

**Determinants of biogas adoption and its impact on livelihoods: evidence from
Domboshava, Zimbabwe**

By

Admire Chawarika

Student Number: 66056551

Submitted in accordance with the requirements for

the degree of

Doctor of Philosophy (PhD) in Agriculture

(Agricultural Economics)

in the

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF AGRICULTURE AND ANIMAL HEALTH

at the

UNIVERSITY OF SOUTH AFRICA

Supervisor: Professor. A Maiwashe-Tagwi

AUGUST 2025

DECLARATION

Name: Admire Chawarika .

Student number: 66056551 .

Degree: Doctor of Philosophy (PhD) in Agriculture

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A. Chawarika

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DEDICATION

This thesis is dedicated to my late mother Alice Immaculate Chawarika and the entire Chawarika family.

ACKNOWLEDGEMENT

I am deeply indebted to many individuals and institutions who contributed significantly to the successful completion of this PhD journey. Their support, guidance and encouragement have been invaluable.

First and foremost, I would like to express my profound gratitude to my supervisor, Professor Aluwani Maiwashe-Tagwi, for her exceptional mentorship, steadfast support and insightful guidance throughout the course of this research. Her intellectual input, patience and constructive feedback were instrumental in shaping this thesis. It has been a privilege and honour to learn under her supervision.

I wish to express my appreciation to the College of Agriculture and Environmental Sciences at the University of South Africa (UNISA), particularly the Department of Agriculture and Animal Health, for their academic and administrative support during the course of my studies. The conducive academic environment, access to resources and collegial support were vital in sustaining my focus and determination throughout this academic journey. I also wish to express my sincere gratitude to the UNISA Postgraduate Bursary, whose financial assistance provided critical support during my studies.

I would also like to extend my heartfelt appreciation to Mr Magamha, the extension officer with the Ministry of Lands, Agriculture, Fisheries, Water and Rural Development, who provided immense support during the fieldwork stage. His knowledge of the study area, rapport with local communities and tireless effort in facilitating interviews and focus group discussions were critical to the success of the data collection process.

To the Chawarika family, I owe a special debt of gratitude. Your unwavering love, patience and encouragement gave me the strength to persevere during difficult times.

Above all, I give glory and honour to Almighty God for granting me the wisdom, strength and perseverance to complete this work. Without His grace, this journey would not have been possible.

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ABBREVIATIONS

DFID	Department for International Development
EU	European Union
GDP	Gross Domestic Product
HIVOS	Humanist Institute for Development Cooperation
IPCC	Intergovernmental Panel on Climate Change
MW	Megawatt
NGOs	Non-Governmental Organizations
PCA	Principal Component Analysis
PSM	Propensity Score Matching
RED	Renewable Energy Directive
SLA	Sustainable Livelihoods Approach
SSA	Sub-Saharan Africa
TAM	Technology Acceptance Model
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
UTAUT	Unified Theory of Acceptance and Use of Technology
VIF	Variance Inflation Factor
ZESCO	Zambia Electricity Supply Corporation

ABSTRACT

This study investigates the socio-economic determinants of biogas technology adoption among livestock farmers in Domboshava, Zimbabwe and examines its impact on rural livelihoods. Despite Zimbabwe's potential for renewable energy technologies, biogas adoption remains limited, particularly in rural areas facing persistent energy poverty. This research addresses key knowledge gaps regarding technology uptake barriers and livelihood outcomes in developing country contexts. The study employed a mixed-methods targeting randomly selected 368 respondents, however 370 livestock farming households were interviewed and formed the basis for the analysis utilizing descriptive statistics, binary logistic regression, multinomial logistic regression and multiple linear regression for analysis. Qualitative methods, comprising institutional mapping and stakeholder analysis, were employed to complement the quantitative findings, drawing on data from 25 key informant interviews. Socio-economic variables included gender, age, education, remittances, asset ownership, non-farm income, land size, livestock units, energy costs, access to credit and extension services. A composite livelihood index was developed to measure multidimensional welfare outcomes. Analysis using binary and multinomial logistic regression revealed that off-farm income, land size, access to credit, gender, livestock units, energy costs, and extension services significantly influenced biogas adoption, while energy costs and livestock ownership were relatively weak predictors. Similarly, farmers' plans to adopt biogas were strongly affected by income, land size, credit access and the availability of information. Multiple linear regression further indicated that biogas adoption significantly enhances household livelihoods, particularly in terms of energy security, income diversification and overall welfare. Based on these findings, the study proposes a tailored institutional framework that emphasizes coordinated roles for government, NGOs, financial institutions and local communities to promote biogas adoption and its contribution to sustainable livelihoods. Policy recommendations include targeted financial mechanisms, improved extension services, gender-sensitive strategies and cross-sectoral coordination. These insights offer valuable guidance for scaling renewable energy solutions and advancing sustainable rural development in Zimbabwe and Africa.

Key terms: Biogas technology; renewable energy; adoption; livelihood; livestock farmers; energy costs; determinants; impact; household; Zimbabwe.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Global warming presents serious risks to biodiversity and the livelihoods of people worldwide. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) continue to encounter major challenges in their efforts to limit the average global temperature rise to 1.5 °C above pre-industrial levels (Brandt and Svendsen, 2022). The failure to meet the set targets will result in altered rainfall distribution and a more pronounced climate change impact (Arneth et al., 2021). The ambitions of the 2015 Paris Agreement to restrict global emissions and maintain sustainable temperatures face multiple challenges from population growth and increased energy demands (Huang and Zhai, 2021). The Intergovernmental Panel on Climate Change (IPCC) asserts that the Earth is poised to undergo permanent and irreversible environmental transformations, evidenced by the heightened frequency and severity of droughts, floods, wildfires and substantial biodiversity decline (Pörtner et al., 2022). The unstable global economy recuperating from the COVID-19 epidemic and dealing with new geopolitical threats will exacerbate the above challenges.

The impacts of global warming will affect the global economy, with developing countries facing significant economic shocks. Burke et al. (2018) estimate that 90% of developing nations' GDP per capita has slowed over time as a result of global warming. This demonstrates the extreme effects of global warming, with developing nations being especially at risk due to a lack of safety nets and adaptive measures (Carley and Kinsky, 2020). Among others, agriculture is one of the sectors that bears the most impact of global warming, particularly within Sub-Saharan Africa (SSA), where most crops have experienced a decline in yield due to global warming. For example, soybean, wheat, maize, and rice yields are down by 5.4%, 3.0%, 6.0%, and 1.8%, respectively (Romanello et al., 2021). The energy supply in developing countries remains precarious, driven by the volatility of global energy prices and the ongoing transition away from fossil fuels aimed at reducing global emissions and minimizing carbon footprints.

According to Taneja et al. (2019), to mitigate against these climate change risks, developing countries must adopt energy-smart practices that are tailored to their specific needs and local conditions. Furthermore, Tagwi's (2022) study highlights that, in addition to the imperative of

transitioning due to climate change, fossil fuel reserves are projected to be exhausted within the next 100 years, underscoring the urgency of shifting to renewable energy sources. The move to renewable energy sources is vital for developing countries. They are more at risk from the harmful effects of climate change. Meinshausen et al. (2022) state that strong and ambitious integration of renewable energy sources is needed to reach the global temperature goals of less than 2 degrees Celsius set by the 2015 Paris Agreement. In line with this, the European Union implemented an energy and climate framework mandating a minimum renewable energy share of 27% by 2030 (Alola et al., 2019). This policy framework will be reinforced by the European Union's proposed carbon tariff, which is designed to further reduce the carbon footprint associated with imported goods.

A well-informed policy based on empirical data regarding the different options is necessary to make the transition to sustainable renewable energy sources. Shah et al. (2019) highlighted various renewable energy sources that developing nations can utilise to tackle the dual issues of energy insecurity and climate change. Wind, solar, hydropower, geothermal and bioenergy represent key alternative renewable energy sources for developing countries, with particular relevance to the African continent (Sayed et al., 2021). These renewable sources can be adopted concurrently depending on environmental considerations, local conditions, and access to finance. According to Cergibozan (2022), bioenergy has been identified as one of the panaceas to tackle the challenge of energy insecurity and global warming in Africa. Bioenergy encompasses biofuels, biomass, and biogas as its principal components (Sakar et al., 2021). Biomass includes solid organic waste, which can be animal or plant material that is used to produce energy. The anaerobic breakdown of organic matter produces biogas.

Biogas is becoming a more viable alternative to traditional energy sources in Africa's rural areas. Biogas reduces dependence on traditional biomass fuels including firewood and charcoal, mitigates greenhouse gas emissions. Smallholder livestock farmers are central to biogas production as they provide the primary feedstock and benefit most from energy savings, health improvements and increased crop yields. Their engagement ensures that biogas systems are appropriately designed, culturally acceptable and effectively utilized. O'Connor et al. (2021) stated that biogas adoption does not compete with other food crops for inputs as it utilises agricultural residues and improves sanitation and waste management for farmers. Additionally, it

is crucial to note that biogas is easily stored and used as needed, which is essential for the baseload. The baseload is the constant load that needs to be supplied throughout the time duration and indicates the efficiency of a power generation technology (Reichenberg et al., 2018). Furthermore, past energy transition processes have often neglected the smallholder farmer, who is instrumental in the agricultural sector of most African countries. Smallholder farmers' limited participation in the production of bioenergy may be due to a lack of awareness of the important opportunities they present, claim Tagwi and Chipfupa (2022). Hence, biogas presents an opportunity to develop sustainable energy sources by including smallholder farmers, who are critical for the food security of most African countries.

Several African countries have embraced biogas adoption with the full participation of their smallholder farmers. Clemens et al. (2018) highlighted that by 2017, 27000 households across Kenya, Tanzania had installed biodigesters. Furthermore, according to Aboagye et al. (2021), Ghana and Nigeria have regulatory frameworks that grant grid access to approved biogas plants. Furthermore, enforcement of environmental waste management practices has incentivised farmers in Ghana and Nigeria to embrace biogas as a way of aligning with the rules and regulations of their countries (Nygaard et al., 2018). The acceptance of biogas as a practical and sustainable renewable energy source has been greatly aided by these policy changes. Tolessa (2024) highlighted a more than 50% adoption of biogas technology in sub-Saharan Africa due to low accessibility to electricity by households. Hence, an efficient policy framework that promotes the adoption of biogas should be in place to support national energy master plans for this technology (Patinvoh and Taherzadeh, 2019). The commercialisation of biogas plants and the expansion of competitive energy markets have been found to be significantly influenced by clear government regulations and prudent macroeconomic conditions.

Zimbabwe is among the African countries currently facing substantial challenges related to energy insecurity. The country requires an estimated 2200 MW of electricity against a current supply of 1000 MW, with the former contributing 60% to the total output (Kajau and Madyira, 2019). Hence, the country meets the shortfall in electricity generation through imports from countries in the SADC region and alternative sources of energy. According to Mukono and Mwiinga (2021), the bulk of the electricity generation is produced as hydroelectricity from Kariba Dam and thermal electricity from Hwange. Currently, the Southern African Power Pool is

facing a significant shortage in electricity supply, which has affected Zimbabwe's ability to import power (Ndlela and Davidson, 2022). Therefore, the country is experiencing load-shedding across all economic sectors as the power authorities ration the available power in the country. This has undermined the productive capacity across the agricultural, industrial, mining and service sectors of the economy. According to The World Bank (2023), Zimbabwe power shortages are estimated to cost the country a total of 6.1% of GDP.

In Zimbabwe, accessing electricity from the national grid is particularly challenging for rural farmers. Since more than 60% of Zimbabweans reside in rural areas, focus should be on the energy issues (Scoones et al., 2019). The Zimbabwean government crafted the 2019 National Renewable Energy Policy, which contains the National Biogas Programme as one of its critical pillars. Chigumira et al. (2019) stated that the principal aim of these two policy frameworks is to enhance biogas production and utilisation in rural regions of the country, where access to grid electricity is still constrained. Furthermore, the majority of rural inhabitants in the country are communal and smallholder farmers who can embrace small technologies including biogas (Chekol et al., 2022). Therefore, biogas can be an important factor in the transformation of the livelihoods of the rural inhabitants of Zimbabwe. In this study, livelihoods refers to the assets, abilities and activities that help a farmer support themselves (Scoones, 2021). Its core pillars include social, human, physical, and natural capital, which collectively influence a farmer's income level. According to Seboka (2019), biogas is an instrumental alternative in reducing energy costs and addressing deforestation in rural farmers. This provides a reference point for Zimbabwe as it implements and assesses the importance of renewable energy sources.

Marambanyika et al. (2020) noted that the Ministry of Energy and Power Development has worked with Humanist Institute for Development Cooperation (HIVOS) and Stichting Nederlandse Vrijwilligers (SNV), among other non-governmental organisations, to promote the use of biogas technology in places like Domboshava. The installation of biogas plants in rural areas of Zimbabwe has been steadily increasing, with farmers primarily utilizing the energy for lighting and cooking purposes. According to Nevzorova and Karakaya (2020), biogas is an environmentally friendly and renewable energy source. Biogas technology utilises agricultural feedstock and animal manure to make bioenergy, and the digested substrate is organic fertilizer. Biogas is a sustainable energy source that enhances the government's Rural Electrification

Agency's efforts to advance off-grid electrification (Baurzhan et al., 2016). Therefore, biogas represents one of the most suitable small-scale technologies for rural farmers to address their daily energy requirements (Tundup et al., 2021). The Zimbabwe National Biogas Programme is already implementing biogas projects in areas including Domboshava.

This study aims to assess the socioeconomic factors that affect biogas adoption and how it impacts the livelihoods of smallholder farmers in Domboshava. The analysis focuses on the biogas technologies that have been implemented in the area, identifying the determinants of both adoption and non-adoption. The impact assessment also looks into how the adoption of biogas technology in Domboshava has affected farmers' income levels. The study contributes to the Sustainable Development Goals (SDGs) by generating evidence on how biogas adoption enhances clean energy access (SDG 7). It also supports Agenda 2063 by promoting sustainable rural livelihoods, advancing renewable energy transitions and strengthening climate-resilient agricultural systems.

