and can be operated at a small and larger scale in urban and rural areas. This clean gas is generated, captured, and combusted inside an enclosure to the kitchen for cooking, heating, and lighting hence reducing greenhouse gas emissions. Effective management and appropriate utilization of biogas energy fill the energy gap. Hence a basic necessity for socio-economic uplift and a key component for achieving all Sustainable Development Goals (UN, 2017).

Despite the global interest and efforts in broadening the diffusion and uptake of biogas technology under different programmes like national biogas programmes, its adoption is still low in the global south (Ortiz et al., 2017). For instance, in sub-Saharan Africa over 2.7 billion people rely on fuel wood for cooking whereas in Uganda the biogas market initiatives are failing because of several barriers hence a total forest cover loss of 967 kha from 2001 to 2021. The challenges include; lack of awareness of the benefits of biogas, high upfront costs, culture, biophysical, among others (Mukisa et al., 2022).

In Uganda there is rampant energy poverty hence a need to transition households towards energy security for sustainable development. Amidst energy inaccessibility, attempts in the country are being made such as promotion of biogas adoption and use. Biogas technology is one of the household sustainable energies with several people adopting it, especially in rural areas of Uganda in central Uganda. In order to promote and increase the use of biogas technology, there is a need for the availability of up-to-date information on the crucial factors for biogas adoption, policy formulation, implementation and managing biogas projects as urged by the Ministry of Energy and Mineral Development

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(MEMD, 2023) and Uganda National Planning Authority (UNPA, 2020). Thus, the assessment of the determinants of biogas helped to ensure the availability of the key factors before adoption. Although Lwiza et al. (2017), reported very high rates of biogas dis-adoption with underpinning factors, she did not consider the factors that propelled adoption, and yet these are key in fostering adoption of the innovation. In addition, the paper pioneers the application of Roger's Diffusion of Innovation theory in Uganda's context thus advancing a new methodological approach to biogas adoption. To this end, we observed that little has been documented to depict the temporal adoption of the biogas technology and underpinning predictors of adoption behavior. To this end, the study (i) mapped the biogas plant across Mpigi district (ii) investigated different categories of biogas adoption based on Roger's theory and (ii) assessed the predictors of home biogas adoption behavior in Mpigi district, Uganda. The following research questions (RQ) guided the study;

RQ 1: What are the different categories of biodigester adopters based on Roger's theory currently in Mpigi district?
RQ: What household dynamics influence the adoption of biodigester technology in Mpigi?

Theoretical framework

We used Rogers' (1983) Diffusion of Innovation Adoption Theory in our study. The theory asserts that the level of innovativeness within a social system, as defined by Roger, is the optimal criterion for categorizing users or adopters of new ideas. He describes innovativeness as the extent to which an individual or unit of adoption is relatively early in embracing new ideas compared to other members of the social system. In his framework, innovation encompasses ideas, practices, or objects perceived as new by individuals or units of adoption. Users of innovations, such as biogas, can be differentiated based on the time when they initially decide to adopt the innovation (Berhe et al., 2017). Furthermore, his theory outlines five stages through which any innovation must progress for acceptance: knowledge, persuasion, decision, implementation, and confirmation, aimed at alleviating uncertainties. Subsequently, the characteristics of an innovation, including relative advantage, compatibility, complexity, trialability, and observability, can be identified. According to Rogers (1983), innovations are swiftly adopted if they offer improvements over previous ideas, align with adopters' needs, and are The theory also classifies adopters using mean and standard deviation, forming a bell-shaped curve on a frequency basis over time.

While biogas technology may no longer be perceived as a novelty by many, Rogers (1983) asserts that its status as an "innovation" hinges on individual perceptions. Consequently, the adoption of biogas technology is framed as an innovation applicable to diverse individuals, including smallholder farmers in rural areas of Uganda. Rogers posits that the diffusion of innovation typically starts with a small number of innovators, constituting 2.5 % of the population. Innovators and early adopters exhibit a venturesome nature and wield significant opinion leadership. These groups, though representing a small percentage of the population, play a pivotal role in influencing the adoption of innovations like biogas technology. Early adopters, characterized by their willingness to take risks, positivity, and sociability, contribute significantly to shaping the perceptions of others in the social system.

In contrast, the early and late majority exhibit a more gradual adoption process. The early majority, characterized by deliberation and frequent interaction with peers, contrasts with the late majority, who tend to be skeptical and resistant to change. External factors, including peer pressure, significantly influence their decisions regarding innovation adoption. The final category, laggards, adopts innovations cautiously, waiting until success is evident. Laggards lack opinion leadership, tend to isolate, and approach innovations with suspicion. Consequently, a comprehensive understanding of user categories in Mpigi District was deemed essential to assess and comprehend the adoption of biogas technology.

Justification for deploying Diffusion of Innovation Theory (DoIT)

Whereas the theory has been applied elsewhere to study the dynamics of biogas adoption in the world (Ahmad et al., 2023), the application of the theory in Uganda's context especially the rural districts fills a methodological gap. And yet the theory has been extensively used to investigate the adoption of biogas digesters and technologies due to its robustness and applicability as underscored by Uhunamure et al. (2019). Amidst the need to achieve Uganda's, Vision 2040 and National Development Plan III (NDP111), we need to ensure accessibility to clean, affordable, and reliable energy sources. However, we cannot achieve access to clean energies like biogas technologies without unveiling the underlying temporal biogas adoption dynamics. Roger's theory clearly describes and quantifies the categories of these adopters thus its suitability for the study. Eliciting the needs of diverse innovation stakeholder groups such as innovators, early adopters, early majorities, late majorities, and laggards potentially enables stakeholders to develop appropriate strategies for fostering attitude change to foster adoption of the clean energy (Katutsi et al., 2023). As a result, the theory was crucial in comprehensively guiding the adoption and diffusion of innovations within a community. The theory revealed the number of adopters versus time in years. These variations of adoption provided basis to further investigate the predictor factors for the observed behavior in adoption.

