MAKERERE UNIVERSITY

MAKERERE UNIVERSITY BUSINESS SCHOOL

REMITTENCES, EDUCATION, ETHNICITY AND ADOPTION OF BIOGAS TECHNOLOGY AMONG HOUSEHOLDS IN UGANDA

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PLAN A

NOVEMBER, 2023

DECLARATION

I, **Nelson Kiiza** declare to the best of my knowledge that this dissertation is my original work and has never been presented to any University or institution of higher learning for any academic award.

Signed ..... Date 5/12/2023

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APPROVAL

This dissertation was prepared under the guidance of my academic supervisors and they have approved it for submission.

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DEDICATION

I dedicate this research report to my family, specifically my wife Charity Ainembabazi Kiiza, my children Nellycia Aineomugisha and Ahairewomugisha Nellywn, and my parents, Late Francis Kamishani and Mrs. Mable Kamishani, and my Big brother Mugisha Charles who have been the core pillars in my educational journey.

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LIST OF ABBREVIATIONS

CAPI	: Computer Assisted Personal Interviews
DOI	: Diffusion Innovation Theory
GDP	: Gross Domestic Product
HHI	: Herfindahl-type index
IEA	: International Energy Association
MEMD	: Ministry of Energy and Mineral Development
MW	: Mega Watt
NDP	: National Development Plan
SDG	: Sustainable Development Goals
SNV	: Netherlands Development Organization
UBOS	: Uganda Bureau of Statistics
UDBP	: Uganda Domestic Biogas Program
UNHS	: Uganda National Household Survey

ABSTRACT

The purpose of this study was to establish factors influencing biogas adoption among households in Uganda. Four specific objectives guided this study: (i) examine the relationship between financial remittances and adoption of biogas energy technology; (ii) examine the relationship between education attainment and adoption of biogas energy technology; (iii) examine the relationship between ethnicity and adoption of biogas energy technology; and (iv) examine the moderating effect of education attainment on ethnicity and adoption of biogas energy technology. To address the specific objectives, the study used the 2019–2020 Uganda National Household Survey (UNHS 2019–2020) data collected by the Uganda Bureau of Statistics (UBOS), covering a total sample of 13,732 randomly selected households. Quantitative research approaches were employed, and a binary probit regression model was used to estimate the marginal effects of financial remittances, education attainment, and ethnicity on biogas adoption among households.

The study found that financial remittance has a positive (0.050) and significant ($p < 0.01$) association with biogas adoption. Meaning that remittance inflow increases the likelihood of a household adopting biogas technology by approximately 5%. Education attainment of household heads is positive (0.050) and significantly ($p < 0.01$) correlated with biogas adoption. This means that an increase in education attainment in terms of years of schooling increases the likelihood of a household installing biogas technology by 5%. Ethnicity is positive (0.020) and significantly ($p < 0.01$) associated with biogas adoption. Implying that ethnic diversity is associated with a 2% increase in the probability of a household adopting biogas technology. The interaction effect of ethnicity and education is positive (0.044) and significant ($p < 0.01$) on biogas adoption. Implying that marginal change in ethnic diversity increases the likelihood of a household using biogas by 4.4% if the household head has attained formal education. Overall, the findings suggest that financial remittance, education, and ethnicity combined have the capacity to explain about 20.9% of biogas adoptions in households. Furthermore, results show that household size, rural residence, regional location of the household, housing condition, and access to grid electricity have a significant positive effect on biogas adoption.

The study recommends that there is a need to fast-track policies and initiatives that encourage remittance inflows, as this enhances household income and the ability to invest in biogas systems. In addition, biogas practitioners should invest in educational and awareness programs, particularly regarding the benefits that the technology can provide, as this will accelerate the uptake of the technology.

CHAPTER ONE

INTRODUCTION

1.1 Background

Energy is a vital requirement for sustainable development and human well-being (IEA, 2020). This is because energy enables households to fulfil their everyday needs, such as cooking, heating, lighting, and productive use. However, many households in developing countries lack safe and affordable energy for cooking, as evidenced by the continued demand and reliance on unprocessed traditional biomass fuels (Blimpo & Cosgrove-Davies, 2019). In Uganda, for instance, nearly 98% of households cook using unprocessed biomass fuels and inefficient stoves (Ssennono *et al*., 2021). The use of such fuels and cookstoves causes adverse effects on the environment, health, and economic development (Bamwesigye *et al.,* 2020; Churchill & Smyth, 2021).

Biogas has the potential to increase access to clean cooking solutions and reduce dependency on unprocessed biomass fuels in both rural and urban areas (Lwiza *et al*., 2017; Kabyanga *et al*., 2018; Amir *et al*., 2020). Biogas is a methane-rich gas that is produced through the anaerobic digestion of organic material, such as livestock waste, human waste, biodegradable domestic waste, municipal waste, and plant material (Amigun *et al.*, 2012; Jan and Akram, 2018; Jan 2021). With at least two cows, a household has the potential to produce a minimum of 20 kg of dung manure that can feed the biogas digester daily and produce enough biogas energy for domestic use. Research has shown that biogas has several benefits. Specifically, biogas is produced using locally available materials such as animal excreta, domestic wastes, and agricultural residues (Kelebe *et al.*, 2017). The digestion process produces bio-slurry with a high nutrient value that is used as an organic fertiliser (Abbas *et al.*, 2017; Ashraf *et al*., 2019). In

addition, biogas is a clean and suitable green-energy option capable of solving the scarcity of energy (Mengistu *et al*., 2015) and reducing the rate of deforestation by substituting the use of fuelwood or charcoal (Khan & Martin, 2016; Roopnarain & Adeleke, 2017). Moreover, a household can save money and time due to reduced purchases of cooking fuel and labour time for fuel wood collection, respectively (Sarker *et al*., 2020).

In Uganda, biogas technology was first introduced in the 1950s, and since then, there have been many initiatives by private individuals, non-governmental organisations (NGOs), the government, and different development partners to promote the technology. For instance, in 2009, Uganda launched the Uganda Domestic Biogas Program (UDBP) with technical assistance from the Netherlands Development Organization (SNV) and other international partners. UDBP is a component of the Africa Biogas Partnership Program that brings together different stakeholders to promote the domestic and institutional use of biogas (Lwiza *et al*., 2017). This was followed by numerous initiatives and incentives aimed at scaling biogas adoption. These include pilot demonstrations, awareness-raising, capacity-building, and the provision of subsidies to households. Biogas technology is of particular significance in rural households, where energy crises thrive (Uhunamure *et al.*, 2019). Available evidence shows that biogas has the potential to generate 1740 Mtoe of energy from animal waste at a recoverable rate of 30% (Walekhwa *et al*., 2009; Fashina *et al.*, 2018). If this energy is fully utilised, Kabyanga *et al*. (2018) note that many households in Uganda would mitigate health, economic, and environmental risks.

Despite the benefits and efforts, the adoption of biogas is slow, and its utilisation is limited among households in Uganda (Lwiza *et al*., 2017; Kabyanga *et al*., 2018). Available evidence indicates that the total installed capacity of biogas is estimated at about 25.8% of its potential,

and about 80% of households disadopt the biogas technology within a period of 4 years after its installation, yet its lifespan is estimated at 25 years. (Lwiza *et al*., 2017). In addition, a report by SNV indicates that the UDBP's target was to install 30,000 biogas digesters across the country; however, only 8,000 were installed (SNV, 2017). Similarly, the Uganda Bureau of Statistics (UBOS) reports that less than 1% of the total population uses biogas to meet their domestic energy needs (UBOS, 2020). Against this backdrop, it becomes inevitable to understand the factors influencing biogas adoption in households.

Existing studies have investigated the factors affecting the adoption of biogas in households. For instance, Mulinda *et al.* (2013) and Walekhwa *et al.* (2009) cite economic barriers such as income as major inhibitors to adoption in Sub-Saharan Africa. Jan and Akram (2018) and Jan (2021) found that education, total daily electric shortfall, total landholdings, female drudgery, occurrence of smoke-related diseases, and awareness of biogas' pros and cons are significantly associated with biogas adoption in Pakistan. Kabyanga *et al.* (2018) and Lwiza *et al*. (2018) note that household size, education, gender and age of the household head, livestock owned, total land area owned, and technological perception strongly influenced households' willingness to pay for biogas in Uganda. While Namugenyi *et al.* (2022) stressed the need for entrepreneurial business models as key to realising the transition to bioenergy, Shallo *et al.* (2020) found that Ethiopian households with better socio-economic status in terms of education, income, credit access, distance to firewood sources, and access to electronic media were more likely to embrace biogas technology. In Bangladesh, Sarker *et al.* (2020) found that age, livestock ownership, extension service, education, family size, income, and access to credit affected biogas adoption. Relatedly, Uhunamure *et al.* (2019) found that education, age, number of cattle, income, family size,

availability, and distance to a firewood source are positively associated with the decision to adopt biogas in South Africa.

However, prior studies have mainly analysed socio-economic factors, such as education, to explain biogas adoption. Factors such as financial remittances and ethnic diversity have received limited attention in the literature, yet these might provide a better explanation for biogas adoption in households. The diffusion innovation theory (Rogers, 2003) postulates that individual attributes and other socio-economic characteristics of the adopter influence the decision to adopt a new innovation or technology. This theory is useful in explaining technology adoption from a socio-economic perspective (Rogers, 2003) and has been used as the theoretical basis for a number of technology adoption studies. In this study, ethnicity looks at cultural differences among different ethnic groups in a given community (Greenberg, 1956; Churchill, 2017). Ethnic diversity emanates from culture and shapes people's choices and actions (Ibrahim & Galt, 2011; Wilson & Portes, 1980). On the other hand, remittance is the transfer of income earned by expatriate workers in a foreign country to their home country in the form of support for their families. Such external income inflows shape household economic decisions as they enhance their ability to invest in costly technologies. Therefore, beyond education, other factors such as remittances and ethnicity could be important in explaining biogas adoption. Therefore, this study attempts to broaden our understanding by investigating the role of education, financial remittances, and ethnicity in explaining biogas adoption in a country where the technology is still in its infancy.

1.2 Statement of the problem

Though biogas energy technology is locally available and not relatively new, its uptake in the country is at a low pace among households in Uganda. On average, the potential of biogas from animal waste and agro-residues is estimated at approximately 1740 Mtoe and 407 MWe, respectively. However, only 25.8% of its potential has been developed (Lwiza *et al*., 2017). Relatedly, about 8.000 biogas digesters were installed under the UDBP, against the target number of 30.000 installations by 2017. Implying that, less than 1% of the total households in Uganda use biogas to meet their domestic energy needs (UBOS, 2021). Continued failure to embrace biogas use in households may lead to increased health and environmental problems arising from increased reliance on unprocessed biomass. Likewise, the country may miss out on the attainment of Sustainable Development Goals 7 and 13, whose overarching aim is to ensure access to affordable, reliable, sustainable, and modern energy for all, and to mitigate climate change, respectively.

In addition, existing studies on the determinants of biogas adoption have focused mainly on socio-technical and demographic factors, which may be inadequate in explaining biogas adoption among households. Studies investigating the effect of education attainment, financial remittances, and ethnicity on biogas adoption are scant. It's possible that persistently low levels of biogas adoption among households could be attributed to low levels of education attainment, limited financial remittances, and increased ethnic diversity.

1.3 Purpose of the study

The study sought to examine the relationship between financial remittances, education attainment, ethnicity and biogas adoption among households in Uganda.

1.3 Specific objectives of the study

i. To examine the relationship between financial remittances and the adoption of biogas energy technology.
ii. To examine the relationship between education attainment and the adoption of biogas energy technology
iii. To examine the relationship between ethnicity and the adoption of biogas energy technology.
iv. To examine the moderating effect of education attainment on ethnicity and adoption of biogas energy technology.