1.2 Problem Statement

Energy insecurity remains one of the most urgent global issues. Its effects on farmers are especially serious. Farmers are vulnerable to energy insecurity because they often do not have the resources or ability to adapt to changing situations (Chanza et al., 2018). The ability to adjust refers to a person's or system's capacity to adjust effectively when circumstances shift. Farm operations, including livestock rearing and irrigation schemes for crop production, require reliable and sustainable energy availability. Zimbabwe is currently experiencing the scourge of load-shedding, which is affecting farm operations and key activities in various agricultural value chains. Renewable energy sources, including biogas, have been noted to be key alternatives to ameliorate the energy challenges, with its adoption being promoted by the government (Kamusoko et al., 2022). The adoption of biogas holds considerable potential in Zimbabwe, a country striving to enhance rural livelihoods while addressing significant energy challenges. Nevertheless, despite the obvious advantages of biogas, its uptake in Zimbabwe, especially in the Domboshava region, is still comparatively low. Energy insecurity has increased due to global warming and smallholder farmers must now both adapt to and lessen the impact of climate

change on their farming operations (Onyutha, 2019). Hence, it becomes critical to identify a sustainable and renewable source of bioenergy that can tackle these multi-faceted challenges.

1.3 Justification of the Study

The study offers the Ministry of Energy and Power Development valuable insights into the variables influencing biogas adoption in rural Zimbabwe and the outcomes that follow. Accordingly, the Zimbabwe National Biogas Programme can benefit from and be informed by the study's conclusions regarding the socioeconomic factors influencing the adoption of technology (Surroop et al., 2019). The study contributes to global development agendas by demonstrating how biogas adoption can advance key Sustainable Development Goals (SDGs) and the African Union's Agenda 2063. The study supports SDG 7 (Affordable and Clean Energy) through promoting access to clean, renewable household energy, while also contributing to SDG 13 (Climate Action) by highlighting reductions in greenhouse gas emissions and deforestation. Additionally, improved energy access enhances agricultural productivity and household livelihoods, aligning with SDG 1 of No Poverty. In the context of Agenda 2063, the study advances aspirations for environmental sustainability and resilient rural livelihoods. Addressing the impact of biogas adoption in Zimbabwe requires a clear understanding of how social and economic factors affect the use of biogas technology. Blythe et al. (2018) stated that the renewable energy discourse is gaining traction across the world and in developing economies as a sustainable factor of production. The findings of this study are pivotal for guiding biogas technology program initiatives both within Zimbabwe and across the broader African region (Zareei, 2018). The study provides valuable lessons on success and challenges in the rural area of Domboshava, which can contribute insights into the African rural energy context. This provides policymakers and their various development partners with pathways for rural renewable energy development. Future biogas programs can be effectively designed based on insights gained from evaluating the impact of previously implemented initiatives (Di Giulio et al., 2018). This study provides feedback on the current status of biogas programs in Zimbabwe.

1.4 PhD Gaps/Originality of the study

1.4.1 General contribution of the study

Previous studies in rural Zimbabwe have predominantly focused on the production and technical aspects of biogas technology. There has not yet been an evaluation of the socioeconomic elements affecting the adoption of biogas and its ensuing effects (Roopnarian et al., 2020). This research addresses the gap resulting from the limited empirical evidence on the status of biogas adoption in Zimbabwe and its economic impact on livestock farmers. The findings could have policy implications that can shape future biogas development in rural farming areas. The study provides a framework for future biogas program adoption. This is done by discussing the recommendation, which were based on the real evidence from successful lessons, failures, and opportunities shown in the study.

1.4.2 National Renewable Energy Policy

The National Renewable Energy Policy of Zimbabwe places biogas as a pivotal alternative for providing energy sources to the rural communities of the country. According to the policy propositions, the country should have an estimated 8,000 domestic biogas digesters and 300 institutional biogas digesters (Chanza et al., 2020). These should sustainably contribute about 150 MW to the country's electricity needs. This study provides an outlook on the trajectory of the government's policy in meeting these set targets. Mukoro et al. (2022) noted that these results can offer input to enhance implementation strategies and encourage the use of renewable energy sources. Against this backdrop, the National Biogas Programme, which is a key part of the National Renewable Energy Policy, can be systematically evaluated.

1.4.3 National Development Strategy

The National Development Strategy for Zimbabwe seeks to achieve sustainable and equitable growth for its citizens. As noted by Tsvuura et al. (2021), the strategy envisions Zimbabwe attaining upper-middle-income status by 2030. Ensuring enough renewable energy is a key part of achieving both the National Development Strategy and Vision 2030 (Gill et al., 2019). In this context, biogas represents a critical energy source that is particularly relevant for smallholder rural farmers. The successful use of biogas can significantly help the country meet its renewable energy goals. Furthermore, achieving the goals of the National Development Strategy requires addressing the current knowledge gap about how the adoption of biogas affects livelihoods and

the overall economy (Nevzorova and Kutcherov, 2019). The study's conclusions can help direct the application of best practices and improve the strategy's ability to successfully meet its energy goals.

1.4.4 United Nations Framework Convention on Climate Change

Guidelines and legal frameworks for combating climate change and improving adaptation and mitigation measures are provided by the United Nations Framework Convention on Climate Change (UNFCCC). Fossil fuels and various traditional power sources have been recognized as significant factors in the negative impacts of climate change. Against this background, biogas is an efficient alternative to renewable energy and is readily available in the agricultural sector, which can provide sustainable energy sources (Thapa et al., 2021). Therefore, biogas not only helps reduce energy costs for rural smallholder farmers but also offers a viable means of mitigating climate change. The findings of this study show the main factors impacting the use of renewable energy sources in developing countries, including Zimbabwe. According to de Souza et al. (2020), these factors affecting biogas adoption can be addressed to meet the main goals of the UNFCCC. Hence, biogas is a useful alternative energy source that supports initiatives to lessen global emissions and combat climate change.

1.5 Research Objectives

1.5.1 Aim

The aim of this PhD thesis is to examine the production and utilisation of biogas in Domboshava, Zimbabwe, in order to understand its adoption and contribution to local livelihoods.

1.5.2 Main objective

The main objective of the study is to assess the determinants and livelihood impact of biogas adoption in Domboshava, Zimbabwe.

1.5.3 Specific objectives

The specific objectives of the study are:

1. To determine the extent of biogas technology uptake among livestock farmers in Domboshava.

2. To analyse the effect of socio-economic factors on biogas technology adoption among Domboshava livestock farmers.
3. To analyse the effect of socio-economic factors on the plans to adopt biogas technology among Domboshava livestock farmers.
4. To analyse the effect of biogas technology adoption on the livelihoods of livestock farmers in Domboshava, using a composite livelihood index.
5. To develop a context-specific framework for the improvement of biogas adoption among livestock farmers in Domboshava.

1.5.4 Research questions

1. What is the current level of adoption and utilization of biogas technology among households in Domboshava?
2. What are the effects of socio-economic factors on biogas technology adoption for livestock farmers in Domboshava?
3. What are the effects of socio-economic factors on the plans to adopt biogas technology for livestock farmers in Domboshava?
4. What is the effect of biogas adoption on the livelihoods of livestock farmers in Domboshava as measured by the composite livelihood index?
5. What context-specific framework can be adopted to improve biogas technology adoption for Domboshava livestock farmers?

1.5.5 Research Hypotheses

2. Socio-economic factors including income, education level, livestock ownership, gender, age, and access to extension services significantly influence the adoption of biogas technology among Domboshava livestock farmers.
3. Socio-economic factors including income, education level, livestock ownership, gender, age, and access to extension services significantly influence the plans to adopt biogas technology among Domboshava livestock farmers.
4. Adoption of biogas technology positively impacts livelihoods of livestock farmers in Domboshava, as reflected by the composite livelihood index.

1.6 Limitations and delimitations

Financial limitations influenced the study's scope, limiting its coverage. To address this, the research focused on a single ward characterized by a high uptake of biogas technology. The study was deliberately delimited to smallholder livestock farmers, both adopters and non-adopters of biogas, in order to identify the factors influencing adoption and participation in renewable energy initiatives. Farmers who do not engage in livestock production were excluded from the target population, as their activities are less directly related to biogas utilization.

1.7 Definitions

Adoption –Adoption encompasses a series of stages, including becoming informed about a specific technology, seeking relevant information, developing interest, evaluating the technology's attributes and ultimately deciding whether to accept or reject it (Rogers et al., 2003). Adoption, as used in this study, means that farmers are aware of biogas technology and actively use it as a substitute energy source.

Treatment group – This is the livestock farmers group that has embraced biogas technology. The terms "treatment group" and "non-treated group" can be utilized to distinguish adopters and non-adopters in both experimental and non-experimental research (Cole and Fernando, 2021). Hence, in this study, the terms "treatment group" and "adopters" can be utilized interchangeably for livestock farmers who adopted the biogas technology.

Livelihood –Livelihood refers to the assets, abilities and activities that help a farmer support themselves (Scoones, 2021). Its core pillars include social, human, physical, and natural capital, which collectively influence a farmer's income level. The livelihood index in this study operationalizes livelihood by taking into account a number of factors related to the household head and their family living in the same area.

Livestock farmer – A family unit that lives and resides in the same dwelling, sharing resources and is engaged in livestock production. Livestock farmers in this study include a farmer and his/her family unit who live together and participate in livestock production while living in Domboshava.

Biogas – The gas that is obtained in the process of anaerobic fermentation of raw materials, which are mostly agricultural products (Janas and Zawadzka, 2018). Biogas is the source of energy generated from biodigesters that various smallholder farmers produce from livestock and crop residues in the focus area.

Socio-economic factors –Socioeconomic factors encompass various dimensions, which may be economic or social in nature and reflect the demographic characteristics of a population (Makate et al., 2018). These elements have a significant impact on whether biogas technology is adopted or not. In this study, socioeconomic factors are treated as determinants that can be categorized into clusters of economic and social variables.

Impact – It involves affecting a change in the livelihoods of livestock farmers as measured by changes in their level of income. Impact is a multifaceted aspect that is inclusive of economic, social, political, environmental, and other key factors (Khan et al., 2020). These determinants of impact can have direct or indirect effects on a particular phenomenon. The impact of biogas technology adoption was assessed by comparing the livelihood index of adopters with those of non-adopters.

Smallholder farmer – Chadambuka and Helliker (2022) categorize farmers in the post-land reform era into estates, large-scale commercial farmers (A2), small-scale commercial farmers (A1), communal farmers and old resettled farmers. In this study, a smallholder farmer is defined as an individual cultivating less than 50 hectares of land. Smallholder farmers typically face challenges related to land tenure, limited representation, and poorly designed input support programs (Mutami, 2015). Accordingly, for the purposes of this study, “smallholder farmers” refers to communal farmers, old resettled farmers, or small-scale farmers engaged in livestock production.

1.8 Summary of the study

Table 1.1 Analytical framework for the study

Research Objectives	Research Questions	Hypotheses	Data Requirements	Data Analysis
1. To determine the extent of biogas technology uptake among livestock farmers in Domboshava.	What is the current level of adoption and utilization of biogas technology among households in Domboshava?		Gender, education, age, remittances, asset ownership, non-farm income, land size, livestock units, livestock farmer family size.	Descriptive Analysis
2. To analyse the effect of socio-economic factors on biogas technology adoption among Domboshava livestock farmers.	What are the effects of socio-economic factors on biogas adoption for livestock farmers in Domboshava?	Socio-economic factors including income, education level, livestock ownership, gender, age, and access to extension services significantly influence the adoption of biogas technology among Domboshava livestock farmers.	Energy costs, Gender, education, age, remittances, asset ownership, non-farm income, land size, livestock units, livestock farmer family size.	Binary Logistic Regression
3. To analyse the effect of socio-economic factors on the plans to adopt biogas technology among Domboshava livestock farmers.	What are the effects of socio-economic factors on the plans to adopt biogas technology for livestock farmers in Domboshava?	Socio-economic factors including income, education level, livestock ownership, gender, age, and access to extension services significantly influence the plans to adopt biogas technology among Domboshava livestock farmers.	Energy costs, Gender, education, age, remittances, asset ownership, non-farm income, land size, livestock units, livestock farmer family size.	Multinomial Logistic Regression
4. To analyse the effect of biogas technology adoption on the livelihoods of livestock farmers in Domboshava,	What is the effect of biogas adoption on the livelihoods of livestock farmers in Domboshava as measured by the	Adoption of biogas technology positively impacts livelihoods of livestock farmers in Domboshava, as reflected by the composite livelihood index.	Composite index, Energy costs, Gender, education, age, remittances, asset ownership, non-farm income, land size, livestock	Multiple Linear Regression

using a composite livelihood index.	composite livelihood index?		units, livestock farmer family size.	
5. To develop a context-specific framework for the improvement of biogas adoption among livestock farmers in Domboshava.	What context-specific framework can be adopted to improve biogas technology adoption for Domboshava livestock farmers?		Research findings and triangulated data from interviews.	Institutional Mapping and Stakeholder Analysis

1.9 Chapter Outline

This chapter gives an overview of the study's background, problem statement, objectives, questions, justification and limitations. Chapter 2 provides a literature review that highlights the theories supporting the research objectives, conceptual framework and empirical studies. Chapter 3 presents the research design and highlights the specific methods used. Chapters 4 through 8 present the study's results in relation to the research objectives. Finally, Chapter 9 concludes the study, offers recommendations and indicates areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter examines important literature related to the study of biogas adoption and its effects on livelihoods. It begins by outlining the theoretical framework of adoption. Then, it covers the conceptual framework that guides the research. The chapter then explores the history of biogas adoption globally, with specific focus on Africa and Zimbabwe. It further examines socio-economic factors influencing adoption decisions and introduces the sustainable livelihoods framework to assess biogas impacts. Finally, it provides research studies and methods used in similar work to create a basis for the study's approach.

2.2 Theoretical Framework of Adoption

Theories of adoption are diverse conceptual frameworks that try to explain how and why people or groups acquire novel concepts, behaviours, or innovations. The innovative idea in question in this study is biogas technology. In general, theories of adoption offer helpful frameworks for comprehending the intricate process of embracing novel concepts, behaviours, or technologies. These theories can assist people and organizations in creating strategies for encouraging adoption and obtaining positive results by understanding the variables that affect adoption. The following theories are discussed: Innovation Diffusion Theory, the Theory of Reasoned Action, the Unified Theory of Acceptance, and the Technology Acceptance Model Figure 3 shows the connections between the theories, highlighting the conditions for adopting biogas and its effects on people's livelihoods.