Although the theory presented a relatively static model of innovation diffusion, rendering it to focus on the stages of adoption without adequately accounting for the dynamic nature of social change, rural African societies. And yet currently, the rural communities of Africa are experiencing rapid social, economic, and technological transformations. Furthermore, Rogers' theory assumes that individuals make rational decisions based on perceived attributes of innovations; however, resource constraints, cultural beliefs, and social norms make decision-making processes for adopting more complex and influenced by factors other than rational evaluation of innovation attributes. To overcome all of these restrictions, the study purposed to focus on houses that had successfully adopted and operational bio-digesters.

Household dynamics and bio-gas adoption

Household characteristics directly influence the adoption of biogas technology in rural homes. The characteristics include the level of income to enhance investment in the technology (Mengistu, Simane, Eshete & Workneh, (2016)). In any society, some groups of people may be against modern technological developments to preserve their ideologies (Sinaruguliye & Hategekimana, 2013). Economic and institutional factors were also identified to affect the success of the Kenyan biogas sector (Mbali et al., 2018).

Furthermore, in Africa, socioeconomic, technical, and cultural constraints, combined with a poor dissemination strategy and unsupportive regulatory bodies limit biogas adoption despite several programs and demonstrations of the viability and effectiveness of biogas plants. Also, Uhunamure et al. (2019); Mengistu, Simane, Eshete, & Workneh, (2016) realized that technical evaluations against other cooking devices, efficiency, environmental aspects, human drudgery, and potential to provide employment and behavioral evaluations influence the uptake and utilization of biogas technology. Therefore, household decisions to adopt a particular technology differ and vary depending on the roles that each factor plays (Musinguzi et al., 2018; Mwirigi et al., 2018; Ortiz et al., 2017; Price, 2017; Uhunamure et al., 2019; Wahyudi, 2017). Hence it is difficult to specify the factors controlling the adoption of biodigester and gas technologies.

Materials and methods

The setting

The study was conducted in Mpigi District, Uganda: lat. $0^0 14^0$N and lon. $32^0 20^0$ E (Fig. 1). Mpigi is one of the districts with high rates of deforestation hence targeted by NGOs to reduce fuel wood consumption. One of the ways of reducing wood fuel use among households was through promoting biogas technology adoption through the Uganda Domestic Biogas Program (UDBP) (Lwiza et al., 2017). The Africa Biogas Partnership Program includes UDBP, and brings together several actors including non-governmental organizations, biodigester construction companies, financial institutions, and government agencies to develop and disseminate domestic biogas plants for use in rural and urban areas. The district is located west of Kampala, Uganda's capital, and along the shores of Lake Victoria. Mpigi District is 1207.8 km^2 (UBoS, 2017). The District has seven sub-counties which include; Buwama, Kammengo, Mpigi town council, Kiringente, Kituntu, Nkozi, and Muduuma (UBoS, 2017). However, the study considered only five Sub Counties (Buwama, Kammengo, Kiringente, Mpigi town council, and Muduuma) known for households with functional biodigesters as per the list obtained from Biogas Solutions Uganda (BSU) (National Implementing Agency of Biogas).

The District was projected to have 147,700 male and 145,200 female persons totaling 292,900 by 2021 (Uganda Bureau of Statistics (UBOS), 2020). The major fuels used for cooking in the District are firewood and charcoal and few use biogas whereas kerosene, solar energy, and electricity are predominantly used for lighting (Lwiza et al., 2017).

Research approach and procedure

The study adopted a cross-sectional research design with a mixed qualitative and quantitative approach. Purposive sampling was adopted to select suitable respondents. The sample size was drawn from households with active operating biogas plants because these individuals had current experience and could provide more accurate responses on the factors that influenced the acceptance of the innovation. Non-commissioned plants (under construction and still feeding their plants) on the list were left out for sampling because they did not appear to have lived adopters' experience with the dynamics of bio-digester uptake and maintenance, and yet that was the focus of this study as seen in Table 1. At the time of the study, there were 138 adopter households on the list obtained from Biogas Solutions Uganda (BSU) (national implementing biogas agency). Out of 138 households with operational bio-digesters, the Majority of 101 (73 %) had biodigester with $6m^3$ of size, followed by 22 (16 %) with 13 m^3, and 9 (7 %) had bio-digesters with $9m^3$. Four households (3 %) had bio-digester with size of $12m^3$ and only 2 (1 %) had those of $4m^3$.