1.5 Research Hypotheses

H_1: Financial remittance is positively associated with the adoption of biogas technology among households.

H_2: Education attainment is positively correlated with the adoption of biogas technology among households.

H_3: Ethnicity is correlated with the adoption of biogas technology among households.

H_4: Education attainment moderates the relationship between ethnicity and biogas adoption among households

1.6 Scope of the study

1.6.1 Geographical scope

The study covered all households in Uganda; this is because biogas installations are more pronounced at the household level (UBOS, 2020). In addition, many interventions aimed at promoting the adoption of biogas technology target households. Uganda has over 8 million households in total located across 15 sub-regions and 149 districts. For this study, a household was the unit of analysis.

1.6.2 Content scope

The study focused on examining the relationship between education attainment, financial remittances, ethnic diversity and biogas adoption. Education attainment, financial remittances, and ethnic diversity were the predictor or independent variables, while biogas adoption was the dependent variable. This is because there is limited empirical evidence on the effect of education attainment, financial remittances, and ethnic diversity on the adoption of biogas among households.

1.6.3 Time Scope

This study was conducted for 8 months, from February 2023 to September 2023.

1. 6.4 Theoretical Scope

This study will be guided by the diffusion of innovation theory and random utility analytical framework. The theory was selected because it clearly acknowledges various factors that influence household adoption decisions. The theory also supports retrospective studies.

1.7 Significance of the Study

i. The study adds to the growing literature on the determinants of household biogas adoption. The findings of the study provide useful insights and broaden our understanding of how education attainment, financial remittances, and ethnic diversity influence the adoption of biogas at the household level.

ii. The findings provide useful insights for effective policy formulation and design to promote biogas use as an alternative solution to the energy deficit problem, especially at this opportune time when climate change mitigation is at the helm of the political agenda.

iii. As Mills et al. (2016) point out, the findings of the study are helpful for policymakers to identify key policy aspects that can be incorporated into the Uganda Domestic Biogas Program and renewable energy planning framework.

iv. The findings of the study will help energy practitioners and biogas distributors segment the residential market and design appropriate marketing strategies to target it.

1.8 The Theoretical Model

The basic theoretical framework for this study originates from the Random Utility Model (RUM), which aims to model the choices of individual households among a discrete set of alternatives. Random Utility theory assumes that individuals are rational decision-makers who seek to maximise utility relative to their choices. A consumer, in this case, a household, assigns perceived utility to each alternative and chooses the alternative that maximises his or her utility. This utility depends on the attributes of a consumer and the alternative itself (Rogers, 2003). Thus, utility can be expressed as shown in Equation 1.

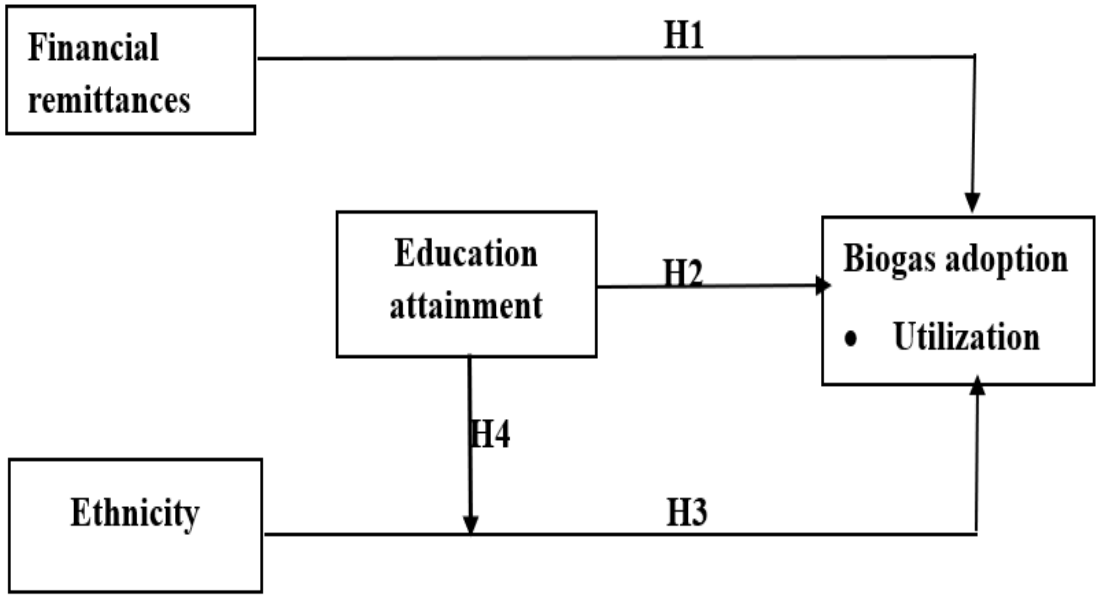
$$U = U(\mathrm{X}) \ldots\ldots\ldots\

$$Adoption\ of\ biogas\ AD = f(\text{EDU}, \text{REMIT}, \text{ETH})$$

Where adoption of biogas (AD) is the dependent variable which is influenced by Education attainment (EDU), Financial Remittances (REMIT) and ethnicity (ETH).

Conceptually, this model is illustrated in Figure 1 below

Figure 1: The conceptual framework



Source: Rogers (2003); Ahmad *et al.* (2023); Ali *et al.* (2023)

Description of the Conceptual Framework

The conceptual framework was constructed based on the past literature. The framework indicates that adoption of biogas technology is the dependent variable, whereas education attainment, limited financial remittances and increased ethnicity are the independent variables. This conceptual framework posits that financial remittances in the form of remittance inflow to a household, education attainment in the form of years of schooling of the household head, and

ethnicity in the form of differences in ethnic groups living in a given community explain biogas adoption in terms of actual use.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter provides a review of the literature in relation to the theoretical, conceptual review and relational review. Under the theoretical review, the theory adopted to inform the study is explained. The conceptual review provides an explanation of the key terms of the study, while the relational review provides literature in relation to the study objectives. It brings out an appreciation of what has been done by other scholars on the variables under study and further highlights existing knowledge gaps.

2.1 Theoretical Review

As technology evolves, several theories and models have been developed to explain the adoption, acceptance, use, and diffusion of new technologies (Alipour *et al.,* 2021; Uhunamure *et al.,* 2021). This study was anchored on the diffusion of innovation theory (Rogers, 2003) and Random Utility Theory (Walker & Ben-Akiva, 2002).

2.2.1 The Diffusion of Innovation Theory

The diffusion of innovation theory has been widely used to explain the adoption and diffusion of new energy technologies in different contexts (Alipour *et al.,* 2021). In 1995, Rogers established the Diffusion Innovation framework as the foundation for conducting research on innovation adoption in communities involving groups of people, which was later modified in 2003. The theory contends that factors that affect the innovation adoption process range from social, economic, and technological to human. More specifically, the theory assumes that potential adopters become interested in new innovation only when they become aware of it. Implying that awareness in the form of educational interventions about the new technology (in our case, biogas technology) is crucial in deciding whether to accept or reject new technology. This is because

knowledge about the pros and cons of using the new technology reduces uncertainty and enhances the ability of consumers to make decisions (Jan & Akram, 2018).

According to Rogers (2003), some inherent characteristics, such as personality behaviours, socio-economic characteristics and communication manners, also affect this decision-making process. Given this framework, the adoption of biogas technology is predominantly channelised through knowledge, persuasion, decision, implementation, and confirmation. This study is interested in the persuasion channel, referring to the phase in which potential adopters (biogas adopters in our case) are exposed to the adoption notion of the innovative product. During this phase, potential adopters are looking for information leading to their adoption decision. Persuasion comes from five characteristics, including relative advantage, compatibility, complexity, trialability, and observability, that help determine the final decision of adopting or rejecting BPT.

Furthermore, the theory emphasises the socio-economic status of the adopter, such as having access to financial support, which enhances the household's decision to adopt new technology. This is because accessibility to financial support in the form of remittances enables households to afford to construct and maintain the biogas technology. Financial remittance helps a household overcome the cost barrier to biogas adoption. Thus, this study examines the effect of financial remittance on the adoption of biogas. The theory also identifies user characteristics, such as social or cultural values, as an important antecedent that influences the adoption process (Rogers, 2005). Therefore, this framework is useful in explaining biogas adoption among households.

2.2.2 Random Utility Theory

The basic theoretical framework for this study originates from the Random Utility Model (RUM), which aims to model the choices of individuals among a discrete set of alternatives (Das

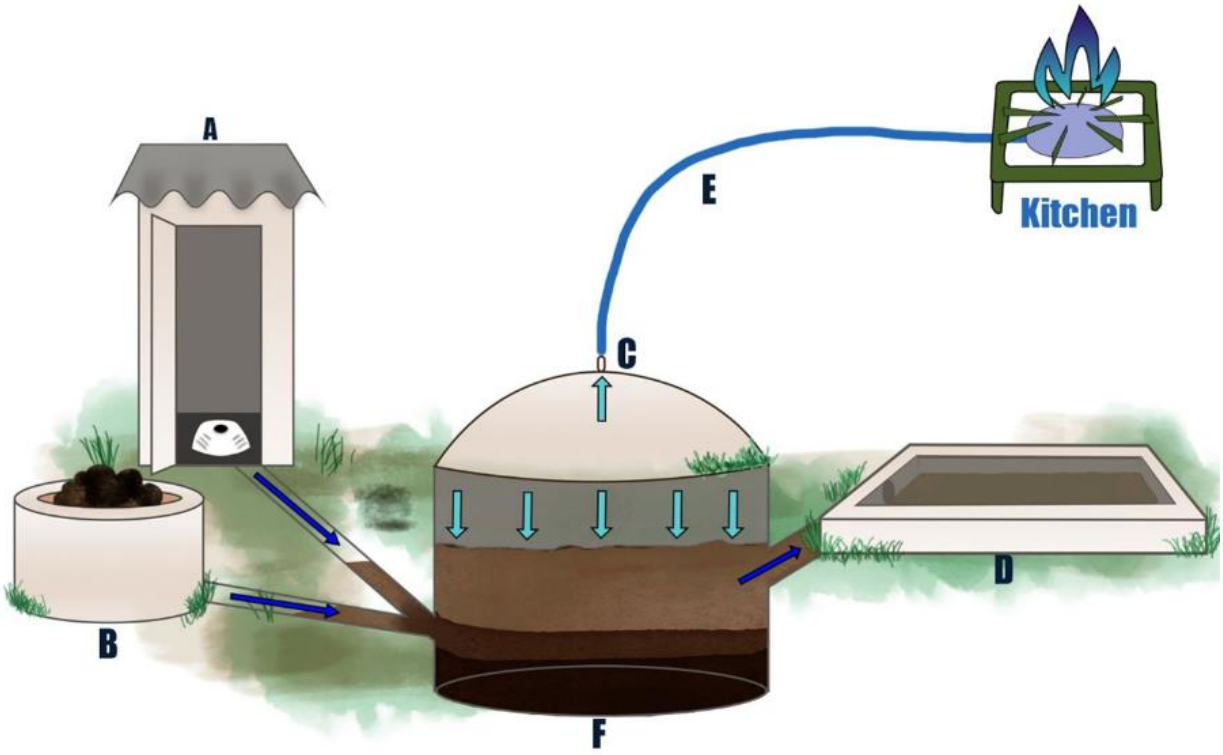
et al., 2017; Kelebe *et al*., 2017). According to the random utility theory, a consumer makes a choice that maximises his or her utility (Walker & Ben-Akiva, 2002). A household adopts biogas technology if the expected utility from using it is greater than the utility of not using it. Similarly, a household decides to reject the technology when the expected utility from using a technology is lower than the expected utility from not using it at all.