2.2.1 Diffusion of Innovation Theory

The diffusion of innovations theory was first presented by Everett Rogers in 1962 as a means of comprehending the ways in which novel concepts, actions, and technological developments proliferate in society. The theory describes the stages of adoption, types of adopters and factors that influence how quickly and widely new technology is adopted (Ahmad et al., 2023). According to Rogers (2003), the diffusion of technology has four key elements: the innovation-decision process, individual innovativeness, the adoption rate and the characteristics of the technology itself. Knowledge, persuasion, decision, implementation, and confirmation are the

steps in the innovation-decision process (Ortiz et al., 2017). This process helps farmers learn about the potential benefits of a technology and evaluate the opportunities provided by biogas technology. The theory also highlights that unequal access to information can act as a significant barrier to fully adopting a technology.

Furthermore, the farmer requires persuasion using various forms and strategies to adopt a particular technology. According to Singhasene and Lamsomboon (2022), the persuasion stage entails initiatives by governmental and non-governmental organizations aimed at motivating farmers to adopt a specific technology. These initiatives include robust extension services, the use of lead farmers who adopt the technology early, and monetary and non-monetary initiatives (Targetti et al., 2021). This stage is facilitated by media campaigns that enhance the farmer’s ability to adopt that particular technology (Jan et al., 2018). The benefits of biogas technology can be communicated to targeted farmers through various mass communication channels.

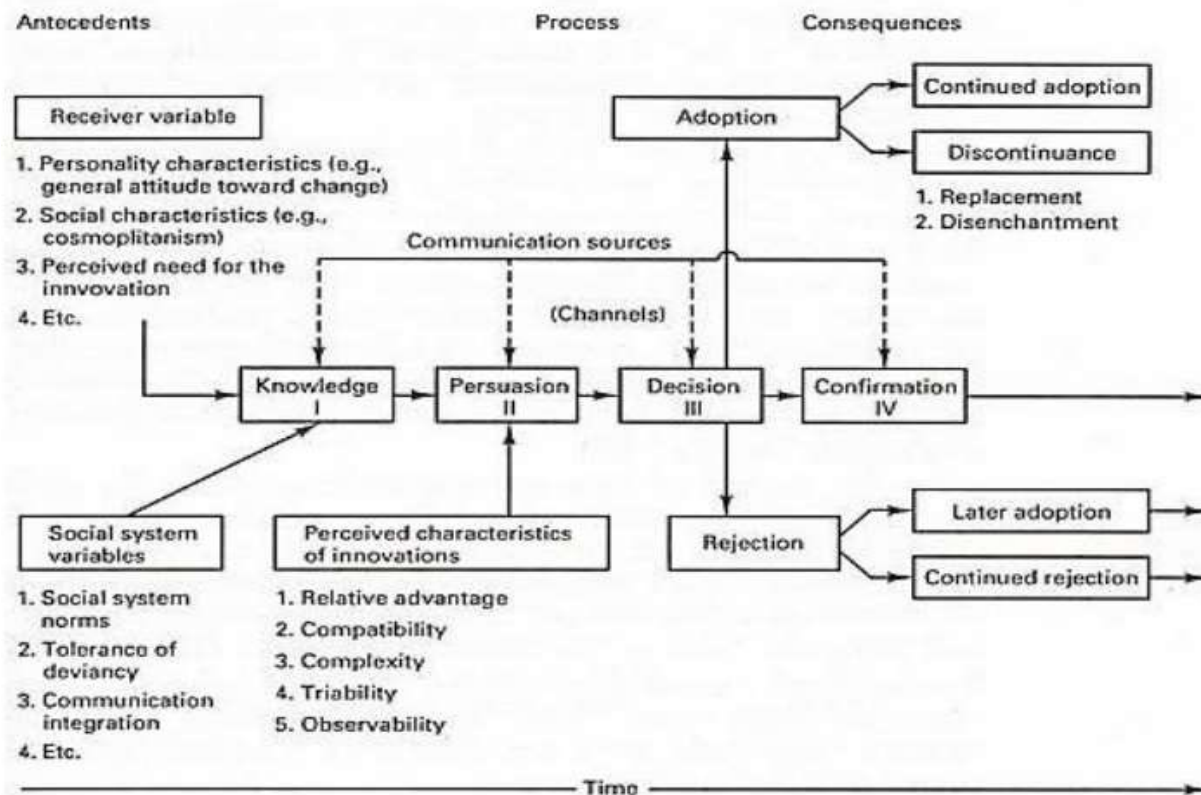


Figure 2.1. Technology Diffusion

(Source: Rogers, 2003)

From Figure 2.1 above, with the knowledge they gained during the knowledge stage, individuals start to build attitudes and views about the invention in this stage. The perceived relative advantage of the innovation over current alternatives, its compatibility with current practices, its complexity and degree of trialability and the chance to test the innovation are some factors that could affect the persuasion stage. The decision stage is a critical component of the diffusion of innovations theory. At this stage, farmers determine whether or not to adopt the innovation (Jabeen et al., 2020). Personal beliefs, societal standards, and the views of others can all have an impact on this choice. Hence, these critical factors should be assessed, and their effects on the farmer's decision should be highlighted. In this case, biogas adoption is greatly influenced by personal and societal views on the nature of its potential benefits (Wang et al., 2020). Implementation follows when people start incorporating the invention into their daily lives at this stage of adoption. Implementation usually involves building and installing biogas plants (Sari and Purnomo, 2022). They may experience difficulties utilizing the innovation and may require assistance to completely apply it.

The confirmation phase is the final stage in the diffusion of innovations theory. At this phase, farmers assess their decision to accept the innovation and decide whether to keep using it or stop. Hence, if the technology is confirmed and they go on utilizing the innovation, they can end up championing it and persuading others to do the same (Yasmin and Grundmann, 2019). The diffusion of innovations theory sorts adopters into specific groups according to their behavior in adopting new ideas. Adopters fall into five categories: innovators, early adopters, early majority, late majority, and laggards (Lund et al., 2020). Innovators are the first to use new technologies, while laggards are the last. The early and late majority constitute the largest proportion of adopters and their adoption decisions are influenced by the experiences and behaviors of innovators and early adopters. According to Kasilingam (2020), these groups of adopters are influenced by receiver variables, which describe the traits of people who could accept an invention.

Receiver variables consist of communication style, personality attributes, and demographic information. Variables related to the social system in which an invention is being implemented are also critical in shaping the decision to adopt a technology. These are the norms, values, communication routes, and power structures of a particular societal group (Wang et al., 2020).

The properties of the invention itself as seen by potential adopters, which are the perceived characteristics, are also fundamental. AI-Rahmi et al. (2021) state that perceived attributes consist of trialability, observability, complexity, compatibility and relative advantage. The diffusion of innovations theory provides a framework for organizations and governments to develop strategies that promote biogas adoption by enhancing their understanding of the different adopter groups and their motivations (Wahyudi, 2017). This can entail granting financial incentives, supplying training and educational programs, and promoting effective biogas plants in various regions.

However, the theory overemphasizes the traits of individual adopters and presupposes that adoption is primarily driven by individual attitudes and beliefs (De Vries et al., 2018). Conversely, many factors influence the adoption of biogas. These include government policies, financial incentives, and the availability of technology. All of these factors play an important role. According to Guttentag and Smith (2022), the theory assumes a linear adoption process with distinct stages and a clear progression from early adopters to laggards. The adoption process, however, might be a lot more intricate and unexpected, with several feedback loops and interactions between various adopters.

2.2.2 The Theory of Reasoned Action

The Theory of Reasoned Action (TRA) explains and predicts a person's behavior based on their attitudes and subjective norms. The theory was first put forth by Martin Fishbein and Icek Ajzen in the late 1970s, and it has since been extensively used in studies on consumer behaviour, organizational behaviour and technology adoption. According to Zeng et al. (2019), a person's attitude towards technology is influenced by both their opinions about it and their evaluation of the consequences of using it. People are more likely to accept and view new technology favourably, for example, if they believe it to be practical and easy to use (Cudjoe et al., 2018). Furthermore, people may grow hostile towards the technology and be less inclined to adopt it, though, if they believe it is difficult to use or comprehend. Subjective norms are a person's opinion of what other people expect from them in terms of whether or not they should use a new technology (Ajzen, 2020). These powerful people could be close friends, family, coworkers and subject-matter specialists.

According to Hou and Hou (2019), a person is more likely to feel positive subjective norms and be inspired to embrace a technology if they believe that influential people have favourable opinions about it. The Theory of Reasoned Action states that intention is the most reliable predictor of behaviour. Furthermore, if someone has a favourable attitude towards a technology and perceives supportive subjective norms, they are more likely to develop a strong intention and make plans to adopt it (Waheed et al., 2018). Many technologies, including waste management solutions, biogas technologies and climate-smart innovations, have been understood and their adoption predicted using this theory (Zersaa et al., 2021). When a new system is introduced with features that are seen as helpful and simple to use, a potential user is more likely to adopt a positive attitude and perceive supportive subjective norms towards biogas technology. A user's intention and planning to adopt are further strengthened by other factors, such as support from friends and family, a positive attitude towards the technology, and the expectation of adoption, which eventually results in actual adoption (Elahi et al., 2022).

The theory's focus on the person's beliefs and attitudes regarding the technology, which are significant indicators of their behaviour, is one of its advantages for adoption. The theory also acknowledges the crucial role of social influence in the adoption of technology, as influential people shape subjective norms (Adnan et al., 2017). The theory can aid in predicting a person's intentions and plans to adopt a behaviour, however, it cannot always predict whether or not that person will carry out the activity. According to Alam et al. (2019), this is because intentions are not always reliable indicators of behaviour, since conflicting aims or limits on the circumstance may have an impact. Furthermore, the theory presupposes that individuals make informed decisions by weighing the benefits and drawbacks of potential behaviours (Amuzu et al., 2018). However, people might not always act logically or rationally, and they can have biases.

When using the Theory of Reasoned Action to understand biogas adoption, attitude means how a person views biogas as a renewable energy source, whether they see it positively or negatively. According to Masukujjaman et al. (2021), if someone has a favourable attitude towards biogas, they are more likely to have a strong intention and plan to use it. Attitudes are influenced not only by personal principles and experiences but also by perceptions of the benefits associated with adopting biogas, including cost savings or environmental advantages (Tanveer et al., 2021). The subjective norm shows the social pressure to adopt biogas. This pressure includes the views

of close relatives, friends, and colleagues who may support or oppose its use (Li et al., 2023). People are more likely to form positive intentions and plans to use biogas if they see that society has supportive expectations. Zeng et al. (2022) point out that the Theory of Reasoned Action helps to explain the factors that affect the acceptance of biogas as a renewable energy source.

Governments, organizations and people can create strategies to improve acceptance and use of this sustainable energy source. They should consider how individuals feel about biogas, how they see societal pressure to adopt it and how they view their ability to take action. According to Dutta and Hwang (2021), a person's intention to adopt biogas can also be influenced by perceived behavioral control in addition to attitude and social norms. Furthermore, Higuera et al. (2019) noted that although the Theory of Reasoned Action presupposes that people make logical decisions based on their attitudes and beliefs, contextual and emotional factors can also have an impact on the adoption of biogas. These factors include fear of the unknown, social pressure and financial limitations. This limited view of decision-making, as described by the Theory of Reasoned Action, represents a significant drawback in its ability to fully capture the main factors driving biogas adoption (Mohammed et al., 2020).

2.2.3 Technology Acceptance Model

A prominent framework for describing the adoption of new technologies is the Technology Acceptance Model (TAM). According to TAM, which was initially developed by Fred Davis in 1986 and subsequently refined by other researchers, perceived utility and perceived ease of use have a significant impact on an individual's intention and plan to adopt technology (Granić et al., 2019; Silva et al., 2017). Perceived usefulness is the extent to which an individual believes that using a technology will enhance their performance and help them accomplish their goals (Ali et al., 2020). Perceived ease of use is the extent to which a person believes that utilising a technology will be simple. These two constructs affect how people feel about using technology and how likely they are to adopt it.

The Technology Acceptance Model states that a person's attitude towards using a technology is closely related to their intention and plan to use it (Wu and Song, 2021). Furthermore, people are more likely to embrace a technology and have a favourable attitude towards using it if they think it is beneficial and easy to use (Fatoki, 2015). The model also implies that adoption of technology may be impacted by outside variables such as support, training, and social influence.

If a person is surrounded by peers who use technology and think it's useful, their intention to adopt it may increase. According to Uhunamure et al. (2021), sufficient training and assistance can also improve the technology's perceived usability and adoption intention. The technology acceptance model has been widely used in both theoretical and practical contexts to understand how different technologies, including mobile applications and business software, are adopted. It has been demonstrated to be an effective predictor of adoption and usage behaviour in a variety of settings.

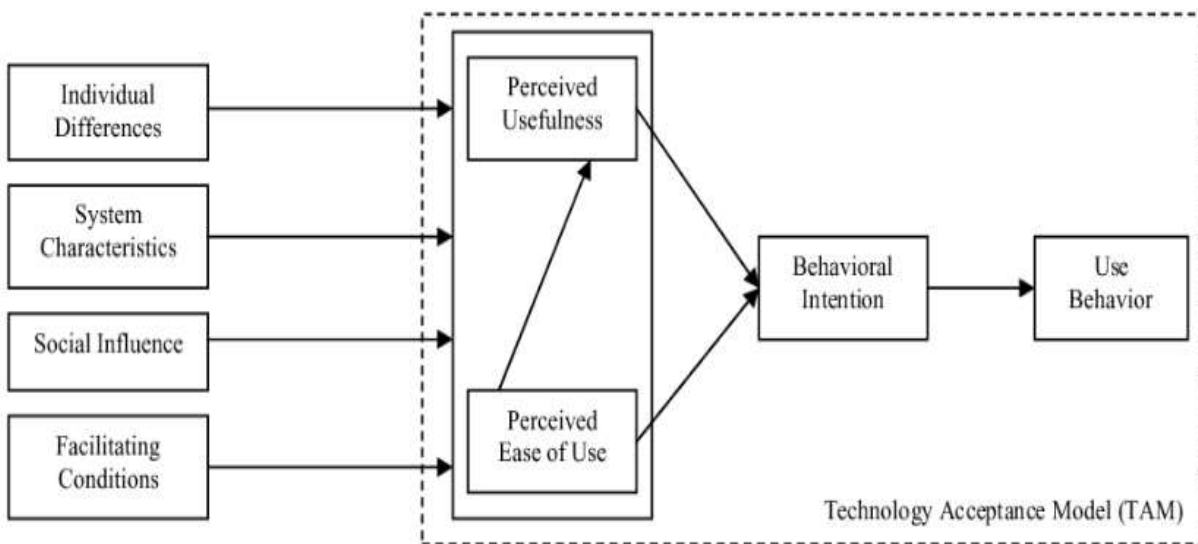


Figure 2.2. Technology Acceptance Model

(Source: Davis, 1985)

Figure 2.2 above highlights the Technology Acceptance Model that has been used to evaluate the success of attempts to integrate new technologies as well as forecast adoption and usage patterns. According to the paradigm, a technology may be more widely accepted and used if its perceived utility and usability are higher (Muvhiiwa et al., 2017). Hence, businesses can use the technology acceptance model to determine where technology needs to be made more useful and easy to use in order to boost adoption and usage. Meidiana et al. (2020) state that the Technology Acceptance Model offers a helpful framework for examining the psychological factors influencing the adoption of new technologies. Businesses can design strategies to boost the uptake and utilisation of their technology. They should assess perceived utility, usability, and other adoption-influencing elements.