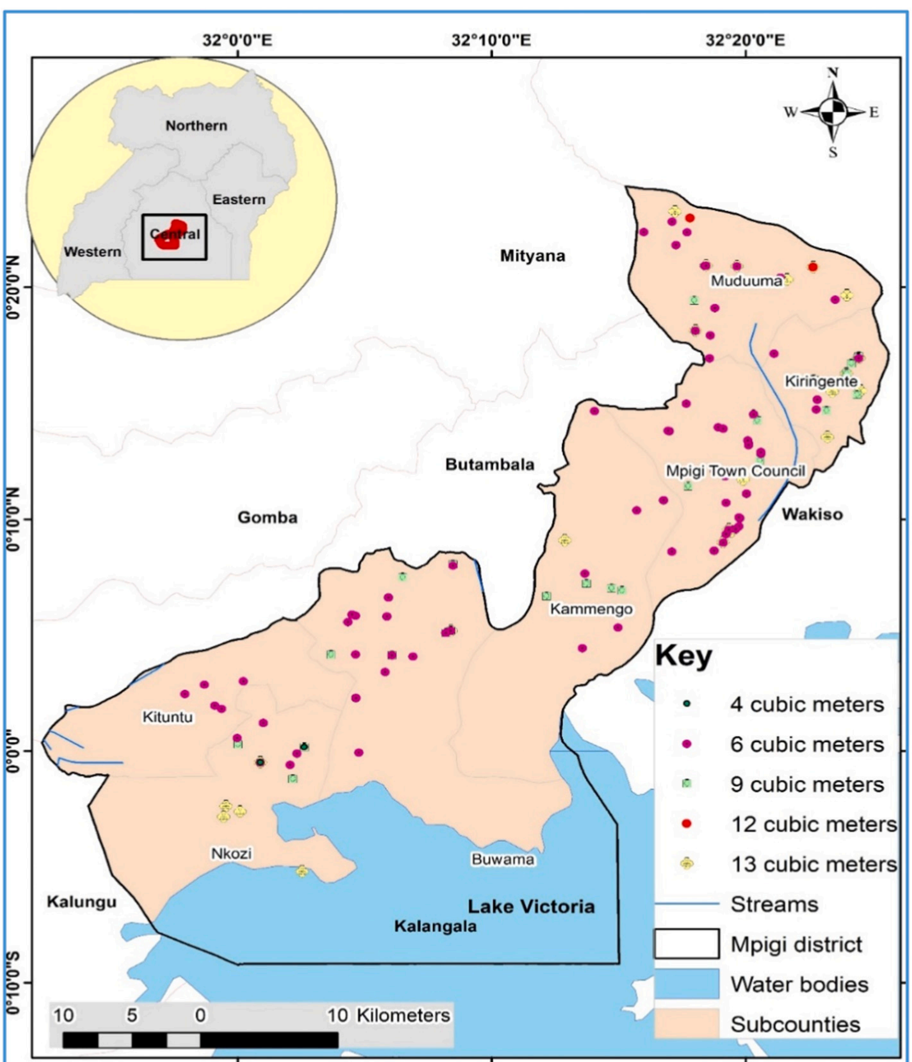

Fig. 1. Location of the study area and mapped households with bio-digesters

To arrive at the representative sample size, we adopted a scientific method of sample size calculation using Krejcie and Morgan (1970) as depicted in Eq. (1);

$$S = \frac{X^2NP(1-P)}{d^2(N-1) + X^2P(1-P)} \tag{1}$$

where; S = required sample size, ^2_X = the table value of chi-square for 1 degree of freedom at a confidence level of 95 % (3.84), N = the population size (138), P=Population proportion (0.5), d = the degree of accuracy (0.05).

Data collection

Semi-structured questionnaires were used to allow for the emergence of new and unforeseen information and justifications through open-ended questions. Besides the questionnaires, checklists and Interview guides were administered to obtain, supplement and validate the household survey data. Field observations were majorly used to validate the availability and source of the feedstock, types, and size of biodigesters installed as well as validate the operational and non-operational biodigesters in the area of study. We purposively conducted household interviews with a sample of 101 active adopters of biogas technology from 5 Sub Counties that had functioning biogas units. The Key informant interviews included one official (Biogas Marketing Hub Officer) from Biogas Solutions Uganda (BSU), five Community Development Officers (CDOs) for each selected Sub-county, and ten local leaders who had the required knowledge on the adoption of Biogas technology in the area. The key informants helped to give detailed information on the factors influencing households to adopt biogas technology in Mpigi District. The selected sample was anticipated to have gained the experience to operate the system and realize the benefits of installing biodigesters. Other adopters who were still constructing and feeding their digesters were eliminated from this study depicted in Table 3. This is because such adopters seemed not to have adequate experience in the use of the technology.

Ethical consideration

We carefully adhered to the rigorous protocols set by Makerere University's Department of Geography, Geoinformatics, and Climatic Sciences while obtaining the research approval. Our commitment extended to ensuring participants' autonomy, as only consenting individuals aged 18 and above were included. Through a well-crafted introduction letter addressed to district units, we emphasized the confidentiality of information, assuring respondents that their identities and contributed content would remain confidential. Unveiling a blend of responsibility and precaution, our team donned face masks and maintained a two-meter social distance during data collection, aligning with Ministry of Health SOPs to combat the spread of Covid-19.

Data processing and analysis

Data processing involved crosschecking and compiling both quantitative and qualitative data collected. Crosschecked data was edited to ensure accuracy. For qualitative data, themes reflecting the objectives of the study were extracted from the collected data. Later, qualitative data was summarized alongside generated categories. For quantitative data, a coding sheet was developed and pre-tested to remove overlapping codes. Numerical codes were assigned to the generated variables to allow easy entry into statistical programmes and analysis. Coded data was verified and entered into the Statistical Package for Social Scientists (SPSS) version 23 and Microsoft Excel for storage.