2.2 Biogas Adoption

The use of biogas as potential renewable energy is becoming more appealing as governments endeavour to boost renewable energy production, ease carbon emissions (especially from fossil fuels), and increase the use of domestic fuel sources. Home biogas systems use anaerobic digestion to convert human and animal waste into a clean, odourless gas that can be used for cooking, heating, and lighting, although it is mainly used for cooking in Uganda. Primarily biogas contains methane (50–75%), carbon dioxide (25–50%), nitrogen (<1–2%), hydrogen (0–1%), hydrogen sulfide (0–2%) and oxygen content (<1%) produced through the anaerobic bacterial decomposition of organic compounds without the presence of oxygen. These gases originate from various waste materials of the respiration of decomposer microorganisms in temperatures lying between 30 and 40 or 50–60 (Islam, Islam, Das & Hoque, 2017). In addition to the production of the gas itself,

biogas systems produce fertiliser (bio-slurry) as a by-product, which lab studies have shown to be more effective than traditional dung fertiliser (Meeks et al., 2019). Finally, although large livestock (cows, buffalo, oxen) are required to adequately fuel the digester, biogas systems can also be connected to a latrine and used as a septic tank. Figure 1 illustrates a stylised diagram and a typical set-up of a fixed-dome anaerobic digester, common across Asian and Sub-Saharan African countries (Raha *et al*., 2014; Bharathiraja *et al*., 2018; Williams *et al.*, 2022).

Figure 2: Schematic illustration of biogas production using a fixed-dome toilet-linked anaerobic biogas digester.



Source: Williams, Quilliam, Campbell, Ghatani and Dickie (2022)

From Fig. 1, the dark blue arrows depict the flow of feedstock, and the light blue arrows show the flow of biogas. The feedstocks from A) the toilet and B) the cow/animal dung and other organic waste inlet flow into the digester (F) after mixing with water. As the organic waste decomposes, biogas builds up inside the digester and flows through a pipe (E) directly to the kitchen stove via a pressure gradient. The production of biogas increases the pressure inside the fixed dome structure (C) and forces the by-product of the process (a nutrient-rich and predominantly liquid product called slurry that can be used as a plant fertiliser) out and into the slurry storage area (D). Typically, the biogas dome (C) is all that can be seen above the ground of the main digester, though in some cases, both (F) and (C) are buried underground.

With these expected dual benefits for economic development and environmental quality, biogas is a technology with the potential to contribute to sustainable development. Biogas promises to reduce pressure on forest stocks, reduce greenhouse gas emissions, and free up additional time for households to use productively. Biogas is a clean, effective, and renewable energy source that offers a versatile carrier of energy and is also considered a substitution for other fuels (including firewood, cow dung, kerosene oil, and agricultural residues) often used in rural areas (Khan & Martin, 2016; Sarker et al., 2020). Biogas production plays a significant role in controlling and collecting organic waste materials that, if untreated, could cause severe public health and environmental pollution problems. The anaerobic digestion process converts this waste into an organic fertiliser and clean water for use in agricultural irrigation (Amigun et al., 2012). Biogas technology can operate at small or large scales in urban or very remote rural locations.

In Uganda, Biogas was introduced in the 1950s and in 2009, the government launched the Uganda Domestic Biogas Program (UDBP) with technical assistance from the Netherlands Development Organization (SNV) and other international partners. UDBP is a component of the Africa Biogas Partnership Program that brings together different stakeholders: Non-Governmental Organisations, biogas construction companies, financial institutions, and government agencies (Ministry of Energy & Mineral Development, Ministry of Agriculture, Animal Industry and Fisheries, and Ministry of Water and Environment) to promote the domestic and institutional use of biogas (MEMD, 2014). Biogas is considered a more appropriate solution to Uganda's domestic energy needs due to the decentralised nature of human settlements in most regions (Kabyanga *et al.*, 2018). Moreover, biogas use can save time and energy at the household level while providing a bio-slurry that can be used to improve agricultural production (Smith *et*

al., 2014). Although the first biogas plant was built over 50 years ago, the technology has not been significantly adopted by households in Uganda (Lwiza *et al.*, 2017).

Technology adoption, according to (Rogers, 2003), is a sequence of steps that range from knowing about the proposed technology, gathering information, interest development, evaluating the technology characteristics and subsequently making a verdict to either acquire or outrightly reject the technology. In case studies like the present study, however, the aim was not only to adopt the technology but also to unravel the fundamental influencing factors that lead households to either use or not use the technology. In the present study, adoption is conceptualised as the utilisation or actual usage of biogas technology (Uhunamure *et al.*, 2019). Therefore, it is important to understand the factors that explain the adoption (acceptance and utilisation) of biogas among households.

2.3 Financial remittance and biogas adoption

Economic liberalisation and globalisation began sweeping the world in the 1980s and 1990s, expanding economic activities and leading to substantial growth in workforce demand. As a result, there was an increase in cross-border workforce movements from both developed and developing countries to various destinations to engage in that economic expansion process. Consequently, the transnational flow of remittances began and soon became a regular and significant source of net wealth transfer to the home countries of the workforce (Barai, 2020). Remittance-embedded transfers have helped beneficiary families increase their financial liquidity, impacting their consumption and savings behaviour (Javaid, 2017; Wadood & Hossain, 2017).

Indeed, remittances have become one of the most significant sources of household income for many remittance-recipient countries. Moreover, this source is aiding developing countries in

improving their balance of payments and accelerating economic growth (Rahman *et al.*, 2021). It can also improve the recipient households' quality of life by modestly boosting their living levels (Song *et al.,* 2021). For instance, remittance income in Bangladesh has highly influenced rural households' adoption of solar home systems as a source of energy (Murphy & Sharma, 2014; Sadeque *et al.,* 2014). To be precise, remittances benefit recipient households by improving their socio-economic condition and way of life.

A remittance refers to a transfer of income earned by expatriate workers in a foreign country to their home country, usually to support their families (Piteli et al., 2019). Similarly, Bhattarai *et al.* (2018) defined remittance as the money received by a household when a member works abroad who may send back money for particular expenses such as the construction of biogas or the purchase of SHS. Remittances are especially essential to developing nations because they are one of their key sources of external financing (Fromentin & Leon, 2019; Hosan *et al.,* 2023). Remittances to middle and lower-income nations have increased considerably in recent decades, with the annual remittance flow to these countries approaching 589 billion US dollars in 2021, rising 7.3% from the previous high of 549 billion US dollars in 2020 (World Bank, 2021). Remittance inflows have been a major source of foreign currency in Uganda since the 1980s. Over the past 20 years, remittance inflows in Uganda have been increasing steadily while outflows have remained relatively stable. This shows that Uganda is a net recipient of remittances. Uganda earned over 1.7 billion US dollars via remittance inflows in 2021, an increase of 2.20% from 2020, accounting for 6.2% of its GDP, making it the sixth-largest remittance recipient country in Africa after Nigeria, Morocco, Ghana, Senegal, Tunisia and Kenya (World Bank, 2022). Overall, Uganda receives 49% of the value of remittances from developed countries and 51% from developing countries, especially neighbours.

Remittances have been shown by many researchers (De & Ratha, 2012; Imai *et al.*, 2014; Hosan et al., 2023) to have a favourable effect on the economic upswing and social development. It is evident that the financial progress of a nation might be connected to foreign remittances (Akçay & Demirtas, 2015). According to De Hass *et al.* (2007), remittances have both beneficial and bad effects on the growth of a country. Remittances at the micro-level potentially play a significant role in household self-insurance and income assistance in recipient countries. Furthermore, Sharma (2018) indicates that remittance has a psychological effect of inducing households to assume that they are better off and motivate them to shift to cleaner fuel.

In Sri Lanka, De & Ratha (2012) examined the association between remittances and household income and discovered that remittance inflows boost both income and consumption. Remittances also influence income inequality among households (Song et al., 2021; Wouterse, 2010; Portes. 2009). Remittances also help to reduce poverty in developing nations and improve the distribution of income (Bang *et al.*, 2016; Zahir & Hayat, 2020).

While a body of research has extensively studied the socio-economic and environmental impacts of remittance inflows, few have analysed the linkage of remittances and energy use at the micro-level. Using nationally representative survey data and a regression model, Bhattarai *et al.* (2018) find that the coefficient of remittances is positive and statistically significant for biogas adoption in Nepal. Implying that the probability of a household adopting biogas increases by around 12 percentage points if the household receives remittance.

Yadou *et al*. (2023) utilised several estimation techniques ranging from fixed and random effects to two-stage least squares and found that migrant remittances contribute to improving access to modern, reliable, and affordable energy services through income growth of remittance-receiving households. However, analysis was done at a macro level, covering a panel of 45 African

countries from 2000 to 2020. This study focused on access to modern, reliable, and affordable energy services generally and not biogas adoption. Similarly, Zhao and Qamruzzaman (2022) explored the role of urbanisation, remittances, and globalisation in energy consumption in 59 BRI nations for the 2004–2020 period. Findings indicate that remittances and urbanisation revealed positive and significant associations with both renewable and non-renewable energy consumption.

Subramaniam, Masron and Loganathan (2022) examined the potential role of remittances on renewable energy consumption in the top recipient developing countries from 1990 to 2016 and found that remittances positively affect renewable energy consumption. This finding implies that remittances can potentially increase the level of renewable energy consumption by increasing affordability. Karmaker et al. (2023) investigated the impact of remittances on renewable energy consumption using a panel of 25 top remittance-receiving countries for 1990–2018. We use a generalised two-stage least squares random effect model to estimate the impact of remittance on renewable energy use. Results showed that remittances and REC have a generally positive relationship among the studied nations. Governments may create a system to incentivise remittance-receiving households to adopt and utilise more carbon-neutral energy devices at a lower cost if they pay with remittances. This approach could lead to higher societal adoption and consumption of green energy. Das, McFarlane, and Carels (2021) examined the causal relationships between per capita remittance inflows and renewable energy consumption in Bangladesh using annual data for the 1980–2017 period. Findings suggest that remittances per capita are associated with a level of renewable energy consumption. The study urges governments to create incentives for remittance-recipient households to invest remittance funds in modern renewable technologies such as solar home energy systems. Hosan *et al.* (2023)

explored the impact of remittances on multidimensional energy poverty in Bangladesh by employing a nationally representative Household Income and Expenditure Survey (HIES)-2016 with a sample size of 46,080 households. Controlling for the relevant characteristics of investigated households, mixed-effect linear regression, two-stage least square, and generalised ordered logistic regression reveal that households with remittance income have a significantly lower level of multidimensional energy poverty in Bangladesh. Hence, an increase in remittance inflow engenders a strong contribution toward alleviating energy poverty in Bangladesh and likely in other developing nations.

The value of remittances as financial aid is a fundamental part of the global financial system; they aid in reducing environmental damage through increasing demand for clean energy (Wang et al., 2021). As such, financial remittance represents a potential stimulus in providing support to households in meeting the increased need for clean energy services. Therefore, we may hypothesise that remittances may have a positive influence on biogas adoption among households in Uganda.

2.4 Education attainment and biogas adoption

Becker (1964) distinguishes between general and specific human capital and argues that general human capital refers to knowledge and skills that are easily transferable across a variety of economic settings, whereas specific human capital relates to knowledge and skills specific to a particular context and are less transferable. Accordingly, human capital can be developed through education, training, and experience (Estrin *et al.*, 2016). Globally, household educational status is considered a key driver of the adoption of renewable energy technology (Ang et al., 2020). This is because couples who are more educated tend to acquire a greater awareness regarding the benefits of biogas energy technology; these benefits include health, environmental,

economic, and social welfare. However, regarding the effect of education, there is mixed evidence in the literature (Gupta, 2018).