The Technology Acceptance Model can also help us to view the use of biogas, a sustainable energy source made from the anaerobic digestion of organic waste. Biogas has several benefits, including reducing greenhouse gas emissions and providing a renewable energy source. However, Mendieta et al. (2021) claim that low awareness, a lack of information and inadequate infrastructure are some of the factors that frequently impede adoption. The degree to which people think that using biogas as an energy source will enhance their daily lives, lower energy costs and offer a sustainable substitute for traditional fossil fuels is known as perceived usefulness in the context of the Technology Acceptance Model (Williams et al., 2022). Individuals are more likely to view biogas as useful if they believe it can save money, reduce reliance on fossil fuels, and lessen their environmental impact (Obaideen et al., 2022).

The degree to which people think using biogas is easy and practical is known as perceived ease of use (Verma and Sinha, 2018). This can take into account things like the accessibility of biogas infrastructure, the simplicity of running biogas systems, and the accessibility of biogas fuels. People are more likely to think that biogas is simple to use if they believe that it is easy to get and utilize (Purwanto, 2018). The Technology Acceptance Model also shows that people's adoption of new technologies can be greatly impacted by outside variables like social influence, training and support. In the case of biogas, this may include elements like government incentives, industry association support, and accessibility to information and education regarding biogas (Pilloni et al., 2020). People may be more inclined to accept biogas, for instance, if they are aware of the environmental advantages of the fuel and if they receive enough training and assistance in operating biogas systems.

The perceived value of biogas may be increased and adoption may be encouraged if government policies offer incentives for its usage, including subsidies or tax credits (Hua and Wang, 2019). The technology acceptance model offers a helpful framework for comprehending the elements that affect biogas's acceptability as a renewable energy source. According to Apfel and Herbes (2021), governments, companies, and people may create plans to enhance acceptance and utilisation of this sustainable energy source by evaluating how helpful and simple biogas is considered to be, as well as the external variables that affect the adoption.

2.2.4 Unified Theory of Acceptance

According to Rezaei and Ghofranfarid (2018), the Unified Theory of Acceptance and Use of Technology (UTAUT) identifies four key elements that affect an individual's intention to adopt new technology: facilitating conditions, social influence, performance expectancy, and effort expectancy. The degree to which an individual thinks that utilising technology will improve their job performance or make tasks simpler is known as performance expectancy (Raza et al., 2021). Therefore, in terms of biogas adoption, prospective users might believe that using biogas enhances their quality of life, decreases reliance on fossil fuels, and offers a dependable energy source (He et al., 2020). An individual's belief that a technology will be easy to use and need little effort is measured by their effort expectancy. According to this research, prospective users might view biogas as complicated, necessitating technical know-how and major changes to daily schedules (Situmeang et al., 2022). Furthermore, if people believe a technology is hard to use or primarily complex to comprehend, they are less likely to adopt it.

According to Mustafa et al. (2023), the social influence factor measures how strongly a person believes that others in their social network, including friends or coworkers, believe that utilising new technology is a good idea. Potential biogas adopters may be impacted by their social network's opinions, which can be either favourable or unfavourable (Sarker et al., 2020). If people in their network are already using a technology and finding it enjoyable, they might be more inclined to do the same. Tamilmani et al. (2021) define facilitating conditions as the extent to which an individual believes they have the time, technical support, and training required to effectively use a new technology. If people believe there aren't enough resources available, they are less likely to adopt a technology. Potential users of biogas might think they lack the necessary funds, land, or other resources to put the technology into practice. The UTAUT model also suggests the following four moderating variables have an impact on the association between the aforementioned parameters and the desire to utilise new technology (Ronaghi and Forouharfar, 2020).

Another important issue is that of gender and the extent to which a person's gender influences how they perceive new technology in literature. For instance, studies have suggested that men may accept new technology more readily than women (Guta, 2018). The influence of a person's age on how they perceive new technology has also been reported. When compared to younger

people, older people are less inclined to accept new technology. According to Tsertsidis et al. (2019), the experience factor describes the extent to which a person's prior exposure to similar technologies influences how they perceive the new technology. According to Jayashankar et al. (2018), people are more likely to accept new technology if they have had positive experiences with it before. Lastly, the degree of control an individual has over whether or not to embrace the new technology is described by the voluntary factor. If people believe that using a technology is being forced upon them, they are less likely to adopt it.

When these criteria are applied to the adoption of biogas, more understanding can be acquired of the process of technology's value adoption in producing renewable energy and decreasing waste with a favourable impact on performance expectations. According to Budiman (2021), the intricacy of biogas technology and the requirement for specialist tools might reduce the effectiveness of an attempt. Social factors have a significant impact on the adoption of biogas because public officials, local authorities and other stakeholders may have different opinions about the technology (Silaen et al., 2020). Furthermore, favourable conditions may be necessary to allow for the widespread use of biogas technology. Among these are the accessibility of funding and technical assistance (Cantarero, 2020). The UTAUT model provides a helpful way to understand the factors that affect the adoption of biogas technology. It also aids in developing effective marketing campaigns. Stakeholders can endeavor to eliminate obstacles to adoption and improve the acceptance of biogas technology by addressing the elements that affect performance expectancy, effort expectancy, social influence and facilitating conditions (Karlsson et al., 2019).

This study is anchored on the diffusion innovation theory and the UTAUT model, as they provide the most comprehensive framework for analysing the socio-economic, perceptual and contextual factors that influence biogas adoption among smallholder farmers in Domboshava.

2.3 Conceptual Framework

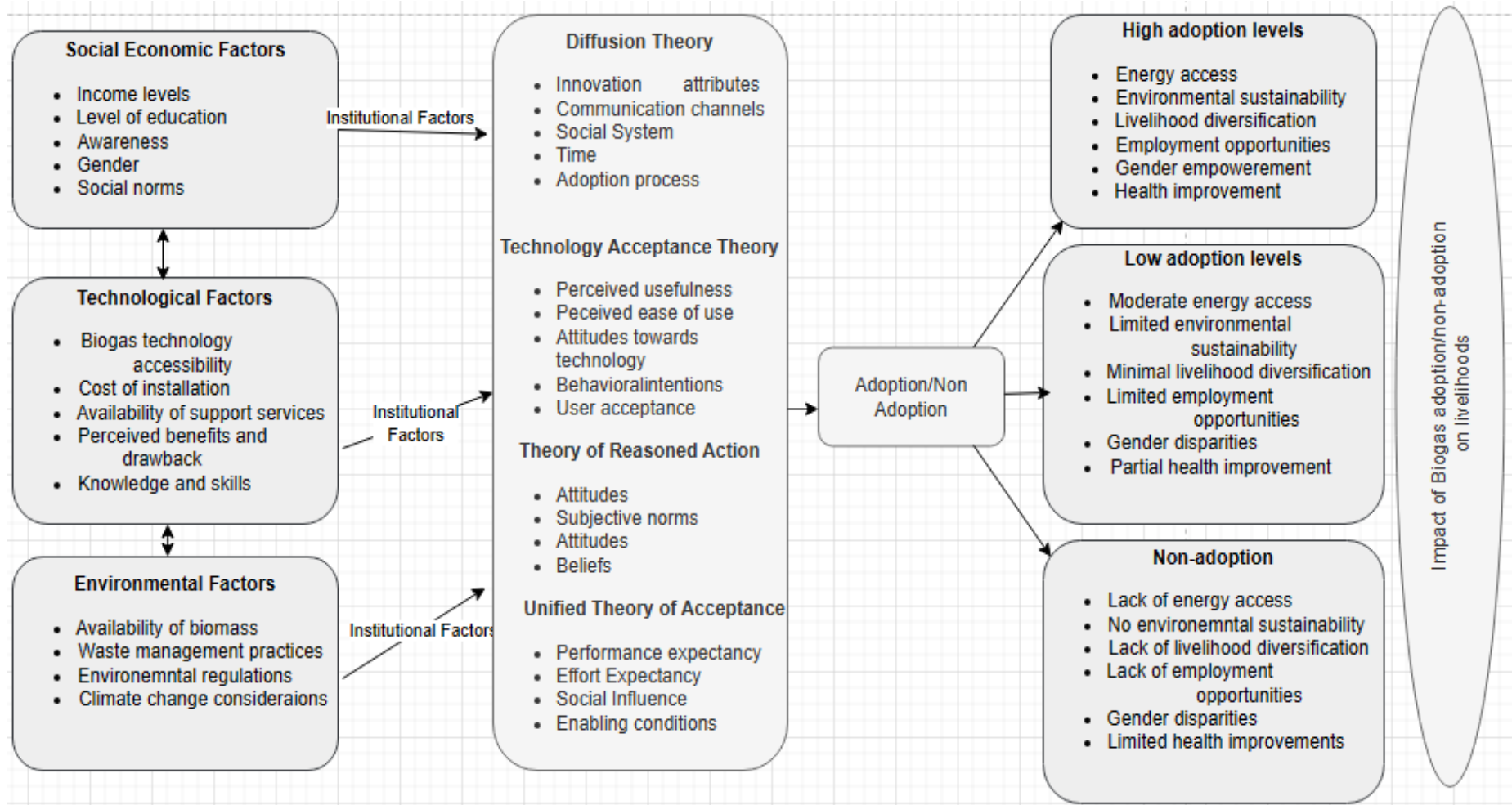


Figure 2.3. Determinants of biogas adoption and its impact on livelihood

Source: Author (2023)

2.3.1 Summary of the conceptual framework

The conceptual framework Figure 2.3 categorizes the factors that affect the adoption of biogas technology into three groups, i.e., technological, socio-economic and environmental factors. It also shows three levels of adoption, i.e., high, low, and non-adoption. According to Wall et al. (2021), high adoption refers to those who have fully embraced biogas adoption and are benefiting from its enormous economic advantages, including increased access to energy, environmental sustainability, social and health improvements, diversification of sources of income, employment opportunities, and female empowerment. Low adoption is the term for partial adoption that has minimal effects and modest benefits (Kelebe, 2018). Non-adoption denotes the absence of adoption with no effect on the means of subsistence. According to Karlsson et al. (2019), policies, rules, governance setups, and support systems are institutional factors critical to biogas technology adoption. They help to shape the adoption process by offering frameworks, assistance, and direction. Institutional factors also affect socioeconomic, technological, and environmental aspects, with implications on adoption and its results (Mengistu et al., 2016).

The adoption of biogas technology affects livelihoods. The impact encompasses financial gains, reliable access to and maintenance of the environment, social and health advancements, diversification of livelihoods, job opportunities, and gender dynamics and empowerment. Based on the adoption levels, the degree of influence varies, with high adoption having the most positive effect while low adoption has little to no effect on people's livelihoods.

The diffusion theory explains how innovations, such as biogas technology, are adopted and dispersed within a social system. According to Rhein and Rhein (2021), it emphasizes the traits of innovation, channels of communication, social system dynamics, and stages of adoption. The diffusion theory contributes to the conceptual framework by explaining the elements impacting the uptake of biogas, including innovative attributes, communication routes, and the adoption process (Shang et al., 2021). It offers insights into how biogas technology is communicated, how potential users view it, and how they progress through the stages of adoption (Torman and Aschemann, 2023). The Technology Acceptance Model (TAM) assesses how people's attitudes and views about technology affect their adoption behaviour as well as their intention to use it.

According to the framework, the Technology Acceptance Model (TAM) explains the factors that affect a person's decision to adopt biogas technology. People's choice to use biogas technology relates to TAM's main ideas of perceived usefulness and perceived ease of use (Ho and Wu, 2021). Behavioral intentions and attitudes toward the technology affect adoption choices, which then impact the actual levels of adoption. According to Obuobi et al. (2022), TAM offers a lens through which to view how people's intentions, attitudes and perceptions influence their adoption behaviour. The adoption process and the elements affecting biogas acceptance at the societal and individual levels are well understood by including both diffusion theory and TAM in the conceptual framework (Shang et al., 2021). The diffusion theory aids in examining the broader societal context and the expansion of biogas use, whereas TAM concentrates on individual opinions and attitudes towards the technology (David et al., 2022). These theories offer detailed understanding of the factors influencing biogas uptake, how it spreads across a social system, and how people accept and adapt to new technologies.

2.4.1 History of biogas adoption

Biogas gained traction a substitute source of energy in Europe in the early 20th century. According to Xue et al. (2020), programmes for research and development were started to improve biogas systems and encourage their adoption in countries including Germany. Biogas was mostly used in small-scale systems during this time and its main uses were for heating and power generation. Hence, in the 1950s and 1960s, there was limited use of biogas for mostly lower-energy appliances (Obileke et al., 2021). However, the oil crisis sparked a rise in interest in alternative energy sources in the 1970s and 1980s, and biogas received more attention in Europe. To increase the effectiveness and scalability of biogas systems, governments and research institutions in several European nations made investments in biogas research and development (Bond and Templeton, 2011). The uptake of biogas technology was facilitated through the provision of subsidies, grants and other financial incentives, particularly targeting rural regions in the United States of America and Europe.