Categories of the adopters of biodigester technology

To analyze the categories of adopters, data was cross-examined for accuracy using descriptive statistics, generated within the statistical package for social scientist (SPSS) computer software version 23. Descriptive statistics such as mean, frequency, and percentage were used for better categorization of the adopters following the diffusion of innovation theory (Rogers, 1983). The analysis captured data from the year when household heads started adopting biodigesters in the area to the time of the field survey (2009 to 2020). The year of installation was considered as the time when adoption began and then used to categorize adopters in the area (time against frequencies and percentages of adopters).

Determinants of adoption of biodigester technology

To analyze the determinants of the adoption of biodigesters, key statistical tests were performed (test for normality and multi-collinearity of the independent variables) in SPSS version 23. We had to use an analysis method that reveals the relationship and influence of the predictor variables (socio-economics factors) and dependent variable (adoption of biodigester). The normality of distribution was based on Shapiro-Wilk and the frequency table obtained, which confirmed that the data was normally distributed and, hence, worthy of further regression analysis. The collinearity diagnostic results (testing for mul ticollinearity of independent variables) showed that variables were not linear at all. Therefore, all factors were taken up for further analysis using a multiple linear regression model. In addition, the multiple linear regression method was used because the independent variables were categorical and had a good fit. The variables considered are presented in supplementary files Table 4 after a careful literature review.

The summary of the model used is as follows;

$$Y = \beta_{0+}\ \beta_1 X_{1+}\ \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 \ldots\ldots \beta_n X_n + \mathcal{E}_i \tag{2}$$

where, Y is the dependent variable which denotes the household's decision to adopt or reject the use of biogas technology (1 = adoption, 0 = otherwise),

β_0 = constant,
X_1 = Age of the household head,
$X_{2=}$Gender,
X_3 = Marital status,
X_4 = Education level of the household head,
X_5 = Family size,
X_6 = Farm location,
X_7 = Occupation,
X_8 = Income levels,
X_9 = Number of cattle heads,
X_{10} = Land size,
X_{11} = Distance to the agricultural extension service,
X_{12} = Distance to the nearest water source,
X_{13} = Distance to the nearest market,
X_{14} = Access to subsidies and loans,
X_{15} = Distance to firewood collection source,
β_1, β_n are the coefficients from the estimation,
$\mathcal{E}_i$ is the error term.

Results

Profile of the household respondents

As shown in Table 1 (supplementary file), households were largely headed by males with an average age of 59 years old and 70 % had attained secondary and tertiary education. This implies the potential to participate in decision-making to adopt biogas technology. In addition, the average income of the adopters was 129.5 US$ per month generated from different sources. The average family size was 8, comprising of the working-age group, school-going children, and young ones hence enough Labour to operate and sustain the digesters. Nevertheless, the land was under several activities for subsistence and commercial use and

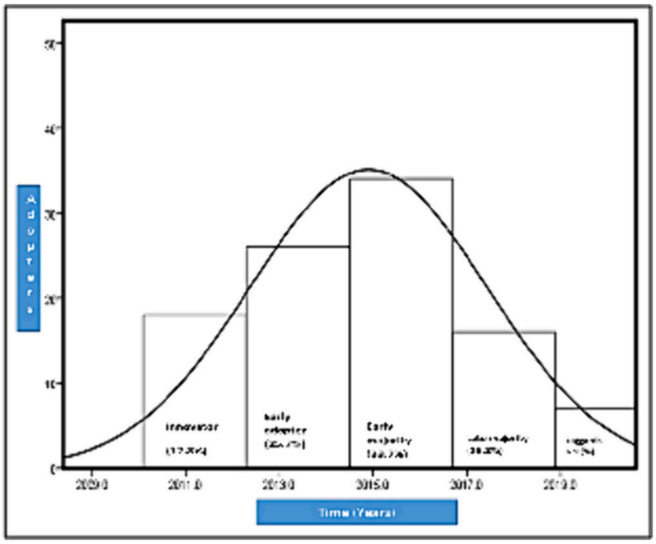

Fig. 2. Categories of adopters of biogas technology

the land size varied among households. For instance, adopters owned an average land size of 8.9 acres where farming was the main activity. On the same land, zero grazing was practiced with an average cattle size of 5. This shows that cow dung and urine are the main feedstock for biogas generation in the area.

In the same area, water sources are within a distance of 0.3 km to households as depicted in Table 1. The water sources included; water taps, boreholes, spring wells, pumped water, and harvested water tanks. In addition, extensional services and market hubs for spares are distant from adopters' households. Whereas, their distance to the nearest firewood collection source is 1.3 km and this could have influenced the adoption of biogas technology. In the study area, zero-grazed farms were around adopters' homes for easy access to dung and most of them received financial assistance in the form of subsidies, loans, and credit to reduce on upfront costs of biodigesters.

Categories of adopters of biogas technology

According to the survey, adopters differ in a variety of ways. Heifer International began by installing biodigesters in rural districts in 2009. It began with giving out one cow to those who could build a cow shelter, and then pigs to others. Local committees in each surveyed village recommended potential households. Workshops were organized in 2009 by officials from the sub-county headquarters, Mpigi Farmers Association (MPIFA) officials, and the District to disseminate the idea of biodigester technology.