Extant literature is replete with studies that have examined the association between education attainment or level and adoption of biogas energy technologies in various contexts. Indeed, the educational level of the household head is considered one of the key factors influencing the adoption of biogas technology. For instance, an earlier study by Mwirigi *et al.* (2009) investigated the socio-economic factors that influence the sustainable adoption of biogas technology in the Nakuru district in Kenya and found that socio-economic factors such as the education level of the household head, family income, farm size, and cost of the dairy cattle significantly influenced the decision to adopt biogas technology. However, the educational status of a household head was found to be insignificant in influencing biogas technology adoption in Uganda (Walekhwa *et al.,* 2009).

Kabir *et al.* (2013) suggested that increasing the level of education and raising awareness on the benefits of biogas plant installation through the existing channels of communication campaigns, participation of print media and active attendance of Government institutions increased the uptake of biogas technology in Bangladesh. Similarly, Mottaleb and Rahut (2019) Used National Sample Survey Organization data and an econometric estimation procedure to demonstrate that human capital, in terms of general education of the household head and spouse, significantly enhanced the decision to use biogas in India.

Mengistu *et al.* (2016) examined the factors that influence households' decisions on the adoption of biogas technology among households in northern Ethiopia, covering a total sample of 179 biogas users and 179 non-users. The results of the logistic regression model showed that the educational level of a household head has a significant positive influence on the adoption of

biogas technology. Likewise, Shallo *et al.* (2020) analysed factors influencing households' decisions to adopt biogas technology among 268 households in rural Ethiopia. The study used a binary logistic regression model for estimation, and the findings reveal significant mean differences in education level between biogas adopter and non-adopter households. Implying that the level of education had a significantly positive influence on the adoption of biogas technology in Ethiopia. The findings of these studies resonate well with a study by Gupta (2018), who established that wealthy and more educated households are more likely to adopt solar energy technology in central Ethiopia.

The findings in Pakistan by Inayatullah & Waqar (2016) unravel the factors influencing biogas technology, including the level of education, daily electricity shortfall and its effect on children's education, female drudgery and awareness of the technology. Jan & Akram (2018)_based on primary data from 200 livestock farming households from four districts to examine determinants of household's predicted willingness to adopt a biogas system in Khyber Pakhtunkhwa (KP) province. Using probit analysis, they found that the education level and awareness of the respondents, among other factors, have a significant effect on biogas adoption. Likewise, Amir, Liu, Shah, Khayyam, and Mahmood (2020) investigated the factors affecting rural households' decision to adopt the technology in three selected districts of Khyber Pakhtunkhwa Province-Pakistan, using data collected from 480 respondents. The results revealed that the household adoption rate of biogas technologies is low. Factors such as education, household income, access to credit, cultivated land area, the number of cattle in the household, and family size affected the adoption of biogas technology.

Uhunamure *et al.* (2019) examined the correlating factors influencing decisions in the sustainable adoption and utilisation of biogas technology in South Africa. The study employed

the logistic regression Model to analyse 72 biogas users and 128 non-users. The result indicated that the education level and awareness of biogas technology of the household head were statistically significant for the adoption of the technology.

In a nutshell, previous studies suggest that education is important for the adoption of biogas in households. This is because a higher education level is associated with more information and more knowledge, which enables individuals to appreciate the benefits of using biogas technology and further enhances their ability to choose biogas over other energy sources. However, empirical evidence on the role of education in biogas adoption is still inconsistent. To address this gap, we use the years of schooling of the household head to measure education attainment and hypothesise that education attainment of the household head is associated with biogas adoption among households.

2.5 Ethnicity and Biogas Adoption

Conceptually, ethnicity could be negatively or positively associated with the adoption and or use of modern energy technologies, depending on the type of technology. Drawing on Hofstede's (2003) cultural dimensions, a growing body of literature has examined how a community's ethnic norms and cultural features influence energy choices among households (see Das *et al*., 2017; Katuwal *et al.,* 2023). This literature has shown that ethnic values, which vary across different ethnic groups, are important to environmental outcomes, given that such values determine the attitudes of groups and individuals towards adopting and using pro-environmental energy technology such as biogas.

Ethnic groups exhibit different attitudes toward modern energy technologies. Some ethnic groups are more inclined to install and use biogas or more energy-efficient technologies in their homes than others (Das *et al.,* 2017). In some societies, ethnic diversity is characterised by an inherent

hierarchical structure, which induces a categorisation of ethnic groups, which leads to discrimination as either ethnic minorities or ethnic majorities. The categorisation of ethnic groups as either ethnic majorities or ethnic minorities is a typical phenomenon in ethnically diverse communities, which has left ethnic minorities relatively disadvantaged, discriminated against and lacking opportunities (Churchill & Smyth, 2017; Churchill & Smyth, 2020). Such ethnic categorisations exist in both developed (e.g., U.S.A) and developing countries (e.g., India, China, Nepal etc). The frequently localised nature of domestic energy use means that it is often linked to ethnically and culturally specific norms and taboos associated with the use of biogas technology, such as the "Not in My Back Yard" (NIMBY) attitude defined as "An attitude ascribed to persons who object to the siting of something they regard contrary to expected behaviour (Williams *et al.*, 2022).

In many African countries, there are deep socio-cultural phenomena, even at the household level. Accordingly, the tendency of households to adopt the technology is based on ethnic or cultural sentiments. Such sentiments, within some cultures, forbid women from accessing kraals to gather dung and also forbid them from cooking with it. Some traditions and religions have strict rules regarding cleanliness, which, to a larger extent, are connected not only to animal excrement alone but also to human excrement (Akintan *et al*., 2018). Potentially, such positions can hinder the dissemination and adoption of biogas technology in the communities, as animal dung and human excreta sometimes serve as materials. As noted by Akintan *et al.* (2018), ethnic influences, together with economic imperatives and the utilitarian value attached to wood fuel smoke, have tended to limit demand for 'clean' cooking solutions such as biogas. This is especially true in cultures where the value of cooking smoke for food and building preservation is seen to outweigh what is viewed as minor irritations such as stinging eyes, headaches, and

poor reasoning. So, while households might possibly be tempted by the idea of the efficiency of the biogas, it has to offer comparable taste, convenience and cooking time benefits, as well as the ability to cook sufficient quantities of food.

A number of studies have investigated the role of ethnicity or ethnic diversity in relation to the adoption of various renewable energy technologies, including biogas and solar. For example;

Bhattarai *et al*. (2018) examined the extent to which ethnic diversity (caste) affects the adoption of biogas and solar energy technologies in Nepal. The study looked at ethnicity in five major categories: Brahmin and Chhetri (1 for yes and 0 otherwise) as higher castes and Dalit, Janajati, Madhesi and other ethnicities as lower castes. Findings showed that Dalit, Janajati and Madhesi ethnic groups are less likely to adopt biogas than the upper-caste Brahmin and Chhetri groups. The findings suggest that ethnic diversity plays a significant role in the adoption of renewable energy technologies. In an exploratory study covering 394 households in Ghana, Osei-Marfo *et al*. (2020) investigate the dynamics of household heads' intentions to adopt biogas technology. It was discovered that ethnicity, in terms of tribal differences, had a significant negative influence on intentions to adopt biogas technology.

Katuwal *et al*. (2023) used nationally representative survey data and probit models to analyse factors affecting the adoption of biogas technology in developing countries. Findings revealed that gender and caste are some of the key demographic characteristics that affected biogas adoption in Nepal. Specifically, the results indicated that Brahmins are about 1.8 percentage points more likely to adopt biogas. Brahmins and Kshetris are traditionally privileged caste groups among more than a hundred caste groups in Nepal. This finding suggests that marginalised groups are still lagging behind the privileged group in the adoption of cleaner cooking technologies, such as biogas, in Nepal (Katuwal *et al.,* 2023). Their findings confirm the

conclusion reached by Das *et al.* (2017), who examined the impact of caste and ethnicity on biogas adoption in India. In that study, the authors conclude that households belonging to disadvantaged socio-economic groups are less likely to adopt biogas technology.

However, contrary findings were reported in another study in Nepal. Williams *et al*. (2022) used qualitative inquiry to explore how sociocultural resistance impacts the adoption of Toilet-linked anaerobic biogas digesters and the subsequent use of the biogas. They found that Caste and gender had no significant influence on the adoption of biogas. Similar arguments were advanced by Wang & Bailis (2015) when they noted that some higher caste households, for example, have chosen to maintain high smoke-producing cooking practices due to associations with ritual purity, whereas some lower caste households were motivated by the increased cleanliness of their homes offered by improved cookstoves. Alternatively, lower caste households may implement more stringent traditional cooking practices to show commitment to purification and ritual practices as a way of improving social status.

Extant literature demonstrates that ethnicity is important in explaining the adoption of biogas technology in households. However, the available evidence on the direction and magnitude of the effect ethnicity has on biogas adoption is inconclusive. In addition, most of the prior studies examining the association between ethnicity and the adoption of biogas technologies have been undertaken in either developed or developing countries, particularly in Asia. Very scanty literature exists on the effect of ethnicity on biogas adoption in Uganda. Along those lines, this study addresses this gap by hypothesising that; Ethnicity is correlated with biogas adoption among households in Uganda.

2.6 Moderating effect of education attainment on ethnicity and biogas adoption

Prior studies have shown that the education level of household heads is important for the adoption of biogas technology. More specifically, the literature suggests that education enhances one's knowledge about the benefits and costs associated with using biogas technology (Uhunamure *et al.*, 2019; Jan & Akram, 2018). Thus, findings indicate that educated household heads tend to adopt biogas technology compared to household heads without any formal education. On the other hand, ethnicity in terms of tribal and religious differences is reported to negatively influence the adoption of biogas technology (Osei-Marfo *et al.*, 2020; Katuwal *et al.*, 2023). Studies that have attempted to examine the interaction effect of education on ethnicity and biogas adoption are very scant. For instance, Shallo *et al*. (2020) find that effective incentives in the form of taxes, financial subsidies, and education are key factors in weakening the socioeconomic and cultural barriers to markedly increasing the adoption of biogas technology in Africa. In another study, Osei-Marfo *et al.* (2020) found that introducing education to household heads had a positive significant effect on ethnic norms and household heads' intentions to adopt biogas technology biogas technology in Ghana.

Muvhiiwa *et al*. (2017) conducted a study on the role of awareness and norms on biogas adoption in South Africa using experimental design. Results derived from a comparison of the 'before-and-after-installation' responses of the persons interviewed revealed that the members of the Muldersdrift community who had been involved in both phases of the case study (explanation followed by experience of a hands-on educational example) had become more willing to adopt the technology. The interaction results further showed that access to educational programmes and exposure to pilot plants dampened the negative effect of ethnic and cultural beliefs on willingness to adopt biogas technology.

Considering limited evidence on the interaction effect education has on ethnicity and biogas adoption, this study contributes to this body of knowledge by examining the moderating effect of education on the relationship between ethnicity and the adoption of biogas technology among households in Uganda.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methods and analytical approaches that were followed in carrying out this study. It gives details of the research approach, the data and data sources, model specification, data analysis procedures, and estimation techniques used.

3.2 Research Approach

This study used cross-sectional data collected by UBOS and quantitative analytical approaches. The cross-sectional approach was used because it allows wide coverage and collects detailed information about the phenomena under investigation at one point in a given time. In addition, cross-sectional survey data allows for the collection of data and investigations on a range of variables. The quantitative research approach was used because it's the most suitable for hypothesis testing, and it appropriately addresses the research objectives and questions under investigation. The study also adopted a descriptive approach mainly to describe the sample characteristics of households.