In addition to the USA and Europe, other regions, especially Asia, have shown a growing interest in and dedication to biogas as an alternative energy source (Mukeshimana et al., 2021). The National Biogas Programme, which was started by the Chinese government in the 1980s, is a noteworthy example. It helped to improve the widespread deployment of biogas technology in

rural areas and greatly improved farmers' access to energy while fostering environmental sustainability (Lu & Gao, 2021). This initiative was instrumental in accelerating biogas adoption within Asia, as it encouraged neighbouring countries to pursue similar technological pathways. International organisations that supported the spread of biogas in developing nations during this time included the United Nations Development Programme (UNDP) and the Food and Agriculture Organization (FAO) (Weigel & Demissie, 2021). To lessen reliance on fossil fuels, India also launched the National Biogas and Manure Management Programme in 1981 (Mittal et al., 2018). Concurrently, Europe advanced towards a more market-oriented biogas system, refining its technological capabilities and expanding the scope of renewable energy utilisation.

The 1990s continued to experience enhanced biogas adoption, with Europe being instrumental in embracing the environmentally sustainable energy source. For instance, Germany expanded its Renewable Energy Sources Act of 1991, which significantly increased the number of biogas plants in the country (Thrän et al., 2020). The European Union created biogas friendly legislation by creating a stable market for biogas and incentivizing further investment in the technology. The USA made significant strides in the adoption of biogas in the 1990s, although it was lagging behind Europe in its implementation (Khairunnessa et al., 2021). The Renewable Energy Production Incentive Programme was pivotal in incentivizing the private sector and farmers to embrace renewable energy sources, including biogas. According to Bibi et al. (2021), these initiatives provided for more specific programmes that increased biogas adoption in the USA, including the Biomass Energy Programme. In Asia, China and India were the leading adopters of biogas, with China expanding its national biogas programme and India strengthening its manure management initiatives.

Biogas adoption increased significantly in the 2000s. This growth was motivated by a stronger emphasis on lowering greenhouse gas emissions linked to fossil fuel use (Sharma et al., 2021). The European Union actively intervened in the energy markets by providing tax credits and feed-in tariffs for biogas energy producers. The Emissions Trading Scheme ensured carbon credit markets for both private and public players to be an incentive to reduce their carbon footprint (Efthymiou and Papatheodorou, 2019). Furthermore, the critical aspects of climate change mitigation necessitated the European Union having an ambitious target for biogas adoption in

this period. According to Kooji et al. (2018), EU members, including Germany, Denmark, and Sweden, became instrumental in the adoption of renewable energy sources and started exporting vital technology and expertise. The European Union's Renewable Energy Directive (RED) required member states to raise the share of renewable energy in their energy portfolios (Chiaramonti and Goumas, 2019). The European Investment Bank supported this goal by providing more funding for biogas projects.

The USA enacted the Renewable Fuel Standard in 2005, which was critical to increasing renewable energy adoption, including biogas. The directive required that a specified proportion of transportation fuels be sourced from renewable energy (Lade et al., 2018). Hence, the USA aligned its renewable energy policies with those of the EU in addressing greenhouse gases and climate change concerns. According to Zeren and Akkuş (2020), Asian countries experienced a rise in renewable energy demand during this period, coinciding with substantial economic growth. China's Renewable Energy Law created a framework and guidelines to encourage the increased use of alternative energy sources, including biogas. Other Asian countries, including India and Thailand, provided subsidies for biogas adoption to incentivize communities to embrace biogas (Monika et al., 2020). The 2000s period also initiated a growing interest on the African continent in utilising renewable energy sources, including biogas, to address climate change impacts. In Africa, the emphasis has primarily been on implementing existing technologies from other countries, rather than conducting original research.

2.4.2 Biogas adoption in Africa

Due to the implementation of policies and incentives by various nations aimed at promoting its use, the adoption of biogas technology in Africa has steadily increased over the past several decades. Nevertheless, compared to other regions, adoption rates remain relatively low and significant barriers to scaling up biogas technology persist across the continent (Tagne et al., 2021). The historical evolution of biogas adoption in Africa is highlighted in this section, along with important obstacles and legislative measures. The adoption of biogas technology on the continent started in the 1950s when it was introduced to Kenya, Tanzania and Uganda. Biogas had mostly been used for urban sewage treatment until the 1970s, when it began to be used more frequently for domestic cooking and lighting in rural areas (Kemausuor et al., 2018). The global oil crisis and the increasing demand for alternative energy sources in the 1970s played a key role

in the adoption of biogas. In the 1980s, numerous non-governmental organizations (NGOs) began advocating for biogas technology in Africa, particularly in East and Southern Africa (Dahunsi et al., 2020). These NGOs provided farmers with technical assistance and training while supporting the development of regional biogas construction industries.

In order to encourage the use of biogas technology, a number of African nations passed laws and offered incentives in the 1990s. According to Roopnarian and Adeleke (2017), the Tanzanian government started the National Biogas Programme in 1992 to promote the use of biogas for cooking and lighting in rural areas (Sehgal, 2018). The program offered technical training, financial assistance for the construction of biogas plants and support for the manufacturing of home biogas equipment. During the same decade, other countries including Kenya, Ethiopia, and Uganda, also introduced policies and incentives aimed at fostering biogas adoption (Clemens et al., 2018). The high upfront costs of biogas plants and farmers' lack of technical expertise were the main reasons why adoption rates remained low in spite of these efforts.

Following the introduction of new policies and incentives by several African countries in the 2000s, the adoption of biogas technology began to accelerate. For instance, the Rwandan government launched its National Biogas Programme in 2004, aiming to provide one million farming households with access to biogas technology by 2012 (Dhliwayo et al., 2020). The programme offered financial support for biogas plant construction, technical training and assistance with domestic biogas equipment production. Aliyu et al. (2018) highlighted that during the same period, other countries including South Africa, Nigeria and Ghana, also implemented policies and incentives to encourage biogas adoption. However, adoption rates are still low when compared to other regions, and there are still significant obstacles to overcome before biogas technology can be scaled up throughout the continent (Emetere et al., 2021). South Africa experienced the ambitious Biofuels Regulatory Framework, which was introduced to promote renewable energy sources including biogas, though its impact has not been widely seen in rural communities.

According to Wassie and Adaramola (2019), the main factors influencing the adoption of biogas in Africa are the growing need for alternative energy sources, the technology's potential to generate revenue, and its positive environmental effects. For cooking and lighting, biogas offers a sustainable fuel substitute that lowers greenhouse gas emissions, increases soil fertility, and

slows down deforestation (Bekchanov et al., 2019). However, a number of factors, such as the high upfront costs of biogas plants, farmers' lack of technical expertise, and inadequate government support, continue to limit adoption. Further impeding the widespread adoption of biogas technology are the relative affordability of fossil fuels and a lack of knowledge about its benefits.

2.4.3 Biogas Adoption in Zimbabwe

Zimbabwe has been experiencing an energy deficit for the last estimated 20 years. Due to their energy needs, different sectors of the nation have been impacted by the energy deficit. The economic effects of this challenge have impacted the country's growth (Uamusse et al., 2019). In the year 2022, the country generated an average of 1100 MW of electricity against a demand of 2200 MW (Zimbabwe). Kariba hydroelectricity power constituted about 60% of the power generated, with Hwange thermal electricity power constituting the remaining 40% (Ruwa et al., 2018). The shortfall in electricity generation was met with limited imports from ESKOM South Africa, ZESCO Zambia, and EDM Mozambique. Additionally, firewood is the primary energy source for about 66.8% of Zimbabwe's population, who do not have access to electricity (Wenga et al., 2023). Therefore, Zimbabwe has multiple energy challenges, including limited generation, access issues, and a non-diversified energy mix. Against this background, the government has started the National Renewable Energy Policy to support alternative and renewable energy sources, including biogas.

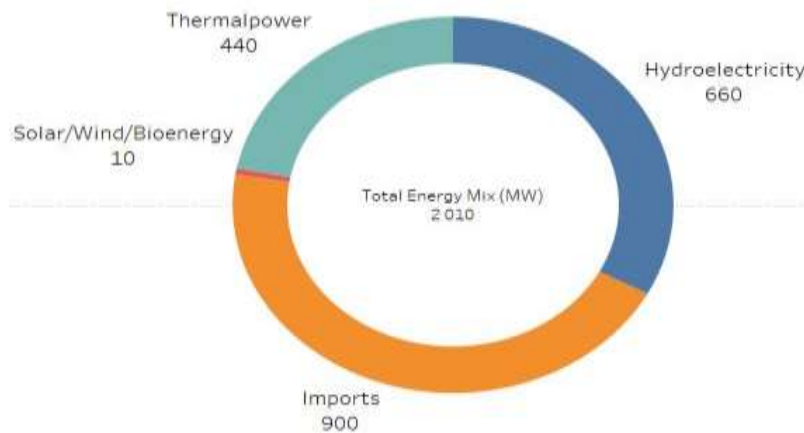


Figure 2.4. Zimbabwe Energy Mix

(Source: Zimbabwe Power Company, 2022)

Figure 2.4 above highlights the energy mix for Zimbabwe and how it is highly skewed towards hydroelectricity, thermal power, and imports. According to Nhubu et al. (2020), alternative renewable energy sources, including biogas, are contributing minimally to the Zimbabwe's energy requirements. Kaifa and Parawira survey data from Zimbabwe highlight that, by 2017 the country had about 711 biogas plants including roughly 650 household digesters, 48 institutional units and 13 municipal plants highlighting that while biogas has taken root nationally, its diffusion remains limited in scope. This has necessitated the government to initiate policy interventions, including the National Renewable Energy Policy (Maramura, 2020). Biogas adoption has been steadily increasing in Zimbabwe, particularly for smallholder farmers who have access to the inputs used in the generation of the energy source. Hence, in addition to using the digested substrate as fertilizer, biogas technology offers a great way to use such organic waste for energy production. The Ministry of Energy and Power Development has introduced several initiatives to encourage the adoption of biogas technology using crop residues and animal waste, including subsidised biogas digesters, technical support and training for rural households and partnerships with NGOs to provide low-interest financing options for installation.

Marambanyika et al. (2020) highlighted that other private players, including SNV and HIVOS, play an active role in promoting the acceptance and use of biogas technology. In Zimbabwe, the main types of bio-digester designs are the Carmatec fixed dome, the Chinese fixed dome, and the floating drum. More than 700 of these have been built to date (Roy et al., 2018). It's crucial to note that while some biogas plants are run by municipalities, the majority are owned by individual farmers. It is also critical to note that, according to the Rural Electrification Agency of Zimbabwe, approximately 90% of the biodigesters in Zimbabwe use cow dung for their digesters, with the remaining depending on sewage, plant residue, and pig manure (Mutate et al., 2023).

2.5 Socio-economic factors influencing biogas adoption

Insights can be drawn from previous studies examining farmers' reluctance to adopt agricultural technologies and the complex determinants influencing the uptake of climate-smart innovations. Researchers have investigated a range of factors, including human capital, risk-taking behaviour and access to technology, which encompass both endogenous variables (financial capital) and exogenous variables (institutional frameworks, geographical conditions, soil quality, rainfall

patterns, farming systems and market infrastructure) (Bharagwaj et al., 2022). These elements fall into four primary categories: socio-demographic traits, institutional factors, farmers' technological perceptions, and socioeconomic circumstances. Risk-related factors include both tangible and intangible elements, including uncertainty and individual risk-taking tendencies (Majchrzak et al., 2022). Variations in individuals' tolerance for uncertainty are often reflected in their adoption of new technologies (Talevi et al., 2022), influencing their utility or value functions and potentially leading to investment decisions that may otherwise appear suboptimal.

2.5.1 Demographic Characteristics

Farmers' decisions regarding the adoption of biogas technology may be substantially influenced by their age. Age-related differences in attitudes, beliefs, and levels of openness to innovation may influence how different age groups decide to use biogas. Understanding the effects of age is essential for creating focused initiatives to encourage the adoption of biogas among farmers in various age groups (Broska, 2021). Firstly, compared to younger generations, older farmers may be more reluctant to change because they frequently have established agricultural practices. According to Rasapoor et al. (2020), it may be more difficult to persuade them to use biogas technology since they may be more attached to conventional techniques and tools. The comfort and familiarity with current practices may serve as a deterrent to adoption. In farming, age and experience frequently match (Peltonen et al., 2020). Older farmers may have years of expertise in their particular agricultural practices.

While this experience can be beneficial, it might also alter how they view the dangers of implementing novel technologies like biogas. There may be operational and financial difficulties; older farmers may be more risk-averse and reluctant to make investments in new technologies (II Islam., 2021). Younger farmers are typically more innovative and willing to accept new technologies that provide advantages like higher productivity, lower costs, or better environmental performance. According to Sobczak et al. (2022), they might be more ready to spend money on biogas systems because they regard them as long-term investments that support their objectives of sustainable and productive farming methods. Younger farmers might also be more open to learning about new technology through workshops, training programmes, and digital platforms (Knierim et al., 2019).

The distribution of labour in agricultural operations is frequently influenced by gender roles and duties within farming communities. Crossland et al. (2021) found that, in many situations, women handle domestic duties and resource management in the home, while men tend to focus more on farming-related activities. The adoption of biogas necessitates the active engagement of both men and women in the home (Tembo et al., 2022). Gender norms and expectations can affect women's access to information, training and participation in decision-making about biogas technology. According to Anditi (2022), the division of labour and the ability to make decisions regarding the use of biogas might be influenced by gender-specific roles and responsibilities. The uptake of biogas technology can be strongly impacted by gender discrepancies in access to resources, including land, money, and information. Women's decisions about the installation and operation of biogas systems may be hampered by their limited access to land ownership and governance.

Similarly, women's ability to invest in biogas technology may be hampered by unequal access to financial resources and finance. Fostering equitable biogas adoption requires addressing these gender disparities in resource access (Gangi et al., 2023). Male family members often wield the majority of the decision-making authority in many farming family units. When it comes to technological adoption and investments in agriculture, men frequently have the last word (Theis et al., 2018). Women may not be as involved in decision-making processes pertaining to the adoption of biogas if they can contribute to the technology's success and longevity. Bullough et al. (2022) stated that, gender roles and expectations within communities are influenced by social norms and cultural elements. Perceptions of gender roles in energy and agricultural activities can shape individuals' opinions and decisions regarding the use of biogas (Bonokwane and Ololade, 2022). Stereotypes and cultural biases may limit women's involvement in technology adoption and decision-making.