The adoption of biodigesters began in 2009 with a few adopters from Tiribogo parish (17.8 %), hence the first category (innovators). This category was made up of youths. As shown in Fig. 2, the number of adopters steadily increased after the opinion leadership role by some local committee leaders, forming part of the second category of early adopters (25.7 %). With the leaders' continued dissemination of biogas potential, the number of adopters increased from 2014 to 2017 resulting in the early majority (33.7 %) and late majority (15.8 %) categories. This implies that the adoption of the technology by leaders sparked other potential farmers to take up the technology. It should be noted that members in early and late majority groups are skeptical by nature. However, members in the early majority are always the first to socialize with others, unlike the late majority. The last category is for laggards who are traditional and they take too long to adopt. In the area, the number of adopters declined by 6.9 % from 2018 to the year of the survey (2020) as seen in Fig. 2. During the survey, laggards were very few, implying that any person who now chooses to adopt biogas technology is under this category according to the assumptions of the diffusion of innovation theory.

Similarly, the results included the year of installation (time) of biodigesters (2009–2020), which was then used to categorize the adopters along the adoption curve. This is because individuals did not adopt the technology all at once, but rather gradually, and thus time is more efficient in categorizing adopters as Roger's theory (1995) stipulates. Therefore, the year of installation for all adopters was grouped into five according to (Rogers, 1983). The frequencies and percentages of adopters for each category were generated in SPSS version 23. The histogram helped to show the distribution of the adopters over the years along the adoption curve. Hence the categories of innovators, early adopters, early majority, late majority, and laggards. The innovation adoption curve maintained the direction as illustrated by the diffusion of innovation theory, (see Fig. 2). In the study area, the majority adopted biogas technology from 2013 to 2017. However, the percentages for each category differ from what the diffusion innovation theory predicts because the use and purpose of innovations vary. In a social system, people perceive new ideas differently over time. As a result, the theory assumes a normal bell-shaped curve over time (Rogers, 1983).

Determinants of adoption of biodigester technology

Multiple linear regression analysis revealed both significant and non-significant determinants of biodigester adoption in the Mpigi District (see Table 2). Table 2 shows that the R square is 0.93 and the standard error of the estimate is 0.14, indicating that the considered independent factors account for 93 % of the variance in the model while other factors excluded from the model account for 7 %.

The obtained coefficients for each independent variable from the multiple linear regression model are as follows;

$$Y = 0.231 + 0.013 \times {}_{1} - 0.031 \times {}_{2} + 0.008 \times {}_{3} + 0.071 \times {}_{4} + 0.032 \times {}_{5} + 0.452 \times {}_{6} - 0.023 \times {}_{7} + 0.057 \times {}_{8} + 0.085 \times {}_{9} + 0.002 \times {}_{10} + 0.003 \times {}_{11} + 0.000 \times {}_{12} + 0.035 \times {}_{13} - 0.277 \times {}_{14} - 0.011 \times {}_{15} \quad (3)$$

Table 2
Summary of the results obtained from the multiple regression model.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	
1	.965[a]	0.93	0.925	0.137	
Model	Unstandardized Coefficients		Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.231	0.14		1.646	0.101
4. Education background	0.071	0.024	0.069	2.934	0.004*
6. The proximity of the farm	0.452	0.041	0.45	10.976	0.000*
8. Level of income	0.057	0.014	0.131	4.105	0.000*
9. Number of cattle heads	0.085	0.015	0.186	5.823	0.000*
14. Access to subsidies and loans	−0.277	0.032	−0.272	−8.657	0.000*

* Significant test (<0.05)

Table 1
Socio-demographic characteristics of the respondents.

Socio-demographic characteristics	Statistics (Mean)
1. Age of the household head	59 yrs
2. Family size (number of persons)	8 People
3. Number of cattle heads	5 animals
4. Income level per month (US$)	129.5 USD
5. Land size (acres)	8.9 acres
6. Distance to agricultural extension services (kilometres)	2.4 Km
7. Distance to the nearest water source (kilometres)	0.3 km
8. Distance to the nearest Market Centre (kilometres)	6.6 km
9. Distance to the nearest firewood source (kilometres)	1.3 km
10. Education (levels)	**Mean (%)**
a. Primary level	30 (29.7)
b. Secondary level	36 (35.6)
c. Tertiary	35 (34.7)

Table 3
Sampling procedure for biogas users selected for the study based on sampling units and biodigester size.

Sub county	Total number of registered biogas users	Sampled biogas users based on Biodigester size (M^3)	Set of biogas users selected	
			Number of selected biogas users from each parish	Parishes from which the users were selected
Buwama	32	22 [9m^3 (4); 6m^3 (17); 13 m^3 (1)]	02 04 06 03 02 02 03	Lubugumu Jalamba Buyijja Bbongole Kawumba Mbizinnya Nabiteete
Kammengo	34	25 [6 m^3 (12); 13 m^3 (9); 9 m^3 (4);	09 10 06 07	Lwagwa-Kibanga Kammengo Kyanja Sekiwunga
Kiringente	17	13 [6 m3 (3) 9 m3 (7) 13 m3 (3)]	06	Kololo
Mpigi Town Council	34	29 [6 m^3 (23); 9 m^3 (3); 13 m^3 (3)]	02 05 04 18	Lwanga Ward A Kafumu Kyali
Muduuma	19	12 [6 m^3 (9); 12 m^3 (1); 13 m^3 (1)	12	Tiribogo
Total	N (136)	n(101)		

The results showed education as a significant factor associated with the adoption of biodigester technology at 0.004 (significance level). The result means that any additional year in school leads to an increase in the decision to adopt biogas by 0.069 units and this increase is significant. The responses confirmed that the idea to adopt the technology came from schools and workshops attended. The training helped household heads to decide on the size and type of biodigesters to adopt. Hence the adoption of rare types such as floating, balloon, and drum biodigester types.