3.3 Data and Data Source

The study used survey data - the Uganda National Household Survey data (UNHS) collected by the Uganda Bureau of Statistics (UBOS) for the period 2019-2020. The 2019/2020 Uganda National Household Survey (2019/20 UNHS) is the latest and seventh in the series of household surveys conducted by UBOS since 1999/2000. The Uganda Bureau of Statistics (UBOS) conducts this integrated household survey every three years, and the 2019/2020 UNHS is a follow-up of the 2016/2017 UNHS. The survey collects data required for measuring the trends in key social and economic indicators for monitoring progress towards achievement of socio-economic goals and for evaluation of different policy frameworks and development programs

such as the Sustainable Development Goals (SDGs), National Vision 2040 and the National Development Plan III (NDP III).

The 2019-2020 UNHS survey data was based on the household population and excluded the population in institutions, refugee camps, forest reserves, police and army barracks, and other special areas. The survey used a two-stage stratified sampling design to randomly select a total sample of 15,786 households for the 2019/20 UNHS, and 13,732 households were successfully interviewed across all the 129 districts in Uganda at that time.The sample was designed to allow the generation of separate estimates at the national level for urban and rural areas and for the 15 sub-regions of Uganda.

Therefore, the 2019-2020 UNHS was chosen because it's the most recent, rich and nationally representative dataset covering a total sample of 13,732 households, **as shown in Table 1**. The data provides information at the household and community level, especially regarding the household's main source of energy for lighting and cooking, household and demographic characteristics, location, and socio-economic factors. The data also allows disaggregation and detailed subgroup analysis. In addition, each household in the UNHS data has a sampling weight designed to be representative of the whole population. Therefore, in this study, we used these household weights in all calculations to obtain unbiased estimates and ensure the generalizability of study findings. Most importantly, this dataset provides relevant information on the main study variables, including the source of energy for domestic use, remittance inflow to households, access to financial services and financial inclusion, and key barriers to biogas use, such as socio-cultural norms. The data provides information on household background characteristics, including gender, age and education, household size, income, household assets, ethnicity,

religious affiliation and employment status, among others. Implying that, the existing survey data allows us to construct relevant variables for empirical analysis.

Table 1:Break down of the sample by region and residence

Region	Rural	Urban	Total
Central	1,502	1,419	2,921
Eastern	3,445	828	4,273
Northern	2,694	657	3,351
Western	2,485	702	3,187
Total	10,126	3,606	13,732

Source: Own calculation based on 2019/2020 UNHS data

3.4 Data quality

The UNHS data was collected using international standard data collection tools for undertaking large-scale surveys. In addition, the instruments were pilot-tested to ensure coherence and consistency with the local context. As a way of ensuring data quality, the 2019-2020 UNHS was collected using CAPI (Computer Assisted Personal Interviews), whereby field staff captured information using tablets during data collection. The tablets are loaded with a data entry application with an in-built range and consistency checks to ensure good quality data. Field team leaders run checks on the data while still in the field and thereafter electronically transmit it to the headquarters for verification. The data is then subjected to all relevant quality checks and editing.

3.5 Measurement of key variables

Biogas adoption: In this case, biogas adoption is the dependent variable, and it's defined as the utilisation or actual usage of biogas technology by a household (Uhunamure *et al.*, 2019). In the present study, Biogas adoption was measured as a dummy variable with two outcomes: whether

a household uses biogas technology as the main source of cooking energy or not. Specifically, the survey asked a question on the household's main source of energy for cooking. Using the answers to this question, we generated the total number of households that use biogas as the main source of energy for cooking and lighting by creating a dummy variable whereby it is equal to 1 if the answer is biogas and is equal to zero if the answer is other sources. Thus, biogas adoption is coded as "1" if the household biogas and "0" otherwise if a household does not use biogas. This measurement approach has been used in literature (see, e.g., Jan & Akram, 2017; Uhunamure *et al.*, 2019; Ahmad *et al.*, 2023).

Education*:* In this study, education is an independent variable, and it's defined as the extent to which a household head has attained skills, knowledge, and information through formal education (He et al., 2022). In the present study, the education attainment of the household head was measured as a continuous variable using average years of schooling (He, Lovo, & Veronesi, 2022).

Financial remittances: A remittance is another independent variable in this study, and it refers to the money or income received by a household when a member works abroad or outside the home who may send back money to support the family (Bhattarai *et al.*, 2018). It could also mean a transfer of income earned by expatriate workers in a foreign country to their home country, usually to support their families (Piteli et al., 2019). In other words, Remittances are essentially external inflows or sources of financing for a household (Fromentin & Leon, 2019; Hosan *et al.*, 2023). In this study, a financial remittance was measured as a dummy variable. The survey asked households about their different sources of income, and they were also asked to indicate a source of funding for biogas installation and maintenance. The answers to these questions were used to generate a dummy variable whereby it is equal to 1 if a household

received a remittance for the past 12 months and is equal to zero if otherwise.

Ethnicity*:* ethnicity is another independent variable used to explain biogas adoption in households.

In the present study, ethnicity refers to cultural values, which vary across different ethnic, racial, tribal or religious groups and which may influence an individual's decision to install and use a biogas technology (Das *et al.,* 2017; Katuwal *et al.,* 2023). For this study, ethnicity refers to differences in tribal and religious groupings, and it was measured at the neighbourhood (village/enumeration area) level based on the level of concentration of a particular ethnic group. Our main measure is computed using the Herfindahl-type index-HHI (Greenberg, 1956), where the focus is on the share of ethnic groups in a given neighbourhood (enumeration area). This measurement approach has been widely used in ethnic studies (Churchill & Smyth, 2017; Churchill & Smyth, 2020) and neighbourhood studies (see Graziano *et al*, 2019; Palm, 2015).

Control variables: Consistent with the literature on biogas adoption, the study controlled for household head characteristics (including sex, age and employment status of the household head) and household attributes (including household size, housing conditions, water source and grid access, regional location and urban-rural residence). These variables were entered into the model as covariates because prior literature has shown that they influence biogas adoption among households (Mengistu *et al*., 2016; Mottaleb & Rahut, 2019; Uhunamure *et al.,* 2019; Jan & Akram, 2018; Amir *et al.,* 2020; Shallo *et al.,* 2020; Sarker *et al*., 2020). Table 2 presents a summary of the study variables.

Table 2: Description of variables used in the model

Variable	Measurement
Dependent variable	
Biogas adoption	Dummy (Yes = 1 if a household uses a biogas technology; No = 0 if otherwise) 0 was base
Independent variables	
Remittance	Dummy (1 = household received a remittance, = 0 if otherwise) 0 was base
Ethnicity	Herfindahl index- HHI
Education attainment	Continuous - Years of schooling
Covariates	
Roof type	Dummy (1 = Permanent, 0 = Not permanent) 0 was base
Sex of household head	Dummy (1= male, 0 = female)
Regional location	Dummy variable =1 if residence is in Central Uganda, 0 otherwise Dummy variable =1 if residence is in Eastern Uganda, 0 otherwise Dummy variable =1 if residence is in Northern Uganda, 0 otherwise Dummy variable =1 if residence is in Western Uganda, 0 otherwise
Residence	Dummy (1= Rural 0=Urban) 0 was base
Age of household head	Continuous
Household size	Continuous – average number of household members
Employment status	Binary variable equals 1 if household head earns non-farm wage, 0 if otherwise Binary variable equals 1 if household head is self-employed in non-farm, 0 if otherwise Binary variable equals 1 if household head earns farm wage, 0 if otherwise Binary variable equals 1 if household head is not working, 0 if otherwise
Electricity access	Dummy variable =1 if a household uses electricity, 0 otherwise
Improved water source	Dummy variable =1 if a household has access to improved water source, 0 otherwise

3.6 Theoretical Model and estimation model

3.6.1 Random Utility Maximization Model

The random utility maximisation (RUM) model is a commonly used theoretical model for analysing discrete choices based on the assumption of the utility-maximising behaviour of individuals. Therefore, to analyse factors affecting biogas adoption, the study employed the Random Utility Model (RUM) to model the choices of individuals among a discrete set of alternatives. The total utility of an alternative depends on the utility of the characteristics that an individual household observes and the utility that an individual does not observe (Das *et al.*,

2017; Kelebe *et al.*, 2017; Katuwal, 2022). The household chooses the one with the highest utility.

The utility of alternative j is:

$$U_{ij} = \beta_j X_{ij} + \varepsilon_{ij} \dots\dots\dots\

adoption is measured as a dummy variable, while the explanatory variables are a mix of categorical and numerical. Hence, a probit analysis was used to assess the probability of households adopting a biogas system. The probit model, which employs a probit link function, was estimated using the standard Maximum Likelihood (ML) procedure (Greene, 2003) to determine the true conditional probabilities as logistic functions of the independent variables in terms of log odds (Carson, 2008). The marginal effect (changes) rather than the log of the odds ratio was used to estimate the changes in remittances, education and ethnicity effect on the adoption of biogas. Probit models have been used in a number of studies on adoption behaviour (Sardianou & Genoudi, 2013; Jan *et al.*, 2017). The general linear regression model can be expressed as follows:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_P X_P + \varepsilon_i = \ X\beta + \ \varepsilon \qquad (1)$$

Where Y is the dependent variable, βs are the regression coefficients, Xs are a vector of explanatory variables, and ε is the error term. In model (1), however, the dependent variable (Y) is linear. While exploring non-linear estimation with a dichotomous dependent variable (Y), as is the case with many social science problems, a link function is introduced in an econometric model as a function linking the actual (Y) to the estimated ($\bar{y}$). In general, a link function is some function F (·) which is stated as:

$$F(Y) = Y^* = \ X\beta + \ \varepsilon \qquad (2)$$

Redefining the dependent variable, we would say:

$$Y = \phi\ (X\beta + \ \varepsilon\ )$$

$$\phi^{-1}(Y) = \ X\beta + \ \varepsilon$$

In our case, the link function is $F(Y) = \phi^{-1}(Y)$, which is known as the probit link, as shown below.

$$Y^* = X\beta + \varepsilon \quad (3)$$

Hence, Y = 1 if a household has adopted biogas and 0 otherwise. We also have a vector of regressors (Xs), which are hypothesised causes of Y. Thus, we can say that the model takes the form:

$$F(Y-1|X) = \phi\,(X'\beta + \varepsilon \quad (4)$$

This binary choice probit model describes that Y = 1 for the given function F(.). The parameters βs are typically estimated by the Maximum Likelihood method. The probit model can be explained below

$$Y^* = \phi\,(X'\beta + \varepsilon \quad (5)$$

Where $\varepsilon \sim N(0,1)$. Then Y can be viewed as;

$Y = 1\ if\ Y^* > 0\ i.e., -\varepsilon < X'\beta$;

$0\ \ if\ otherwise$

By substituting the variables of interest, the expanded form of the model is as follows;

$$\boldsymbol{BA}_i = \beta_0 + \beta_1 EDU_i + \beta_2 REMIT_i + \beta_3 ETH_i + \beta_4 X_{ij} + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\boldsymbol{BA}_i = \beta_0 + \beta_1 EDU_i + \beta_2 ETH_i + \gamma + \beta_4 X_{ij} + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where $\boldsymbol{BA}_i$ is the dependent variable biogas adoption coded as "1" if a household uses biogas and "0" otherwise. β_0 is the slope; $\beta_1 EDU$ is the coefficient of education; $\beta_2 REMIT_i$ is the coefficient of financial remittance $\beta_3 ETH_i$ is the coefficient of Ethnicity; $\beta_4 X_{ij}$ represents a vector of other household and demographic characteristics (such as age, gender, family size, employment status, access to an improved water source, electricity access etc), these are controlled for in the model. ε_i is normally distributed random error term. The term $(ETH_i *$

$EDU_i)$ in equation 8 represents that interaction which tests the moderating effect of education on the relationship between ethnicity and the adoption of biogas technology by households.