According to Ngcobo et al. (2022), farmers' decision-making processes regarding biogas technology usage heavily depend on education and awareness. Farmers' knowledge, comprehension, and perceptions of biogas can be considerably influenced by education, access to information, and awareness campaigns, which in turn can affect their adoption decisions (Rahman et al., 2022). People can gain the knowledge and comprehension they need about biogas technology, its advantages, and how it operates through education. Farmers who have

more education are more likely to understand the technical details, commercial viability, and environmental advantages of biogas (Li et al., 2022). They might also have the skills needed to assess how biogas systems could work in their specific farming practices (Awasthi et al., 2019). Farmer decision-making on the use of biogas can be facilitated by education, which can close the information gap.

Farmers' knowledge and awareness influence biogas adoption by impacting the access to and availability of educational resources, extension services, and training programs. The dissemination of information on biogas technology, its installation, operation, and maintenance can be significantly aided by easily accessible and focused informational resources, including brochures, manuals, films, and websites (Marie et al., 2021). Important deciding criteria for farmers when deciding whether to use biogas technology include farm size. The size and nature of the farm can have an impact on the amount of waste produced, its economic viability, and the general applicability of biogas systems. Farm size affects whether using biogas is economically feasible (Lauer et al., 2018). Organic waste, including animal manure, crop residues and agricultural byproducts, is sometimes found in greater quantities on larger farms. For biogas systems to operate well, there must be an adequate supply of feedstock. Due to economies of scale, larger farms are more likely to generate surplus organic waste, thereby enhancing the profitability of biogas production (Winqvist et al., 2019). Producing a significant amount of biogas can guarantee a positive return on investment and help defray the initial investment costs.

According to Khan (2016), a farm's financial capacity influences the decision to adopt biogas technology. Investment costs for biogas systems can be high and include the cost of building digesters, storing gas, and purchasing power generation machinery. Greater financial resources may be available to larger farms, allowing them to cover the initial costs of installation and operation. According to Alexander (2019), larger farms may find it financially feasible to embrace biogas due to the possibility of long-term economic benefits like decreased energy prices, money from selling surplus electricity or heat, and cost savings on waste management. The initial investment expenditures for biogas technology are high and include building digesters, gas storage systems, and power generation machinery (Akbulut et al., 2021). These costs can change depending on the size and complexity of the biogas system. To cover these

upfront costs, farmers need access to financial resources. Farmers with limited funds may have difficulty covering the initial investment, which creates a barrier to adopting biogas.

Biogas systems need ongoing operational and maintenance costs in addition to the initial expenditure. This covers the cost of acquiring organic waste as a feedstock, the routine upkeep of the digester, gas storage systems, and machinery used in power generation, as well as the cost of observing and enhancing the biogas production process. These ongoing expenses must be covered to keep the biogas system running well. This requires access to financial resources.

2.5.2 Institutional Factors

According to Feiz et al. (2022), when making decisions about implementing biogas technology, farmers are significantly influenced by institutional considerations. The adoption and spread of biogas systems can be incentivized or hindered by institutions like government laws, rules, market structures, and support networks (Böbner et al., 2019). To create an atmosphere that encourages the use of biogas, it is essential to comprehend the impact of institutional elements. Government rules and policies significantly impact the use of biogas (Kapoor et al., 2020). Farmers may be encouraged to use the technology if supportive legislative frameworks are in place that prioritizes the use of biogas, which should be integrated into the master plans. According to Ndiritu and Engola (2020), these regulations might include tax breaks, financial incentives, feed-in tariffs and supportive regulatory frameworks that streamline the licensing and permitting procedures for biogas projects and feed-in tariffs. For farms considering adopting biogas, clear and consistent policies offer assurance and lower barriers.

According to Hyman and Bailis (2018), the adoption of biogas is greatly aided by institutional assistance provided by government organisations, research institutes, and extension services. These organisations can offer farmers technical support, educational opportunities, and capacity-building projects. These organisations run efforts to raise awareness, share knowledge, and disseminate information to assist farmers in understanding the benefits, operational features and maintenance requirements of biogas systems (Ali et al., 2022). Farmers' confidence in implementing biogas technology is increased by having access to such institutional backing. The adoption of new technologies and innovations connected to biogas is also influenced by institutional considerations. Mateescu and Dima (2022), stated that the creation and dissemination of suitable biogas technologies depend heavily on research organisations,

academic institutions, and technology suppliers. By working together, these organisations and farmers can share information, skills, and technological improvements more easily, ensuring that farmers have access to the newest and most effective biogas systems (Donner et al., 2020).

Institutional variables have an impact on how the market develops for biogas-based goods, including organic fertilizers, power, and heat. According to Jacobs (2016), supportive policies and institutional frameworks can create favorable market conditions. They do this by ensuring access to grid connections, setting up feed-in tariffs or power purchase agreements, and encouraging the use of biogas byproducts. Farmers have options to generate cash thanks to efficient markets and off-take agreements, which make the implementation of biogas feasible from an economic standpoint (Ederer et al., 2023). Institutional considerations affect the coordination and cooperation of the different parties involved in the adoption of biogas. A cooperative ecosystem for the adoption of biogas can be developed by government agencies, NGOs, research institutes, industry groups, and farmers' cooperatives (Budiman, 2021). Coordination across institutions promotes efficient planning, resource allocation, and programme implementation for biogas technology, allowing for effective support and assistance for farmers.

Institutional factors affect how much people are aware of and accept biogas technology. Public knowledge and comprehension of the advantages and possibilities of biogas systems can be improved by institutional assistance, information campaigns, and educational programmes (Takman and Andersson, 2021). Institutions can help communities accept biogas technology by addressing social and cultural hurdles, dispelling myths, and fostering societal acceptability.

2.6 Livelihood Framework

The term livelihood describes the tools and resources people utilise to maintain themselves, their families, and their way of life. It includes all of the skills, resources, money, and activities needed for people or households to meet their fundamental needs and enhance their general well-being (Nikolakis and Grafton, 2015). A livelihood is critical to a community's social and economic fabric. It connects closely to concepts of sustainability, development, and poverty. According to Chambers and Conway (1992), a livelihood is made up of the skills, resources (material and social), and pursuits required to ensure a standard of living. Researchers can determine forms of livelihood through three approaches: prospective, retrospective and circumspetive (Murray, 2002). Thus, a person's livelihood includes all the resources, activities

and strategies they use to support themselves and their families. It is a complex idea that is necessary to comprehend both reducing poverty and promoting economic well-being.

The Sustainable Livelihood Approach (SLA) provides a broad framework for understanding livelihoods. In development research and practice, the SLA helps to understand and improve the well-being of individuals, especially those in marginalized and rural communities (Cafer et al., 2022). The SLA, which was developed by the UK Department for International Development (DFID) in the late 1990s, focusses on the skills, assets, and methods people employ to maintain their livelihoods in a way that is socially just, economically feasible, and environmentally sustainable. It is a comprehensive, people-centered strategy that looks at livelihoods from many angles and strengthens them in an effort to combat poverty and vulnerability. The Sustainable Livelihood Approach Framework below indicates the intricate relationship between the environment, assets, strategies, and outcomes.

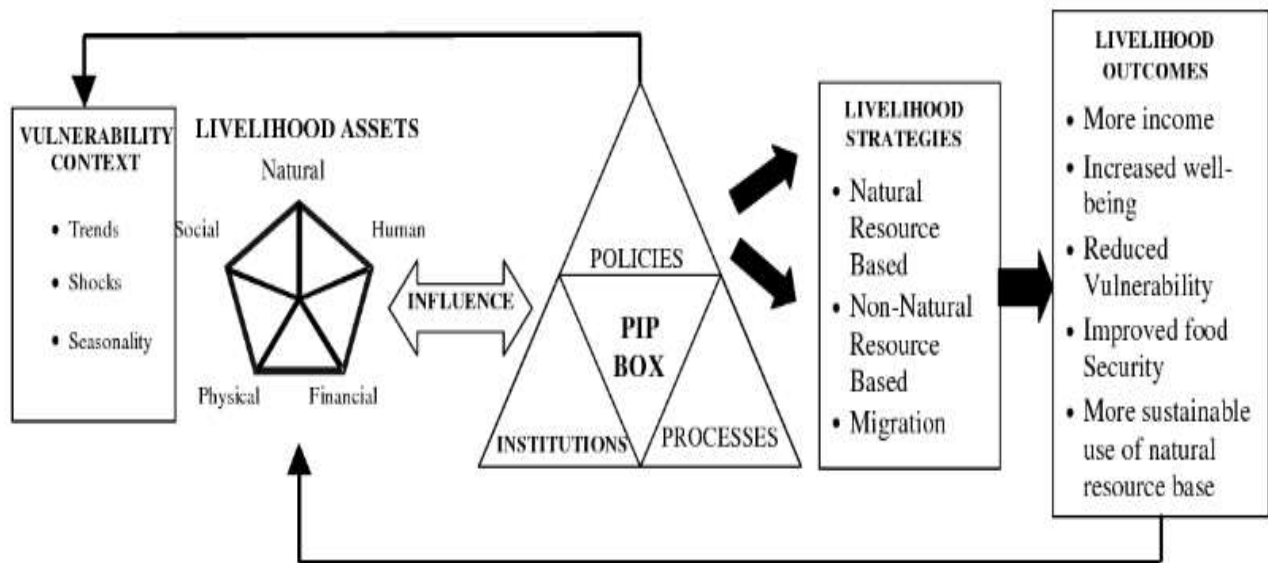


Figure 2.5. Sustainable Livelihood Approach Framework

(Source: Chambers and Conway, 1992)

From Figure 2.5 above, the main goal of interventions at the first stage is to identify and prioritize the most marginalized and vulnerable groups in a community or region. Understanding the risks and vulnerabilities that affect people's livelihoods is emphasized by the vulnerability context. These hazards may be political, social, environmental, or economic (Pandey et al., 2017)

Assets include natural, physical, human, financial, and social resources that form the basis of any livelihood. Institutions encompass both official and unofficial guidelines, policies, and rules that impact individuals' access to and utilisation of resources. Examples include laws and regulations, social mores, and the availability of financing and education (Quandt, 2018). The livelihood strategies are formulated to deal with and adjust to risks and changes in their line of work. These tactics can include migration, savings and insurance plans, diversification, or a combination of these, among others.

The term livelihood outcomes describes the effects or consequences of several strategies and treatments meant to enhance the sustainability and general well-being of people and communities (Yang et al., 2018). These results are crucial for evaluating the efficacy of development programmes and figuring out whether they help people live better lives generally, reduce poverty, and become more resilient. The livelihood assets in the framework are essential for assessing the impact of biogas adoption for livestock farmers in Domboshava.

2.7 Review of Analysis Methods

The aim of the empirical studies reviewed in this research is to offer evidence-based insights into the factors that influence biogas adoption and its impact on livelihoods in Zimbabwe. Hence, by combining quantitative and qualitative methods, these studies provide a clear understanding of what drives adoption decisions and the various effects of biogas technology on the livelihoods of rural communities. The findings from these studies aim to guide future research on renewable energy use and sustainable development in Zimbabwe. This includes helping shape policies and designing targeted programs.

Moli et al. (2021) conducted a study in rural Bangladesh to see if using biogas improves the livelihoods and incomes of specific households. The study used Propensity Score Matching (PSM) and the Logit Regression Model to look at the effects of biogas technology adoption on income and living standards. They selected 80 respondents for the analysis through simple random sampling, including both adopters and non-adopters. The findings showed that biogas adopters earn significantly more than those who do not use the fuel (Marie et al., 2021). The use of biogas technology is positively linked to an increase in cattle numbers and fuel prices (Abbas et al., 2017). Results indicate that biogas adoption can be an important imperative for farmers in Zimbabwe, particularly in Domboshava, to improve their welfare. However, the key push factors

for the success of biogas adoption in Bangladesh included high fuel prices and cattle possession. Although these driving forces may differ from those in Domboshava, Zimbabwe, the study offers a valuable perspective on the socioeconomic factors that affect whether biogas adoption projects succeed or fail (Surroop et al., 2019).

Balgah et al. (2018) evaluated the impacts of biogas adoption in Western Cameroon using descriptive and trend analyses. The results indicated that biogas adoption substantially enhanced beneficiaries' social, human, physical and financial capital, irrespective of gender. According to the study's findings, using biogas technologies could simultaneously enhance livelihoods and advance environmental sustainability. The study provides an important viewpoint on the changes in key variables, including land, livestock, and crop output, before and after biogas adoption (Yang et al., 2021). However, since the research focused on descriptive analysis only, there was no control over variables that could also have had an impact on the changes in key variables, including land, livestock, and crops. Hence, the research could have been complemented by a more robust method to determine the extent to which biogas adoption in Western Cameroon impacts the key livelihood variables.

The study is related to research conducted by Amir et al. (2022), who utilised descriptive analysis to assess whether livelihoods were transformed by biogas adoption in Khyber, Pakistan. The findings indicate that biogas utilization substantially decreased the time required for cooking and fuel collection. It also created opportunities for other activities to be done with the time saved and improved the fuel and energy consumption pattern. The study does not include a control group of non-adopters for comparison (Moli et al., 2021). Establishing a clear cause-and-effect link between the adoption of biogas and the observed results is difficult in the absence of a control group.

Shallo et al. (2020) examined what affects the adoption of biogas technology in southern Ethiopia. They surveyed 268 farmers, including 134 biogas adopters and 134 non-adopters. They used a mix of simple random and purposive sampling methods. The researchers analyzed the data using binary logistic regression and descriptive statistics. The results revealed significant differences between adopters and non-adopters in areas such as education level, cattle holdings, farmer income, farmland size, number of trees planted, distance to water sources, markets, and firewood. Mengistu et al. (2021) found that factors like access to electronic media, income level,

access to credit, closeness to firewood sources, and education positively influence biogas adoption.

The methodology can introduce selection bias and potentially compromise the sample's representativeness (Munafò et al., 2018). The criteria for the purposeful selection of non-adopter farmers were not clearly specified, which could affect the validity of comparisons between adopters and non-adopters. Ansah et al. (2019) highlighted that the dynamic nature of adoption processes and potential inverse relationships among variables should be considered in such studies. The research provides important insights into the social and economic factors that influence biogas adoption in developing countries. It points out important elements that influence biogas use in Domboshava, Zimbabwe. The findings show that social and economic factors significantly impact farmers' choices and the use of this technology.