The results revealed that an increase of one cow to a farm leads to the adoption of biogas technology by 0.186 units. Hence the number of cattle heads was found significant at 0.000 (*p*-value). This means that there is always a chance to adopt biogas technology as the number of cattle increases hence replacing firewood and charcoal. In addition, positive beta coefficients indicate the probability of biogas adopters converting dung into biogas is high. From the household survey, it was confirmed that in Mpigi, biogas is mostly from cow dung and urine. The responses from the local leaders clarified this by emphasizing that the lack of cows was the reason why most households failed to adopt the technology and the lack of awareness of biogas from other substrates like

Table 4
Measurements of the determinants considered for the study.

Measurable indicators	Definition	Effect (+ or -)	Type	Related studies
1. Family size	0 = 1–3 1 = 4–6 2 = 7–9 3 = 10 members and more	+/−	continuous	(Kelebe, 2018; Romadhoni et al., 2016; Uhunamure et al., 2019)
2. Age	1 = 0–17 2 = 18–30 3 = 31 = 59 4 = 60 years & over.	+/−	Continuos	(Kelebe, 2018; Romadhoni et al., 2016; Uhunamurea et al., 2019)
3. Gender of household head	Female = 0, Male = 1	+/−	Categorical	Berhe et al. (2017)
4. Education	0 = No education 1 = primary 2 = secondary 3 = Tertiary	+	categorical	(Kelebe, 2018; Romadhoni et al., 2016; Uhunamurea et al., 2019)
5. land size	1 = 0–3 2 = 4–7 3 = 8–11 4 = 12 acres and above	+	continuous	(Kelebe, 2018)
6. Cattle heads	0 = 1–2 1 = 3–5 2 = 6–8 3 = 9 cows and above	+	Continuous	(Kelebe, 2018; Uhunamurea et al., 2019)
7. Distance to the firewood collection source	1 = Below 1 km 2 = 1–2 km 3 = Above 2 km	+	continuous	(Kelebe, 2018)
8. Income level	1 = 0–27.3 US $ 2 = 27.4–54.7 US$ 3 = 54.8–82.1 US$ 4 = 82.2 US$ & above	+	continuous	(Qu et al., 2013; Truc et al., 2017; Uhunamurea et al., 2019; Hafeez et al., 2017; Mwirigi et al., 2018)
9. Occupation	1 = farming,2 = self-employed, 3 = employed, 4 = temporary, 5 = unemployed	+	categorical	(Das et al., 2017)
10. Marital status	1 = Single, 2 = married, 3 = widowed, 4 = separated.	+/−	categorical	(Kelebe, 2018)
11. Proximity of the farm	Is your farm near home? 1 = yes, 2 = No	+/−	binary	(Manjeshwori & Keshav, 2003)
12. Distance to the agricultural extension services	1 = Below 1 km 2 = 1–2 km 3 = 3 km & above	−/+	continuous	(Kelebe, 2018; Uhunamurea et al., 2019)
13. Distance to the nearest Water source	1 = Below 1 km 2 = 1-2 km 3 = 3 km $ above	_	continuous	(Kelebe, 2018; Shallo et al., 2020)
14. Access to subsidies and loans	0 = otherwise, 1 = Yes.	+	Categorical/ dummy	(Kelebe, 2018; Romadhoni et al., 2016; Uhunamurea et al., 2019)

(*continued on next page*)

Table 4 (*continued*)

Measurable indicators	Definition	Effect (+ or -)	Type	Related studies
15. Distance to the nearest market	1 = below 1 km 2 = 1-2 km 3 = 3 km &above	+/−	continuous	(Kelebe, 2018)

Fig. 3. Early activities for biogas production

human excreta. From the field survey, heaps of collected dung were seen in the homes of adopters as shown in Fig. 3.

The adoption of biodigester and gas technology increases by 0.450 units as the farm gets closer to the household, and this increase is significant at 0.000. (*p*-value). The zero-grazed sheltered cows were discovered near the adopters' homes. This simplified the collection of cow dung and urine from the farm to the biodigesters while also reducing the family's workload of collecting feedstock without incurring additional costs for transporting dung. Another reason was for the safety of their cattle.

Based on the results, access to subsidies and loans was a significant factor with a negative coefficient on the adoption of biogas technology. This means that lack of access to loans and subsidies causes a reduction in the adoption of biogas by 0.272 units and this reduction is significant. This is because most of the benefits are indirect and hard to know when to recover installation costs after adoption. From the local leaders, most of the users first received financial support or subsidies from NGOs like Heifer International. However, others obtained loans from their fellow friends with zero interest. The adopters also confirmed that the lack of subsidies stopped most households from taking up the technology.