Equation 7 specifies the model for testing hypotheses H1, H2, and H3, while equation 8 tests hypothesis H4.

3.7 Data processing, analysis, and presentation

STATA software version 16.0 was used for data analysis. During the analysis of data, descriptive statistics were used to present the results of the sample characteristics; correlation analysis was carried out to determine the degree of relationship between biogas adoption and its determinants. Then, binary probit model regressions were used to estimate the marginal effects of independent variables on biogas adoption by households. The regression analysis enabled the researcher to examine the predictability of the studied variables.

3.8 Unit of analysis and inquiry

The unit of analysis in this study is a household. This is because adoption in terms of the use of biogas for cooking and lighting is a decision taken mainly at a household level. A household consists of a person or a group of persons living together under the same roof or in the same compound. Likewise, the unit of inquiry was a household head. This is because the head of a household is often the main decision-maker in a household.

3.9 Diagnostic and Robustness Tests

The estimates of the main model were subjected to relevant diagnostic and robustness tests to ensure the validity of the findings. First, the bivariate correlation matrix was used to test for multicollinearity within the study variables. This is intended to identify variables that are correlated and may affect the predictive results. Second, the adequacy of the model was examined by overall goodness-of-fit tests, receiver operating characteristic curve (ROC) and

examination of influential observations. The robustness of the results was confirmed using a sensitivity test.

3.10 Ethical Considerations

When carrying out research, specific ethical issues were taken into consideration. First, all the necessary procedures pertaining to access to and use of data from the various organisations were followed, and all the data or information provided by the various organisations was handled with utmost confidentiality. Throughout the literature review, the researcher ensured acknowledgement to authors of different materials used. The researcher sought formal permission to use the data set from UBOS. Results from this study will be shared among the various organisations/individuals that contributed to the study and for policy formulation and implementation.

CHAPTER FOUR

PRESENTATION AND INTERPRETATION OF FINDINGS

4.1 Introduction

This chapter presents results and interpretations in accordance with the study objectives. The chapter entails descriptive statistics, pairwise Correlation results, goodness of model fit results and regression results. The study was guided by the following research objectives;

i. examine the relationship between financial remittances and the adoption of biogas energy technology.
ii. Examine the relationship between education attainment and the adoption of biogas energy technology
iii. examine the relationship between ethnicity and the adoption of biogas energy technology.
iv. Examine the moderating effect of education attainment on ethnicity and adoption of biogas energy technology.

4.2 Descriptive statistics

Table 3 presents the proportion of households that use biogas and those that received remittances. Out of 13,732 households surveyed, about 2% use biogas energy technology, while over 98% do not use biogas as their main source of energy for cooking and lighting. Implying that biogas adoption is still limited among households and that the majority of households still depend on other fuels to meet their cooking needs. In addition, analysis in Table 3 indicates that over 30% of households had received a remittance while about 70% percent had not received any remittance inflow.

Table 3: Distribution of households by biogas adoption status and remittance inflow.

Variable	Freq.	Percent	Cum.
Biogas non-adopters	13,590	98.46	98.46
Biogas adopters	212	1.54	100
Households didn't receive remittances	9,607	69.67	69.67
Households received remittances	4,182	30.33	100
Total	13,789	100	

Source: 2019/2020 UNHS data (UBOS, 2020)

Results presented in table 4 indicate that the mean years of schooling for respondents is 6. Meaning that the majority of household heads had attained some primary level education, which resonates with the national demographic characteristic in Uganda. Results also show that the mean age of a household head is 45 years, with the minimum age being 15 and the maximum being 108 years. Furthermore, the results in Table 4 reveal that, on average, 71% of households reported living in neighbourhoods of diverse ethnic groups. The mean size of a household was approximately 5 members.

Table 4: Distribution of respondents by average years of schooling, age and ethnicity

Variable	Mean	Median	Min	Max
Years of schooling	5.9	6	0	17
Age	45	42	15	108
Ethnicity (HHI)	0.716	0.824	0.076	1
Household size	4.7	4	1	24

Source: 2019/2020 UNHS data (UBOS, 2020)

Results presented in Table 5 indicate that the majority of the households surveyed are male-headed, constituting 67%, as compared to 33% who are female-headed. This result aligns well

with the national demographic statistics, which indicate that the majority of households in Uganda are headed by males (UBOS, 2022).

Table 5: Sex of household head

Sex	Freq.	Percent	Cum.
Female	4,517	33	32.89
Male	9,215	67	100
Total	13,732	100	

Source: 2019/2020 UNHS data (UBOS, 2020)

Table 6 presents the distribution of respondents or households by region. Results show that the majority of the respondents were from Eastern Uganda (31.1%), followed by Northern Uganda (24.4%), followed by Western Uganda (23.3%), while Central had the least number of households interviewed (21.1%). The regional distribution of respondents depicts the national population statistics, whereby Eastern Uganda has the highest number of households in Uganda.

Table 6: Distribution of respondents by regional location

Region	Freq.	Percent	Cum.
Central	2,917	21.13	21.13
Eastern	4,296	31.13	52.26
Northern	3,371	24.42	76.68
Western	3,218	23.32	100

Source: 2019/2020 UNHS data (UBOS, 2020)

Table 3 presents the distribution of household heads by employment status. Results show that 28.6% of the household heads are not employed, 16.3% are in subsistence on-farm employment, 14.2% are in nonfarm wage employment, 18.9% are in nonfarm self-employment, 7.9% are in farm wage employment, and 14.1% are employed on farm. These statistics suggest that the majority of household heads are not working or unemployed, followed by non-farm self-employment, while farm wage employment was the least.

Table 7: Employment status of household head

Employment status	Freq.	Percent	Cum.
On-farm employment	1935	14.1	14.1
farm wage employment	1085	7.9	22.0
nonfarm self-employment	2585	18.9	40.9
nonfarm wage employment	1943	14.2	55.1
Subsistence on-farm employment	2237	16.3	71.4
Not working	3918	28.6	100
Total	13703	100	

Source: 2019/2020 UNHS data (UBOS, 2020)

Table 8 describes household-level characteristics. Results show that the majority of the respondents indicated that they reside in homes with permanent roofs (72.2%), while only 7.81% resided in homes with temporal roofs. In addition, about 47% of respondents reside in houses with a permanent wall, while only 35.3% live in houses with a permanent floor. Furthermore, results in Table 8 indicate that the majority of households have access to improved water sources.

Table 8: Household characteristics

Variable	Freq.	Percent	Cum.
Roof			
Not permanent	3,832	27.8	27.77
Permanent	9,969	72.2	100
Wall			
Others	7,203	52.2	52.19
Permanent	6,599	47.8	100
Floor			
Others	8,928	64.69	64.69
Permanent	4,865	35.25	99.93
Source of water			
Improved	11,000	81.31	81.31
Unimproved	2,529	18.69	100

Source: 2019/2020 UNHS data (UBOS, 2020)

4.3 Correlation between the Study Variables

Table 9 presents the results of the pairwise correlation Test. Correlation analysis shows the degree of association between two or more variables. Pairwise correlation coefficient (r) is a measure of the strength of the association between the two variables. Where the relationship between the variables is not linear, then the correlation coefficient does not adequately represent the strength of the relationship between the variables. The correlation coefficient (r) ranges from -1 to 1. r = -1 indicates a perfect negative linear relationship between variables, r = 0 indicates no linear relationship between variables, and r = 1 indicates a perfect positive relationship between variables. To investigate the correlation among the constructs, a Zero-order correlation table was generated. Results show that the majority of the variables have no correlation at all or are very low, between 0.00 and 0.29 (Asuero et al., 2006).

Table 9: Pairwise Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Remittances	1.000															
(2) Ethnicity	-0.288*	1.000														
(3) Education	0.120*	-0.214*	1.000													
(4) Sex of HH head	0.000	-0.103*	0.309*	1.000												
(5) Age of HH head	-0.064*	0.044*	-0.269*	-0.154*	1.000											
(6) Age squared	-0.064*	0.046*	-0.272*	-0.155*	0.982*	1.000										
(7) Household size	-0.050*	0.014	0.026*	0.160*	0.059*	-0.001	1.000									
(8) Residence	0.222*	-0.257*	0.251*	-0.037*	-0.085*	-0.083*	-0.114*	1.000								
(9) Region	-0.045*	0.292*	-0.158*	-0.014	0.039*	0.039*	0.042*	-0.176*	1.000							
(10) Employment status	-0.027*	0.045*	-0.068*	-0.095*	0.207*	0.225*	-0.045*	-0.006	0.098*	1.000						
(11) Type of roof	0.151*	-0.414*	0.205*	0.053*	0.074*	0.062*	-0.004	0.191*	-0.137*	-0.049*	1.000					
(12) Type of floor	0.222*	-0.295*	0.299*	0.022*	0.005	-0.004	0.019*	0.270*	-0.318*	-0.057*	0.516*	1.000				
(13) Type of wall	0.225*	-0.277*	0.356*	-0.002	-0.027*	-0.032*	-0.019*	0.352*	-0.253*	-0.044*	0.407*	0.616*	1.000			
(14) Source of water	-0.074*	0.031*	-0.134*	0.034*	0.015	0.016	-0.002	-0.125*	0.180*	-0.035*	0.050*	-0.132*	-0.131*	1.000		
(15) Grid Electricity	0.300*	-0.308*	0.357*	-0.006	-0.093*	-0.092*	-0.101*	0.481*	-0.303*	-0.031*	0.258*	0.382*	0.496*	-0.146*	1.000	
(16) Biogas Adoption	0.049*	-0.091*	0.117*	0.012	-0.031*	-0.030*	-0.056*	0.116*	-0.110*	-0.011	0.056*	0.099*	0.119*	-0.038*	0.191*	1.000

Robust standard errors in parentheses
Level of significance * $p<0.05$

4.4 Model specification test results

Prior to estimating the primary model and making any statistical inferences, it is imperative to assess the adequacy of the model fit and identify influential data that could potentially impact the estimation of coefficients. Without verifying that the data meets the assumptions underlying the probit regression method adopted, the results may be misleading. According to Archer and Lemeshow (2006), the evaluation of the suitability of a probit regression model involves several methods. These methods include overall goodness-of-fit tests, assessment of the area under the receiver operating characteristic curve, and study of influential observations. Thus, the following diagnostics were performed for each of the models of the binary probit regression analysis: specification errors test and goodness-of-fit for survey data test. Table 10 and Figure 2 present the results of model specification. The results of the specification errors test in Table 10 show that the model equations were well specified as predicted by the hat-statistic ($p < 0.05$); the hat-square statistic shows that no additional variables were significant ($p > 0.05$). [1]In other words, the results of the specification test show that the probit transformation is a correct functional form for the outcome variable.