Uhunamure et al. (2019) highlighted the factors affecting farmers' decisions to adopt and use biogas in Limpopo Province, South Africa. They sampled 128 non-users and 72 biogas users. Data analysis was done using a logistic regression model. However, the unequal sample sizes between non-users and adopters may create bias and restrict how widely the findings can be applied. A more balanced representation of adopters and non-adopters would have been critical to reduce potential bias. Ahmad (2022) conducted a study in Bangladesh and found that several important factors influence adoption. These include the farm head's education level, age, number of cattle, distance to fuel wood sources, crop production, and access to credit, loans, and subsidies. The study indicates the importance of key socio-economic variables in determining biogas adoption, a finding corroborated by Luo et al. (2021) in Pakistan.

2.7 Chapter Summary

The chapter examined the theories and models used to explain how biogas is adopted. It covered important viewpoints, including the Theory of Reasoned Action, Unified Theory of Acceptance and Use of Technology, Technology Adoption Model and the Diffusion of Innovation Theory. These perspectives offer insights into the factors that influence adoption decisions. The historical background of biogas adoption was outlined, tracing its origin and growth, with emphasis on significant turning points and technological developments that have influenced its uptake across regions. Focus was given to the African context, highlighting the potential benefits of biogas for rural communities and the initiatives undertaken by governments and organizations to promote

its use. Furthermore, an overview of Zimbabwe's energy landscape was provided, alongside an exploratory analysis of the determinants influencing biogas adoption in the country.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter offers a clear description of the study area. It explains the research design and details the methods used to address the research objectives. The chapter also describes the data analysis methods employed, which include descriptive analysis, binary logistic regression, multinomial logistic regression, multiple linear regression, stakeholder and institutional analysis. Additionally, the chapter also presents the ethical considerations.

3.2 Study area

Domboshava is a peri-urban communal area of Zimbabwe's Mashonaland East Province, in the country's northeastern region. It is located around 28 kilometres northeast of Harare, the country's capital, and is governed by the Goromonzi Rural District Council (Marambanyika et al., 2020). The district, which has a total size of 981 square kilometres, is distinguished by its varied topography, which includes lush valleys, granite outcrops, and undulating hills. The majority of people in the primarily rural area work in agriculture. According to Gutsa (2017), the main agricultural products are maize, tobacco, cotton, and horticultural crops. Subsistence and commercial farming are what support the local economy. The district's economy depends heavily on the rearing of livestock, especially cattle, goats, and chickens (Tanyanyiwa, 2019). Domboshava is predominantly an agricultural area, and farming is very important to the community's economy. The district's adoption and long-term viability of biogas systems can be aided by the availability of these waste resources (Maramura et al., 2020).

Domboshava struggles with access to energy, just like many rural areas in Zimbabwe. For their heating and cooking needs, a sizable section of the populace depends on conventional biomass fuels like firewood and charcoal (Chanakira and Dzapasi, 2022). Replacement of traditional biomass with biogas technology can help reduce the use of traditional biomass resources. This change may also lessen the related environmental and health issues. Domboshava's infrastructure is rather rudimentary, and there is little access to utilities and services. According to Mbwirire (2017), primary and secondary schools are available; however, access to higher education institutions could require travel to surrounding urban centres. Although more specialized medical care could necessitate travelling to Harare, health services are offered through clinics and rural

3.3 Research Design

The framework that directs the entire investigation process is referred to as the research design. The researcher's techniques and strategies are designed to test the hypotheses and provide an effective response to the research questions. A well-structured research design guarantees the validity, reliability, and applicability of the data gathered, claim Halcomb and Hickman (2015). A well-structured research design guarantees the reliability, validity and applicability of the data gathered, claim Halcomb and Hickman (2015). A mixed-methods was used in this study, combining quantitative and qualitative techniques.

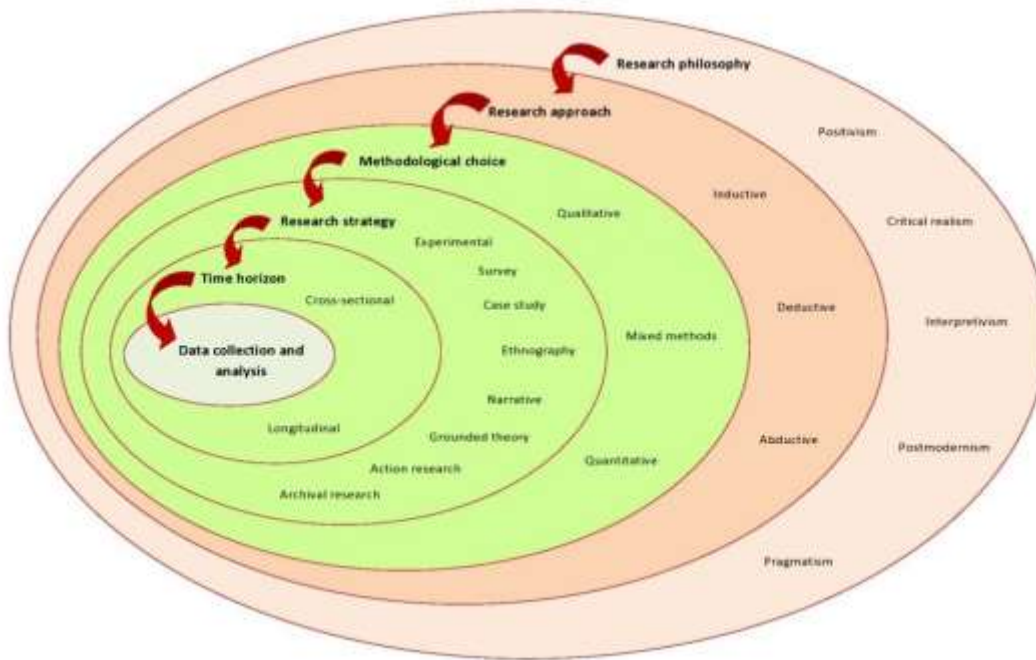


Figure 3.2. Research Design for the study

A critical realist philosophical framework served as the foundation for the study. Examining the use of biogas technology and its effects on livelihoods in Domboshava, Zimbabwe, was the main goal. Critical realism provided the view to explore the underlying structures and mechanisms shaping this phenomenon. This was supported by a deductive approach that involved creating theories about the factors affecting biogas adoption and its effects on livelihoods. Next, quantitative data was collected to confirm, validate or refute these theories. To capture both

statistical evidence and contextual detail, a mixed-methods was used. This incorporated both qualitative and quantitative methods to represent the experiences of the community. Data collection took place through a cross-sectional survey, allowing the study to evaluate how much biogas was adopted and its immediate effects on local livelihoods at a specific moment in time.

3.3.1 Quantitative Methods

According to Creamer (2017), quantitative methods offer a methodical and exacting way to gather, examine, and evaluate numerical data. They provide quantification, generalizability, and statistical inference, revealing the connections between variables and enabling comparisons between various populations or groups (Yarkoni, 2022). The study aims to provide evidence on the factors that influence biogas adoption and its effects on livelihoods in Domboshava. It uses quantitative methods to gain a clearer understanding of this important topic. Husband (2020) notes that semi-structured interviews offer flexibility and allow for the exploration of relevant issues. Interview questions addressed a variety of topics, including reasons for using biogas, perceived advantages and disadvantages, socioeconomic factors, and the effect on livelihoods.

3.3.2 Qualitative Methods

Focus group discussions were used, and qualitative information on views that were useful in the development of the pathways. Qualitative research methods allow for an in-depth examination of the social, economic, and environmental determinants that affect the use of biogas, as well as its impact on the general quality of people's lives (Puzzolo et al., 2016). The key stakeholders were identified through convenience sampling, and data gathered included one Ministry of Energy and Power Development, one non-governmental organisation, one Domboshava Rural District, 2 chiefs, 6 village heads, and farmers in Ward 4 Domboshava. Qualitative methods complement this by uncovering detailed insights into participants' experiences, perceptions and motivations that quantitative tools alone may not capture, providing a deeper understanding of biogas adoption (Knowles et al., 2020). Hence, by utilising qualitative methods, the research can produce in-depth and context-specific insights, advancing our understanding of the study's issue. Using a structured interview protocol as a guide, in-depth interviews with chosen key informants were used to gather qualitative data. The validity of the data collection instruments was ensured

by aligning all survey questions with the study objectives and grounding them in established literature on renewable energy adoption. Reliability was ensured through consistent administration of the questionnaire, use of standardized procedures during interviews and training of research assistant to minimize interviewer bias. Credibility was achieved by using triangulation collecting data from chiefs, village heads, farmers, district officials and ministry representatives to ensure multiple perspectives supported the findings

Through a focus group, participants expressed their perceptions, difficulties and experiences with adopting biogas during these conversations (Dooley, 2020). The researchers kept thorough field notes when participating in interviews. According to Fetters and Rubinstein (2019), these notes record observations, nonverbal clues, and contextual details that could improve the comprehension of the material. A thematic analysis identified recurring themes, patterns, and insights about the factors influencing biogas adoption and its impact on livelihoods. Hendren et al. (2023) noted that combining qualitative findings with quantitative results improves the reliability and validity of research. This comparative method was employed to identify points of convergence or divergence and to highlight complementary findings that can offer new perspectives on the study objectives (Dawadi et al., 2021). Finally, interpreting both quantitative and qualitative results, along with discussing their implications, provided a clear understanding of the factors and effects of biogas adoption in Domboshava, Zimbabwe.

3.4 Data collection methods

3.4.1 Population and sampling of Ward 4 Farmers

Given that Ward 4 has a population of around 7000 farmers, which includes 4620 livestock farmers, the objective was to ensure that each of the six villages was represented; probability sampling techniques were applied (Marambanyika et al., 2020). These six villages include Chinamhora, Chogugudza, Chisodza, Murape, Mungate, and Zimbiru Village. Sharma (2023) defines stratified random sampling as the method of splitting the population into strata, or separate subgroups, on the basis of specific characteristics which are of relevance to the aims of the study. In this study about the factors affecting biogas adoption and its effects on livelihoods, the population was divided by the six villages in Ward 4 of Domboshava. Stratification allows for equitable representation of every village in the sample, thus improving the representativeness as well as the reliability of the results (Rahman et al., 2022). The approximate population of each

village has been obtained from local authorities and community leaders. The approximate population of each village has been obtained from local authorities and community leaders.

After stratified sampling of the villages, the sample size was determined proportionally across the villages based on their population size. This ensures that each village is represented according to its relative importance in the population (Oribhabor and Anyanwu, 2019).

The sample size for Ward 4, Domboshava, was calculated using Slovin's formula:

$$n = \frac{N}{1+N*e^2} \dots\dots\dots (1)$$

Where:

n = Sample size

N = Population size

e = Margin of error

Substituting with the livestock farmers' population of 4620 and a margin of error of 0.05 (5%) for Ward 4, Domboshava:

$$368 = \frac{4620}{1+4620*0.05^2} \dots\dots\dots (2)$$

368 respondents were the estimated sample size for Ward 4, Domboshava, using Slovin's formula with a 5% margin of error. The sample of 368 livestock farmers is split proportionally between the two groups: biogas adopters and non-adopters, as well as the villages, based on their population size. This approach guarantees proportional representation of each village within the sample.

The 368 samples includes farmers who adopted biogas and those who did not. According to local authorities' records, the population of biogas adopters is 127 farmers from the 6 villages. Considering the small number of adopters, there was no sampling for biogas adopters, as the whole population (127 farmers) was used. The balance of the 368 sample is 241, which was proportionally sampled from the population of non-biogas adopters.

The contributions of the six villages to the population of livestock farmers in Ward 4 are as follows: Mungate 27%, Chogugudza 19%, Chinamhora 16%, Chisodza 14%, Murape 13%, and Zimbiru 11%. Hence, the sample size is distributed according to the proportional contribution of each village to Ward 4's population.

Table 3.1 Population and sampling for Biogas Adopters

Villages	Total Number of Livestock farmers	Population of biogas adopters	Proportional Sample	Sample of adopters
Mungate	1250	34	27%	34
Chogugudza	900	24	19%	24
Chinamhora	750	20	16%	20
Chisodza	625	18	14%	18
Murape	580	17	13%	17
Zimbiru	515	14	11%	14
Total	4620	127	100%	127

Table 3.2 Population and sampling for Biogas Non-Adopters

Villages	Number of Livestock farmers	Population of biogas non-adopters	Proportional Sample	Sample of non- adopters
Mungate	1250	1216	27%	65
Chogugudza	900	876	19%	46
Chinamhora	750	730	16%	38
Chisodza	625	607	14%	34
Murape	580	563	13%	31
Zimbiru	515	501	11%	27
Total	4620	4493	100%	241

All 127 livestock farmers who adopted biogas from all the villages were used. This is because the number of biogas adopters in each village in Ward 4 Domboshava was low. Simple random sampling was used to choose non-adopters from each village. Since all adopters were included in the study, efforts were made to achieve near-equal representation of non-adopters across the villages, as indicated in the table above. This approach ensured that all groups are well represented. It allowed for a detailed study of the factors that affect biogas adoption and its impact on livelihoods.

3.4.2 Primary data

The data was gathered through administering questionnaires, key informant interviews, focus group discussions, and observational techniques (Gobrekidan et al., 2018). The questionnaire comprised both close-ended questions having pre-established response options and open-ended items meant to draw richer insights. The survey questionnaire covered aspects including farmer demographics, biogas adoption status, reasons for adoption, perceived benefits and challenges, economic indicators, and livelihood outcomes. According to Clancy et al. (2019), researchers obtained primary data by conducting key informant interviews with important stakeholders. This group included decision-makers, community leaders, biogas technology suppliers and households that had already adopted biogas. Issifu et al. (2022) noted that semi-structured interviews allowed for in-depth discussions on relevant topics. This approach helped gather valuable qualitative information about adoption motivations, social dynamics, challenges and the perceived effects on livelihoods. Objective 5, which seeks to develop a context-specific framework for improving biogas adoption among livestock farmers in Domboshava, was primarily informed by qualitative data collected through focus group discussions, key informant interviews and consultations with community leaders and institutional stakeholders.

Focus groups with adopters and non-adopters enabled the investigation of group dynamics, collective decision-making procedures, and common difficulties and advantages related to the adoption of biogas (Ikonya, 2018). Direct observation was utilised in the gathering of primary data through observations of farmer routines, biogas adoption-related interactions and biogas systems. Background information, nonverbal clues, and additional understanding of the management and operation of biogas systems, as well as their impact on daily tasks that sustain daily life, were provided by observations (Slámová et al., 2021).