The level of income was positively significant in the adoption of biogas technology in Mpigi District. This is because installing the biodigester needed some materials such as bricks, cement, and labor as seen in Fig. 4. This meant that an increase of one dollar in the household head's monthly income led to an increase in the chances of adopting biogas technology by 0.131 units. From what was observed, most adopters belonged to the working class with other income-generating income sources. Most adopters had savings in banks, others received salaries to have bigger digester equipment (Akbulut et al., 2014). Also, the interviews conducted recognized income levels as a cardinal factor when adopting biogas technology in the area. This was confirmed by one of the respondents in Nsaamu village (Mpigi Town Council) who said;

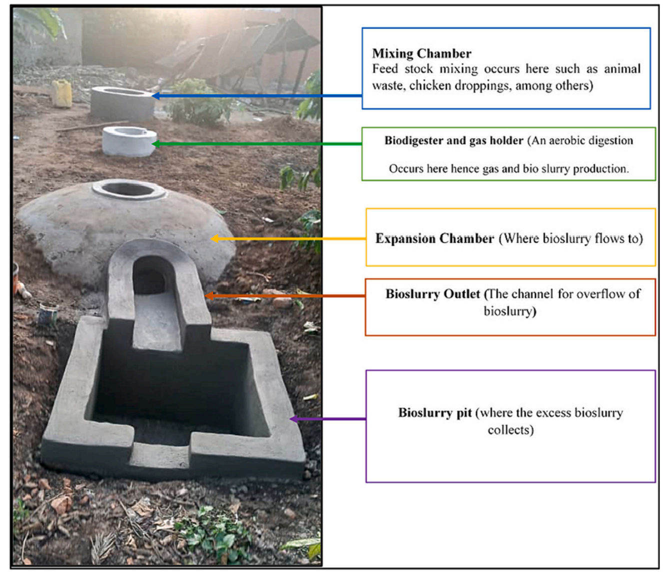

Fig. 4. Typical biodigester system installed in one for the households in the study area

> "…money is not a problem to me that is why I managed to install 3 biogas plants of 9m^3, 13m^{3,} and 15m^3 on each farm. A lot of dung used to accumulate day by day and my boys were suffering to carry it to the gardens, even preparing their tea and boiling water for milking was hard then I decided to install biodigesters on each farm…".

Discussion

Adoption began in 2009 with a very small number of adopters as also observed in other areas such as Kampala peri-urban (Tumutegyereize et al., 2017). Biodigester technology adoption fits in Diffusion Innovation theory where adoption started with smaller numbers of innovators, then increased steadily to early adopters and later reduced with the late majority, and laggards (Ahmad et al., 2023). Therefore, the adoption trend corresponds to the assumptions of the innovation diffusion theory (Rogers, 1983). The decline in adoption of the technology in this study is related to what Tumutegyereize et al. (2017) found in Kampala peri-urban areas where biodigester adoption was at 50 % in 2009, and after 3 years it dropped to 12.5 %. In addition, Smith et al. (2013) revealed slightly similar findings in Tiribogo village where a flexible balloon digester type ended up with very few innovators. The low adoption of biogas at first was due to the perceived uncertainties of the technology such as tasteless food, homes catching fire, brokage of gas pipes, among others. Likewise, the mini-grid connection (an innovation) in the same village was also first adopted by very few people, and its uptake stopped with innovators and early adopters (Price, 2017). Also Fri and Savitz (2014) found innovators typically draw on ideas from a variety of sources to make small advances that can add up to a major technological change.

As underscored by Roger's theory, after a few years of introducing the technology, adoption began to rise and then fell (2016 to 2018). This is attributed to technology's failure to meet the population's expectations such as preparing all meals on biogas, and fully do away of biomass. Furthermore, some people took time to adopt innovations due to competition from other innovations that serve a similar purpose (Rogers, 1983 & Hixon et al., 2012).

In line with the determinants, five (5) factors revealed a significant influence on biogas uptake including household income level, farm location, and distance, education background of the household head, number of cattle heads, subsidies, loans, and credit.

As revealed by Shallo et al. (2020), factors such as education serve as a conduit for individuals to encounter diverse innovations, encompassing streamlined and contemporary cooking technologies that alleviate labor burdens and diminish daily expenditures. Consequently, this facilitated the displacement of conventional fuels such as firewood and charcoal (Qing et al., 2022) among some households. Moreover, the enlightened mindset cultivated through education compelled individuals to actively experiment with newfound knowledge and ideas acquired through education through topics that foster the uptake of cleaner, energy-efficient technologies, exemplified by biogas technology (Ngcobo et al., 2022; Rahman et al., 2021). These results are slightly similar to findings reported across developing countries such as South Africa, Bangladesh, Vietnam, and Pakistan (Hafeez et al., 2017; Truc et al., 2017; Uhunamure et al., 2019).

Elsewhere, Uhunamure et al. (2019) pointed out that educated household heads were always more environmentally knowledgeable and conscious about the detrimental impact of fossil fuels on the environment in South Africa. On contrary findings by Yasmin and Grundmann (2019) found that the educational background of the household head was a non-significant factor influencing the decision to adopt biogas technology in China and Pakistan.

Also, the number of cattle heads was an important factor; the more cattle heads, the more feedstock collected, and thus the opportunity to utilize biodigester technology [Key informant]. As a result, an increase of one cow leads to a significant chance of an increase in technology adoption. The continuous feeding of dung and urine into the digesters led to proper functionality. This is because, in the study area, dung and urine were perceived as more effective and efficient substrates for biogas production as revealed by studies elsewhere in sub-Saharan countries (Berhe et al., 2017; Hafeez et al., 2017; Uhunamure et al., 2019; Yasmin & Grundmann, 2019). Ideally, the size of the digester is determined by the number of cattle heads owned. Cow dung is an important input for biogas technology because there is no mechanism in place to collect or use other wastes such as poultry litter, crop residues, industrial residues, and municipal wastes for biogas production (Berhe et al., 2017). However, as the distance to the farm location decreases by one unit, the decision to adopt biogas increases. This therefore ameliorated the role of the number of cattle heads on the farm in fostering biogas adoption.