Table 10: Model specification

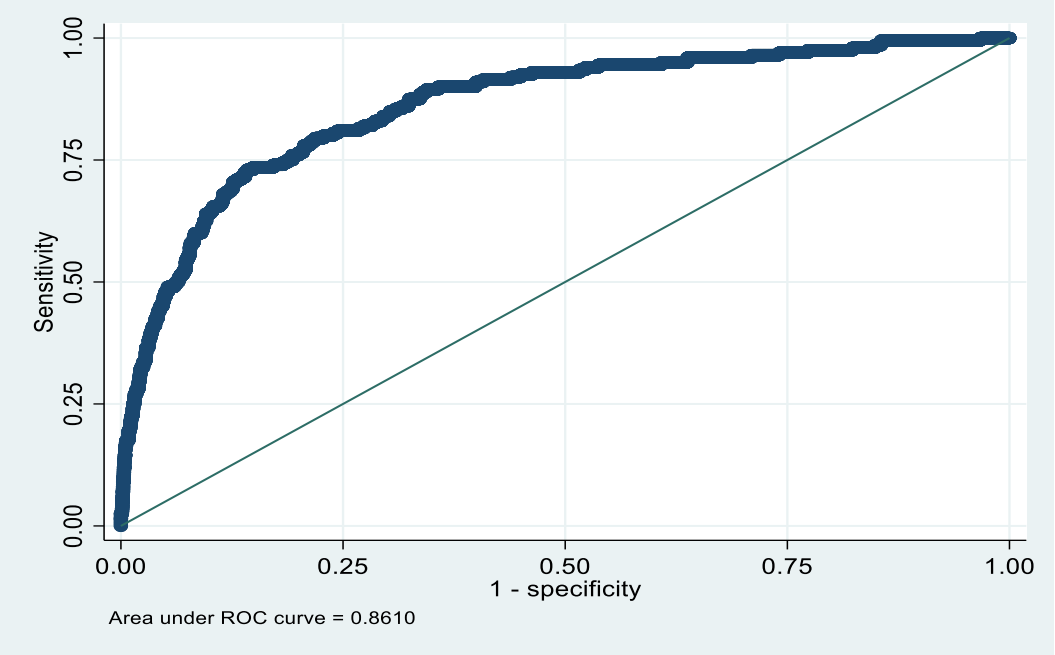
		Linearised				
Solar	**Coef.**	**Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
_hat	1.983	0.377	5.258	0.000	1.244	2.722
_hatsq	0.250	0.286	0.874	0.104	-0.311	0.812
_cons	0.863	0.881	0.979	0.324	-0.864	2.589

In addition, the Receiver Operating Characteristic (ROC) curve was used to select the optimal model and drop the sub-optimal model. Figure 2 shows that probit regression has acceptable

[1] The specification error test was performed using the link test command in Stata16, which is implemented as follows: after fitting the logit model under, say, obtain the fitted values (hat) and their square (hats) and then run a logit model with hat and its square as the covariates. The significance of hatsq is the linktest. The model is correctly specified and a good fit if the differences between the observed and fitted values are small and significant and if there is no systematic contribution of the differences to the error structure of the model.

discriminatory power, as indicated by the area under the curve (AUC>0.70). The results of the goodness-of-fit for the survey data F-adjusted mean residual test also confirm that all models were correctly specified (Archer & Lemeshow, 2006; Archer et al., 2007)

Figure 3: Model specification



4.5 Regression results

Table 11 shows regression estimates of household biogas adoption among households, with non-adoption "0" being the base category. The coefficients with an asterisk(s) indicate that the corresponding t-statistic is significant, which suggests that the associated explanatory variable has an effect on the outcome variable. Nearly all parameter estimations are statistically significant at 1%. The key explanatory variables of interest include financial remittance, education and ethnicity (Herfindahl index). The coefficients in the probit model are the marginal effect of the determinants on biogas adoption. As can be seen from the regression results, all the key variables have a significant positive effect on the adoption of biogas technology. More specifically;

4.5.1 Financial remittances and adoption of biogas energy technology.

Results in Table 11 reveal that the estimated coefficient on “remittance” is positive (0.050) and statistically significant at a 1% level of significance ($p < 0.01$). Implying that remittance inflow increases the likelihood of a household adopting biogas technology for domestic use by approximately 5%. In other words, households that receive remittances are 5% more likely to adopt biogas technology compared to households without remittance inflow. This finding supports the first hypothesis that financial remittance is positive and significantly associated with the adoption of biogas in households.

4.5.2 Education attainment and adoption of biogas energy technology

Another factor considered to influence the adoption of biogas technology is the education attainment of the household head. The estimated coefficient on "education attainment of the household head" is positive (0.050) and statistically significant ($p < 0.01$), as shown in Table 11. In the current study, a statistical significance ($p < 0.01$) shows a positive relationship between the level of education and adoption of biogas technology. This means that an increase in education attainment in terms of years of schooling increases the likelihood of a household installing a biogas energy technology. In other words, the results show that there is a 5% increase in the likelihood of a household adopting biogas technology if the household head has attained some level of formal education. Perhaps because educated people are more environmentally knowledgeable and conscious about the detrimental impact of using unprocessed biomass fuels on the environment. Hence, educated people are willing to try new technologies that can help abate adverse outcomes on health and the environment. This finding supports the second hypothesis that education is positively and significantly associated with the adoption of biogas in households.

4.5.3 Ethnicity and adoption of biogas energy technology.

To estimate the effect of ethnicity on the adoption of biogas, the Herfindahl index was generated and used to measure ethnicity. The Herfindahl–Hirschman index is a measure of the concentration of ethnic groups in a given village or Enumeration Area. Table 11 shows that the estimated coefficient on ethnicity is positive (0.020) and statistically significant at a 1 % level of significance ($p < 0.01$). This means that the relationship between ethnicity and biogas adoption is positive and statistically significant. Specifically, we find that an increase in ethnic diversity is associated with a 2% increase in the probability of a household adopting biogas technology. Implying that, households that live in the neighbourhood with diverse ethnic groups are 2% more likely to adopt biogas compared to households that reside in communities with homogenous ethnic groups. It is possible that in villages or communities with diverse ethnic groups, individuals are less rigid and perhaps pay limited attention to cultural values, which increases the likelihood of adopting biogas technology. Thus, the third hypothesis is supported.

Consistent with the literature (Mengistu *et al.*, 2016; Uhunamure *et al.*, 2019; Jan & Akram, 2018; Amir *et al.*, 2020; Shallo *et al.*, 2020; Sarker *et al.*, 2020; Bryant & Afitiri, 2021) the results indicate that the individual and household level characteristics including household size, rural residence, regional location of the household, housing condition and access to grid electricity have a significant positive association with adoption of biogas technology as the main source of energy among households.

Overall, our findings suggest a strong positive relationship between financial remittance, education, ethnicity and biogas adoption. More specifically, the Pseudo R squared shows that financial remittance, education and ethnicity combined have the capacity to explain about 20.9% of the variance in biogas adoption (Pseudo $R^2 = 0.2086$).

Table 11:Estimated marginal effects of Remittance, Education and Ethnicity on Biogas adoption

Variables	Marginal effects	Standard Errors	T	P>t	[95% conf.	interval]	sig
Received remittances	0.050	(0.007)	6.937	0.000	0.036	0.050	****
Ethnicity	0.020	(0.007)	2.780	0.006	0.006	0.020	****
Years of schooling	0.052	(0.014)	3.848	0.000	0.026	0.052	****
Sex of HH head (female)	0.001	(0.002)	0.420	0.673	-0.003	0.005	
Age of the HH Head	0.000	(0.000)	0.830	0.404	0.000	0.001	
Age squared	0.000	(0.000)	-0.800	0.421	-0.001	0.000	
Household size	-0.001	(0.000)	-3.440	0.001	-0.002	0.000	****
Residence (Urban)	0.052	(0.016)	3.152	0.000	0.020	0.084	****
Region (Central)							
Eastern	0.007	(0.002)	2.990	0.003	0.002	0.012	***
Northern	0.006	(0.003)	2.030	0.043	0.000	0.013	**
Western	0.006	(0.003)	2.300	0.022	0.001	0.011	**
Employment status							
farm wage employment	-0.007	(0.004)	-1.860	0.063	-0.014	0.000	*
nonfarm service employment	-0.003	(0.003)	-0.890	0.372	-0.010	0.004	
nonfarm wage employment	-0.003	(0.003)	-0.790	0.432	-0.009	0.004	
Subsistence in farming employment	-0.008	(0.003)	-2.700	0.007	-0.014	-0.002	***
Not working	-0.003	(0.003)	-0.970	0.331	-0.009	0.003	
Housing condition							
Type of roof (permanent)	-0.005	(0.003)	-1.720	0.085	-0.010	0.001	*
Type of wall (permanent)	0.004	(0.002)	2.000	0.046	0.000	0.009	**
Type of floor (permanent)	0.002	(0.002)	1.330	0.184	-0.001	0.005	
Improved water source	-0.001	(0.002)	-0.330	0.745	-0.005	0.004	
Use of Electricity for cooking	0.008	(0.002)	3.480	0.001	0.004	0.013	***

Robust standard errors in parentheses
* p<0.01, ** p<0.05, *** p<0.1

Probit regression — Number of obs. = 13,345
LR chi^2 (21) = 433.31
Prob > chi^2 = 0.0000
Log likelihood = -821.9553 — Pseudo R^2 = 0.2086

4.5.4 Moderating effect of education attainment on ethnicity and adoption of biogas.

The fourth hypothesis sought to test the moderating effect of education on the relationship between ethnicity and biogas adoption. Moderation exists only if the interaction term has a

significant effect on the outcome variable; otherwise, no moderation exists. The regression results for the moderation are presented in Table 12.

In line with hypothesis four (H_4), the results in Table 12 show a significant and positive moderating effect of education on the relationship between ethnicity and biogas adoption. The estimates indicate that the interaction effect of ethnicity and education increases the likelihood of a household adopting biogas technology for domestic use by 4.4% at a 1% level of significance. Implying that marginal change in ethnic diversity increases the likelihood of a household using biogas by 4.4% if the household head has attained formal education compared to when the household head has no formal education. This means that the positive effect of ethnicity on biogas adoption is strengthened if a household head has no formal education. In other words, education strengthens the effect of ethnicity on the adoption of biogas. Thus, hypothesis 4, which is education moderates the effect of ethnicity on biogas adoption, was supported.

Table 12: Moderating effect of education attainment on ethnicity and biogas adoption.

Variables	Marginal effects	Standard Errors
Ethnicity	-1.455**	(0.732)
Years of schooling	0.010	(0.030)
Ethnicity # education of HH heads	0.044***	(0.022)
Covariates	Yes	
Constant	-1.527***	(0.506)
Observations	13,435	

Robust standard errors in parentheses
Control variables included here are consistent with those in Table 11
Level of significance, *** significant at 1%, ** significant at 5% and * significant at 10%

4.6 Sensitivity check

To check for the robustness of the results, the researcher conducted additional sensitivity tests. First, the results in the main model were re-estimated using different sub-sample analysis. In the

first segment, I used 75% of the total sampled households; in the second segment, we used 50%, while in the third segment, we used 25% of the total sampled households to estimate adoption decisions for biogas. The results in Table 13 confirm findings in the main model that, financial remittances, education and ethnicity have a positive effect on biogas adoption. We find that the previous results are not significantly affected by the reduction in the sample size.

Table 13: Re-estimated Logit models of Biogas adoption in households by splitting the total Sampled households into 75%, 50%, and 25%

	(1)	(2)	(3)
VARIABLES	**75% sample**	**50% sample**	**25% sample**
Financial remittances	0.0309***	0.0275***	0.021***
	(0.00131)	(0.00196)	(0.00307)
Ethnicity	0.015**	0.0163**	0.0149**
	(0.00696)	(0.00811)	(0.0063)
Education	0.0326***	0.0177***	0.0069***
	(0.01236)	(0.01359)	(0.01408)
Control variables	Yes	Yes	Yes
Observations	10,004	6,674	2,791

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the discussion, conclusions, and recommendations arising out of the research findings in chapter four and suggests areas for further study.

5.2 Discussion of Findings

For this study, findings are discussed in line with the research objectives that the study sought to address. These include;

(i) To examine the relationship between financial remittance and the adoption of biogas energy technology among households.

H_1: Financial remittance is positively correlated with adoption of biogas technology

(ii) To examine the relationship between education attainment and the adoption of biogas energy technology among households.