The nearer the farm to the home, the easier the collection of dung and urine was to the biodigesters as also reported by Berhe et al. (2017) in Ethiopia.

Access to subsidies, loans, and credit was also statistically significant in promoting the adoption of biogas. The implication of the result indicated that an increase in access to credits by potential adopters corresponded with an increase in the adoption of biogas technology. When the financial constraint is solved then the initial costs (a major limitation) are lower. In the same context, Uhunamure et al. (2019) and Shallo et al. (2020) argued that loans empowered poor households to afford biodigester construction. In addition, a study by Berhe et al. (2017), underscored the role of credit services in enabling adopters to get their biodigesters repaired and maintained in Ethiopia. In Pakistan, slightly similar findings were reported such as the remoteness of financial institutions that made it hard for capable farmers to adopt biogas technology hence the continued use of biofuels (Yasmin & Grundmann, 2019). In situations where the household income level was low, chances of biogas adoption would be low. However, the chances would be further reduced by the inaccessibility of financial services. Household heads that had savings increased the possibilities of installing biodigesters in their homes since the acquisition of the materials became easier.

As revealed elsewhere across the globe, such as in China, Vietnam, Limpopo province, rural Bangladesh, and Kenya by Truc et al. (2017); Hafeez et al. (2017); Uhunamure et al. (2019), household income significantly affected biogas adoption. However, a study by Kelebe, Ayimut, et al. (2017) is contrary to this finding where income level was found non-significant in the rate of biodigester adoption in Ethiopia. This was due to the existing government subsidies for biodigester installations at the household level. In the same vein, proper biodigester and biogas adoption guidelines and policies in rural Africa need to be established to maintain steady biogas uptake. In Uganda for example, besides the ambiguous Uganda Energy Policy of 2023 (Ministry of Energy and Mineral Development (MEMD), 2023), there is hardly a policy stipulating clear plans of gridding this energy thus staggering the biogas adoption. However, the existing energy policies advocate for the adoption of biogas by highlighting the importance of demand-side issues such as subsidies to counteract high end-user power tariffs and expanding energy coverage to rural areas that heavily rely on biomass for energy needs. In addition, there are Biofuels Programme supports investments in ethanol, biodiesel, methanol, and biogas production, the policy recommends dealers in petroleum products blend fossil fuels with biofuels up to 20 % (Uganda Government, 2020). The Uganda Renewable Energy Policy 2002–2017 highly recommends the conversion of waste to energy through biogas production (Uganda Government, 2020; Ministry of Energy and Mineral Development (MEMD), 2007). We can then leverage the existing ambiguous energy policies and formulate streamlined biogas policy frameworks and guielines that maintain the steady uptake of biogas by reducing demand-side issues such as application of subsidies in Uganda as also echoed by Mukisa et al. (2022).

According to the field technical officer at BSUL, the number of animals and access to water sources are critical determinants of biogas adoption for different biodigester units to function properly. Both factors influence the biodigester's functionality, as well as the quality and quantity of biogas generated. However, Community Development Officers (CDOs) and local leaders believed that education and income levels largely determined who would adopt technology in the area. Furthermore, according to CDOs and local leaders, the majority of adopters have obtained education and have at least reached the secondary level. This contract in the perception of the local leaders/CDOs and the technical persons in biodigester uptake revealed a need to incorporate different stakeholders in the sustainable energy sector in Africa as also recommended by Mukisa et al. (2022). This will promote current biogas advancements through a collaborative network involving various stakeholders, emphasizing the critical role of effective partnership of adopters but also international endeavors within the biogas domain to facilitate knowledge exchange as emphasized in a review on barriers of biogas uptake by Nevzorova & Kutcherov, (2019).

Conclusions

Adoption of biodigesters in Mpigi District is primarily influenced by the household head's education level, number of cattle heads, level of income, farm location, and access to subsidies and loans. This implies that their absence affected the technology's adoption. Biodigester adoption in the region increased from 2009 to around 2017. To date, the number of adopters is decreasing, slowing down the uptake of the technology. And yet, the adoption of biogas technology has reduced over-dependence on traditional fuels, thereby increasing energy security among rural people. We need to utilize biodigester technology uptake and increase its potential to contribute towards the achievement of Goal 7 (Affordable, efficient, and access to clean energy for all), 13 (Urgent action to combat climate change), SDGs 1 (No Poverty), 2 (No Hunger) and 5 (Gender Equality). As Hassan, Kabir, Hoq, Johansson, & Thollander, 2022 urged, it is crucial to ensure the availability of adequate local information and skills for the successful implementation, support, and future maintenance of the innovation. It is important to emphasize the relevance of this recommendation to other countries seeking to enhance the adoption of biogas. In Uganda, ongoing discussions involving various stakeholders aim to establish a dedicated policy that accelerates the adoption of biogas. This initiative is particularly pertinent due to the growing population of animals in the country, which currently stands at >14.2 million cattle, 16 million goats, 4.5 million sheep, 47.6 million poultry, and 4.1 million pigs (Tumusiime et al., 2023).

CRediT authorship contribution statement

G. Namirembe: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration.

P.Mukwaya: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Validation.

F. Mugagga: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Validation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request from the corresponding author.

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