H_2: Education attainment is positively associated with adoption of biogas technology

(iii) To examine the relationship between ethnicity and the adoption of biogas energy technology

H_3: Ethnicity is associated with the adoption of biogas energy technology

(iv) To examine the moderating effect of education attainment on ethnicity and adoption of biogas energy technology

H_4: Education attainment moderates the relationship between ethnicity and the adoption of biogas energy technology

5.2.1 Financial remittance and biogas adoption

The study sought to examine the relationship between financial remittance and biogas adoption. In line with our hypothesis (H_1), this study finds that remittance has a significant positive association with biogas adoption. Hence, H_1 is supported. This means that households that receive a remittance inflow from their relatives working outside the home are more likely to adopt biogas technology. This is because a remittance inflow is a source of income. Therefore, when households receive such money, they are able to acquire and install biogas technology in their homes. Implying that financial remittances enhance ability of the receiving households to afford biogas energy system hence adoption. Therefore, when households receive remittances in the form of external income, they use part of that money to invest in biogas energy systems and associated appliances. This finding suggests that remittances increase the probability of households using biogas energy technology in Uganda.

This finding is in line with earlier studies that found that access to remittance inflow boosts demand and use of renewable energy in different study contexts (Bhattarai *et al.,* 2018; Wang *et al.,* 2021; Subramaniam *et al.,* 2022; Karmaker *et al.,* 2023). More specifically, Bhattarai *et al.* (2018) find that the coefficient of remittances is positive and statistically significant for biogas adoption in Nepal. Wang *et al.* (2021) find that remittances increase the demand for clean energy in developing countries. Das *et al.* (2021) found that remittances per capita are associated with a level of renewable energy consumption in Bangladesh. Subramaniam *et al.* (2022) found that remittance inflows boosted both household income and demand for renewable energy. Karmaker *et al.* (2023) used a generalised two-stage least squares random effect model to estimate the

impact of remittance on renewable energy use. Results showed that remittances have a positive relationship with renewable energy consumption.

However, most of the prior studies were conducted in the Middle East, and their analysis was done at the macro level. In addition, prior studies have mainly analysed remittances in relation to all renewable energy technologies, especially solar and grid electricity use. Therefore, the current study contributes to the existing body of knowledge by providing empirical evidence on the role of financial remittances in promoting biogas adoption among households in the context of a low-developed country like Uganda.

5.2.2 Education attainment and biogas adoption

The study sought to examine the relationship between educational attainment in a household and biogas adoption. In line with our hypothesis (H_2), the study finds a positive and significant relationship between the education attainment of a household head and the likelihood of biogas adoption among households. Hence, H_2 is supported. This means that educated household heads are more likely to adopt or use biogas technology in their homes, perhaps because such people are more informed and knowledgeable about the benefits of using biogas energy as opposed to unprocessed biomass fuels, and based on that, they are able to make an informed decision to adopt the technology. In addition, it is possible that educated people have access to better-paying job opportunities, which enhance their ability to afford the technology. Therefore, the study findings demonstrate that education attainment in the form of years of schooling increases the likelihood of a household adopting biogas technology in Uganda.

The study findings are supported by prior studies (Mwirigi *et al.,* 2009; Mengistu *et al.,* 2016; Inayatullah & Waqar, 2016; Jan & Akram, 2018; Uhunamure *et al.,* 2019; Shallo *et al*., 2020; Amir *et al.,* 2020) who found a positive association between the level of education and biogas

technology adoption in different study contexts. Specifically, Mwirigi *et al.* (2009) found that socio-economic factors such as the education level of the household head, family income, farm size, and cost of dairy cattle significantly influenced the decision to adopt biogas technology in Kenya. Mengistu *et al.* (2016) and Shallo *et al.* (2020) found that the educational level of a household head has a significant positive influence on the adoption of biogas technology in Ethiopia. Inayatullah & Waqar (2016), Jan & Akram (2018) and Amir *et al.* (2020) discovered that education increased the likelihood of households adopting a biogas system in Pakistan. Uhunamure *et al.* (2019) indicated that household heads' education level and awareness of biogas technology were statistically significant for the adoption of the technology in South Africa. Mottaleb and Rahut (2019) demonstrate that human capital, in terms of the general education of the household head and spouse, significantly enhanced the decision to use biogas in India. However, on the contrary, an earlier study by Walekhwa *et al.* (2009) found that the educational status of a household head was insignificant in influencing biogas technology adoption in Uganda. The inconsistency in findings could be attributed to the fact that by 2009, biogas technology was being promoted at the institutional level and not yet known to the population. So, very few households were using it. Also, the sample used in the prior study for analysis was very small and, hence, non-representative of the population.

5.2.3 Ethnicity and biogas adoption

The study sought to examine the relationship between ethnicity and biogas adoption. In line with our hypothesis (H_3), we find that, in Uganda, ethnicity is positively associated with biogas adoption. Hence, there is sufficient evidence to support the third hypothesis (H_3). The coefficient of ethnicity is positive and statistically significant on the adoption of Biogas. The empirical estimation demonstrates that ethnicity has a strong positive effect on household Biogas adoption.

This finding suggests that households who live in ethnically heterogeneous neighbourhoods are more likely to adopt biogas energy technology compared to households who live in ethnically homogenous neighbourhoods. The plausible explanation is that, as communities get integrated, ethnic or cultural norms and beliefs that hinder the use of biogas become diluted. Also, it's possible that when people live in ethnically diverse neighbourhoods, they learn new ways of life, and this may include using biogas for cooking, especially if the neighbours are using it.

Our findings support several earlier studies that investigated the effect of ethnic diversity on biogas adoption in different study contexts in developing countries. For instance, Osei-Marfo *et al*. (2020) discovered that ethnicity in terms of tribal differences had a direct, significantly negative influence on the intention to adopt biogas technology in Ghana. Similarly, Bhattarai *et al.* (2018) and Katuwal *et al*. (2023) found that ethnicity in the form of caste had a significant effect on the adoption of biogas and solar energy technologies in Nepal. Their findings suggest that marginalised groups tend to lag behind the privileged group in regard to the adoption of cleaner cooking technologies, such as biogas, in Nepal. Likewise, Das *et al.* (2017) concluded that households belonging to disadvantaged socio-economic groups are less likely to adopt biogas technology. However, our findings are contrary to study findings by Williams *et al.* (2022), who found that Caste had no significant influence on the adoption of biogas in Nepal. It's important to note that although there is a growing body of literature investigating the association between ethnicity and biogas, their findings are not conclusive, and none of these studies were undertaken in Uganda. Therefore, our study is unique as it provides empirical evidence of the positive association between ethnicity and biogas adoption from a low-income country perspective.

5.2.4 Moderating effect of education on ethnicity and biogas adoption

The study sought to examine if the educational attainment of the household head moderates the relationship between ethnicity and biogas adoption. In line with our hypothesis (H_4), the results show that the moderating effect of education attainment of the household head on the relationship between ethnicity and biogas adoption is positive and significant. This suggests that in households where the heads are educated, their likelihood of adopting biogas energy technology increases more if they reside in an ethnically diverse neighborhood. This finding suggests that education strengthens the effect of ethnicity on the adoption of biogas technology among households. This is because education enhances one's knowledge and cognitive ability; these enable households to overcome cultural biases and appreciate the benefits of using biogas in their homes. In addition, education is associated with status and better income, which have been proven to increase the adoption of modern energy technologies. Therefore, attainment of education enhances the ability of the head to overcome cultural biases that hinder the use of biogas technology and subsequently increase the likelihood of adoption.

This study finding is supported by Muvhiiwa *et al.* (2017), who investigated the role of education and norms on biogas adoption in South Africa using experimental design. Results derived from a comparison of the 'before-and-after-installation' responses of the persons interviewed revealed that the members of the Muldersdrift community who had received hands-on education and also shared experiences with different ethnic groups had become more willing to adopt the technology. The interaction results further showed that access to educational programmes and exposure to pilot plants dampened the negative effect of ethnic and cultural beliefs on willingness to adopt biogas technology.

Bearing in mind that there is limited evidence on the interaction effect education has on ethnicity and biogas adoption, this study contributes to the existing literature by providing empirical evidence on the interaction effect of education on the relationship between ethnicity and adoption of biogas technology among households in Uganda.

5.3 Conclusion

Although the adoption of biogas technology is relatively low among households in Uganda, the technology has the potential to address two overarching challenges (including ensuring access to clean cooking solutions for all and climate change mitigation) that have topped the agenda of both policymakers and researchers worldwide. In light of these concerns, this study sought to investigate factors influencing the adoption of biogas technology among Uganda's households. A total of 13,732 households were analysed using the binary probit model to estimate the relationship between financial remittances, education attainment, ethnicity and adoption of biogas energy systems in households.

In line with the study hypotheses $H_{1,}H_{2,}$H3, and H4, the study finds that remittances, education attainment, and ethnicity are significantly and positively associated with biogas adoption. More specifically, findings suggest that remittance inflow from family members and friends working abroad enhances the economic status of the households, which enables them to invest in biogas energy technology. Thus, remittance inflow is an important determinant of biogas adoption in households. Findings also suggest that education attainment in terms of years of schooling of the household head increases the probability of a household adopting biogas technology. This implies that education enhances the knowledge and cognitive abilities of the households to make informed adoption decisions, hence improving biogas adoption and use. In addition, the study findings suggest that ethnicity is important in biogas adoption decisions. In other words, an

increase in ethnic diversity increases the likelihood of households adopting biogas technology. Furthermore, the interaction effect of ethnicity and education attainment of the household head is significant and positively associated with biogas adoption.

Among the covariates, the study found that household size, rural residence, regional location of the household, housing condition and access to grid electricity increased the likelihood of households adopting biogas technology as their source of energy.

5.4 Recommendations

Based on the study findings, the following recommendations are suggested: First, our findings reveal that remittance inflow enhances biogas adoption among households. Therefore, the government should formulate policies that encourage Ugandans working in the diaspora to remit their money back home. The government should incentivise the remittance inflows by, for example, reducing the cost of sending money to Uganda. This will increase remittance inflow, which enhances household income and the ability to invest in clean cooking solutions such as biogas.

Second, the findings suggest that educated household heads are more likely to adopt biogas systems in their homes. Therefore, to successfully promote the adoption of biogas technology, it is paramount to educate the intended beneficiaries about the health, environmental and socio-economic benefits that the technology can provide, as this will accelerate the uptake of the technology.

Third, ethnic diversity increases the likelihood of biogas adoption. Therefore, dealers in biogas energy systems should target neighbourhoods or communities with less diverse cultural backgrounds as a mechanism to promote the adoption of the technology. In such communities'

households pay less attention to cultural beliefs or norms, which often undermine the transition to clean cooking solutions.

Furthermore, the descriptive results reveal that the adoption of biogas varies by household size, rural-urban residence, regional location of the household, and housing condition. Therefore, efforts and initiatives to scale the adoption and utilisation of biogas technology should take into account the socio-demographic differences. In other words, any policy intervention aimed at scaling biogas adoption in households should pay attention to household and demographic differences in terms of family size, rural-urban residence, regional location, housing condition (type of wall) and status of grid electricity access.

5.5 Areas for future research

The current study was limited to establishing the relationship between financial remittance, educational attainment, ethnicity, and adoption of Biogas. These factors explain about 21% of biogas adoption. Perhaps other studies should investigate other factors that may explain biogas adoption in households. In addition, it would be interesting to understand the dynamics of remittance inflow and biogas adoption. Therefore, future studies could consider undertaking a longitudinal study to understand the effect of remittance inflow on biogas adoption over time.

5.6 Limitations of the study

However, the results of this study are robust and offer useful insights into key factors that influence biogas adoption in households. The study is not without limitations. The study focused on the adoption of biogas in households in Uganda, a low-developed country. Therefore, the findings of the study are applicable to households in similar contexts. The study analysed biogas adoption decisions using the binary approach (i.e., adopt or not to adopt), which gives a limited understanding of which type of biogas technology households are adopting.

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