3.4.3 Target Groups for Questionnaire and Focus Group Discussions

The household questionnaire target group included livestock farmers sampled from Domboshava Ward 4. These include 127 biogas adopters and 241 non-adopting livestock farmers derived from the sample. Three focus group discussions, each comprising 10 participants, were conducted including 2 chiefs, 6 village heads, biogas-adopting and non-adopting livestock farmers, as well as representatives from the Domboshava Rural District and the Ministry of Energy and Power Development. The qualitative data from focus group discussions and key informant interviews were analysed using thematic analysis, which involved transcribing the discussions, coding the data, identifying recurring patterns and organising these into major themes relevant to biogas adoption. These themes included perceived benefits, cultural attitudes, technical challenges, institutional support gaps and recommendations for improving uptake were then integrated into the findings to complement the quantitative results.

3.4.4 Risk Management in Primary Data Collection

To mitigate these risks, the researcher was accompanied by a support person who is an extension officer in Domboshava. This additional presence aims to provide a supportive environment, ensuring the well-being and safety of both the participants and the researcher. The support person's role included monitoring the emotional well-being of participants, intervening if any distressing situations arise, and facilitating a safe space for open discussion.

3.4.5 Secondary data

According to Wadoux et al. (2021), secondary data were employed to utilise existing knowledge, identify trends and patterns and contextualise the findings from primary data. Furthermore, combining secondary and primary data sources improves the study's strength and allows a thorough understanding of the factors influencing biogas adoption and its effects on livelihoods in Domboshava (Almeida, 2018). Key sources of secondary data included official reports, policy documents, peer-reviewed research articles and datasets from the Ministry of Energy and Power Development and other relevant ministries. Additionally, NGOs and international organizations including SNV and HIVOS, involved in renewable energy had an important role in making sure data was collected thoroughly through key informant interviews. The Domboshava rural development council, chiefs, and headmen in Ward 4 of Domboshava were important in providing secondary data to complement primary data from the targeted respondents.

3.4.6 Analysis and Integration of Secondary Data

The analysis of secondary data aimed to identify important trends, patterns, and insights related to biogas adoption and its effects on the lives of residents in Domboshava. This process sought to uncover trends, contradictions, and new information while comparing findings from both primary and secondary data sources. Results from secondary data were combined with the primary data collected from specific respondents in Domboshava. Researchers assessed whether the secondary and primary data matched or differed. This made it evident what factors affect the use of biogas and how it affects livelihoods. Using secondary data helped to present primary data findings into context and supported them, improving the overall depth and strength of the study.

3.5 Data analysis

Objective 1: To determine the extent of biogas technology uptake among livestock farmers in Domboshava.

To determine the use of biogas in Domboshava, an analytical method based on descriptive findings was used, thus providing a basis for developing meaningful conclusions. Determination of the correlations, patterns, and trends present in the data took into account variables including financial incentives, technological obstacles, societal perceptions, and governmental regulations that could affect the uptake of biogas.

To ascertain the livestock farmers who have embraced biogas technology, descriptive statistics was generated. According to Loeb et al. (2017), these statistics offer a succinct and clear summary of the data and make it simple to compare and analyse them. Key descriptive statistics, particularly measures of central tendency, including mean, median and mode, were computed to determine the average or most frequently occurring values for variables including age, education level, farmer income, land size and other critical socio-economic indicators (Mishra et al., 2019). The variability or distribution of the socioeconomic parameters among the adopting livestock farmers was revealed by measurements including standard deviation, range, and interquartile range. This aids in determining if the sample is diverse or homogeneous (Johnson and Bhattacharyya, 2019). To ascertain the distribution and proportions of various socioeconomic characteristics among the livestock farmers adopting biogas, categorical variables including gender, marital status, occupation and financial resources were tabulated.

Table 3.3. Descriptive Analysis Variables

Variable	Description	Measurement	Expected Sign
Biogas adoption (Domboshava community consists of livestock and non-livestock farmers. The focus of research is on livestock farmers)	Whether livestock farming family adopted biogas or not	Dummy (1=yes,0=no)	
Age	Head of the farming family's age	Number of years	-
Gender	Gender of household head	Dummy (0=female, 1=male, 2=Other)	+
Education	Education status of head of farming family	Number of formal educational years	+
Extension	Access to extension services	Dummy (1=yes, 0=no)	+
Off-farm income	Income of head of farming family from off-farm activities	Number in US\$	+/-
Group Membership (Social Capital)	Whether the farming family head belongs to any community group	Dummy (1=yes, 0=no)	+
Livestock units (Physical capital)	Livestock numbers	Number	+
Land size (Natural capital)	Size of land for cultivation	Hectares	+/-
Access to credit (Financial capital)	Whether the farming family head has access to credit	Dummy (1=yes, 0=no)	+
Access to internet (Technological capital)	Whether the farming family head has access to internet	Dummy (1=yes,0=no)	+

The distribution and trends of socioeconomic indicators among the adopting livestock farmers might be visually displayed using graphical forms like histograms, bar charts, or pie charts. These visualizations improve how the data is understood and presented, making it simpler to see trends, outliers, or relationships (Butscher et al., 2018). The socio-economic descriptive analysis provided a thorough overview of the livestock farmers in Domboshava who have adopted biogas. It helped in identifying important traits like education, income, and resource accessibility that may affect the decision to embrace biogas. The research advanced knowledge of the

socioeconomic forces driving biogas use and guide targeted initiatives or policies to encourage its uptake among livestock farmers in the area.

Objective 2: To analyse the effect of socio-economic factors on biogas technology adoption among Domboshava livestock farmers.

Das (2021) states that the binary logistic regression model is applied when the dependent variable is categorical, specifically with two possible outcomes. The binary model is employed when the outcome variable has two alternative states, hence the name. This model is frequently used in the economic literature to calculate the likelihood that an economic agent selects one alternative over another (Maćkowiak et al., 2023). Therefore, binary logistic regression is a widely used statistical method that models the probability of a dichotomous outcome including adoption versus non-adoption based on a set of explanatory variables and has been widely utilized in technology adoption research. The explanatory variable can either be categorical or continuous in nature.

Grounded in an underlying utility function, this study examined how livestock farmers adopted biogas farming as an energy and climate change strategy. Accordingly, livestock farmers adopt biogas if the presumed utility of biogas use is greater than non-adoption. Therefore, when an event's likelihood is taken into account as being equal to Prob (Y = 1 if adopted and 0 otherwise).

$$\Pr(Y_i = 1|X_i) = \frac{\exp(X_i\beta)}{1+\exp(X_i\beta)} = \frac{1}{1+\exp(-X_i\beta)} \dots\dots\dots (3)$$

In the above equation, $\Pr(Y_i = 1|X_i)$ is the likelihood that an event will occur given an independent variable X_i and a dependent variable taking the value of 1. X_i represents all other independent variables. By including natural logarithms, the above equation can be represented as:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \dots\dots\dots + \beta_KX_K + \varepsilon_i \dots\dots\dots (4)$$

The dichotomous dependent variable highlights the natural log probability of biogas adoption (P_i) divided by the probability of non-adoption of biogas ($1 - P_i$).

$$Biogas\ adoption = \ln[P(Y = j|X)/P(Y = 1|X)] = \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3 AccesstoCredit + \beta_4 Education + \beta_5 Landsize + \beta_6 Extension + \beta_7 Livestockunits + \beta_8 Offfarmincome + \beta_9 Energycosts + \varepsilon_i \dots \dots \dots (5)$$

Marginal effects were calculated to quantify the change in the probability adoption status averaged across all observations. Therefore, marginal effects offer a clear interpretation of the effect size in terms of probability, in contrast to odds ratios.

Objective 3: To analyse the effect of socio-economic factors on the plans to adopt biogas technology among Domboshava livestock farmers.

Multinomial logistic regression can accommodate multiple discrete outcome categories, making it suitable for analyzing multiple categories of adoption in this study. The multinomial logistic regression is a version of binary logistic regression (Shah et al, 2022). The approach can be used in scenarios in which the dependent categorical variable includes more than two levels. The approach presupposes the independent variables do not meet the requirements of normality, linearity, and homoscedasticity. According to Abdallah (2018), the multinomial logistic regression model, therefore, evaluates the distribution of category membership of the dependent variable by using a number of independent variables as predictors. For the study, the multinomial logistic regression is represented as follows:

$$\ln[P(Y=j|X)/P(Y=1|X)] = \beta_0 + \beta_1 Age + \beta_2 Gender + \beta_3 AccesstoCredit + \beta_4 Education + \beta_5 Landsize + \beta_6 Extension + \beta_7 Livestockunits + \beta_8 Offfarmincome + \beta_9 Energycosts + \varepsilon_i \dots \dots \dots (6)$$

Where j = 2 (intending to adopt) or j = 3 (adoption) and the reference category is j = 1 (non-adoption).

The change in the probability of each adoption status linked to a one unit change in a predictor variable was measured using marginal effects, which were averaged over all observations. As a result, the effect size can be directly interpreted in terms of probability thanks to marginal effects.

Model Diagnostics

The Likelihood Ratio Chi-Square Test was used to evaluate the overall significance of the model against a null model with no predictors. The Hosmer-Lemeshow Test checked the model's calibration by comparing observed and predicted frequencies. The Variance Inflation Factor showed the correlation among the predictor variables in the model. The Pseudo R-squared indicated the proportion of variance explained by the model.

Objective 4: To analyse the effect of biogas technology adoption on the livelihoods of livestock farmers in Domboshava, using a composite livelihood index.

In research, a livelihood index is a composite metric or instrument that is used to evaluate and quantify the livelihood status or general well-being of individuals or households within a certain community, area, or population. Its goal is to give a thorough picture of all the different facets of people's lives, frequently encompassing their environmental, social, and economic components. Researchers analyze and compare the overall quality of life, vulnerability and living standards of various communities or groups using livelihood indices. The livelihood index is derived from the Sustainable Livelihoods Approach dimensions of social capital, physical capital, natural capital, economic capital, and human capital.

Table 3.4. Livelihood Index Objective Indicators

Human Capital	Social Capital	Economic Capital	Natural Capital	Physical Capital
Education level (Primary, Secondary, Tertiary)	Membership in community groups (Percentage of farmer family in community groups)	Income (Average annual income per farmer)	Land ownership (Percentage increase in land area after biogas adoption)	Access to Infrastructure (Access to affordable and reliable energy sources)
Health status (Percentage of farmer family with access to healthcare)	Network size (Number of social connections per farmer)	Amount of credit and financial support.	Environmental sustainability (Percentage reduction in firewood consumption after biogas adoption)	Type of housing (Percentage of farmer family with durable and safe housing)

To synthesize the multifaceted dimensions of the sustainable livelihoods framework, a composite index, designated as the livelihood index, was constructed using principal component analysis (PCA). Principal component analysis (PCA), a quantitative method, converts a set of potentially interrelated variables into a smaller set of uncorrelated variables by determining principal components. This approach is particularly useful for reducing data complexity by identifying the key features that represent the underlying patterns and variability in the dataset.

$$\begin{aligned}
 \text{LivelihoodIndex} = & \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Gender} + \beta_3 \text{Education} + \beta_4 \text{Landsize} + \\
 & \beta_5 \text{Extension} + \beta_6 \text{Offfarm income} + \beta_7 \text{Livestockunits} + \beta_8 \text{Adoption of biogas} + \\
 & \beta_9 \text{Access to credit} + \beta_{10} \text{Energy costs} + \\
 & \varepsilon_i \dots\dots\dots (7)
 \end{aligned}$$

Assumptions of Multiple linear regression to be observed

Analysis of the multiple linear regression was carried out in the STATA 15 statistical package. Homoscedasticity and multicollinearity are two assumptions that were addressed to provide effective coefficients that can be employed to draw conclusions.

Objective 5: To develop a framework for the improvement of biogas adoption for Domboshava livestock farmers.

The framework offered a guide for encouraging and enhancing Domboshava livestock farmers' adoption of biogas. It addressed issues including long-term sustainability, information dissemination, monitoring, policy advocacy, funding, and technical support. This strategy helped eliminate obstacles and encourage the widespread use of biogas technology. This will improve livelihoods, increase access to energy, and enhance environmental sustainability in Domboshava and across the country. The formulation of the framework was carried out through needs assessment and stakeholder engagement with the critical entities affecting biogas adoption in Domboshava.

3.6 Ethical consideration

Ethical considerations were observed throughout this study, ensuring both the protection of participants' well-being and the integrity of the research process. The study obtained the informed consent of every participant in the study. The aim, steps, dangers, advantages, and voluntary nature of involvement were made clear. The study employed data collection and storage methods that ensured participants' privacy and confidentiality through anonymization. Participation was entirely voluntary, with no form of coercion involved. Additionally, all procedures adhered to relevant data protection regulations during data collection, storage and analysis. Before the commencement of the research, approval was received from the relevant Institutional Review Boards and Ethics Committees. This includes the ethical clearance letter from the University of South Africa. It's crucial to give the livestock farmers feedback after the study to ensure transparency, thank them for participating, and let them know about any conclusions that will be helpful to them. A dedicated feedback workshop of about 30 participating livestock farmers will be organized. The workshop will highlight the study's main findings, conclusions, and suggestions.

3.7 Chapter Summary

This study used a mixed methods to meet the five research objectives. Descriptive statistics assessed the extent of biogas adoption among livestock farmers in Domboshava. Binary logistic regression analyzed how socio-economic factors influence the likelihood of adopting biogas. Multinomial logistic regression looked at the factors affecting plans to adopt biogas technology. Multiple linear regression assessed the impact of biogas adoption on livelihoods, measured by the composite livelihood index. Lastly, institutional mapping and stakeholder analysis guided the creation of a specific framework to improve biogas adoption in Domboshava.

CHAPTER 4

UPTAKE PATTERNS AND USAGE LEVELS OF BIOGAS TECHNOLOGY IN DOMBOSHAVA

4.1 Introduction

This chapter highlights the level of uptake and utilization of biogas technology among livestock farmers in Domboshava, Zimbabwe. It focuses on household characteristics including gender, age, education, off-farm income, asset ownership, non-farm income, land area and livestock units. The chapter examines how these variables influence the adoption of biogas. It also highlights patterns and trends in usage among biogas adopting households.

4.2 Study Area

The Figure 4.1 below highlights biogas adoption by village in Domboshava for livestock smallholder farmers.

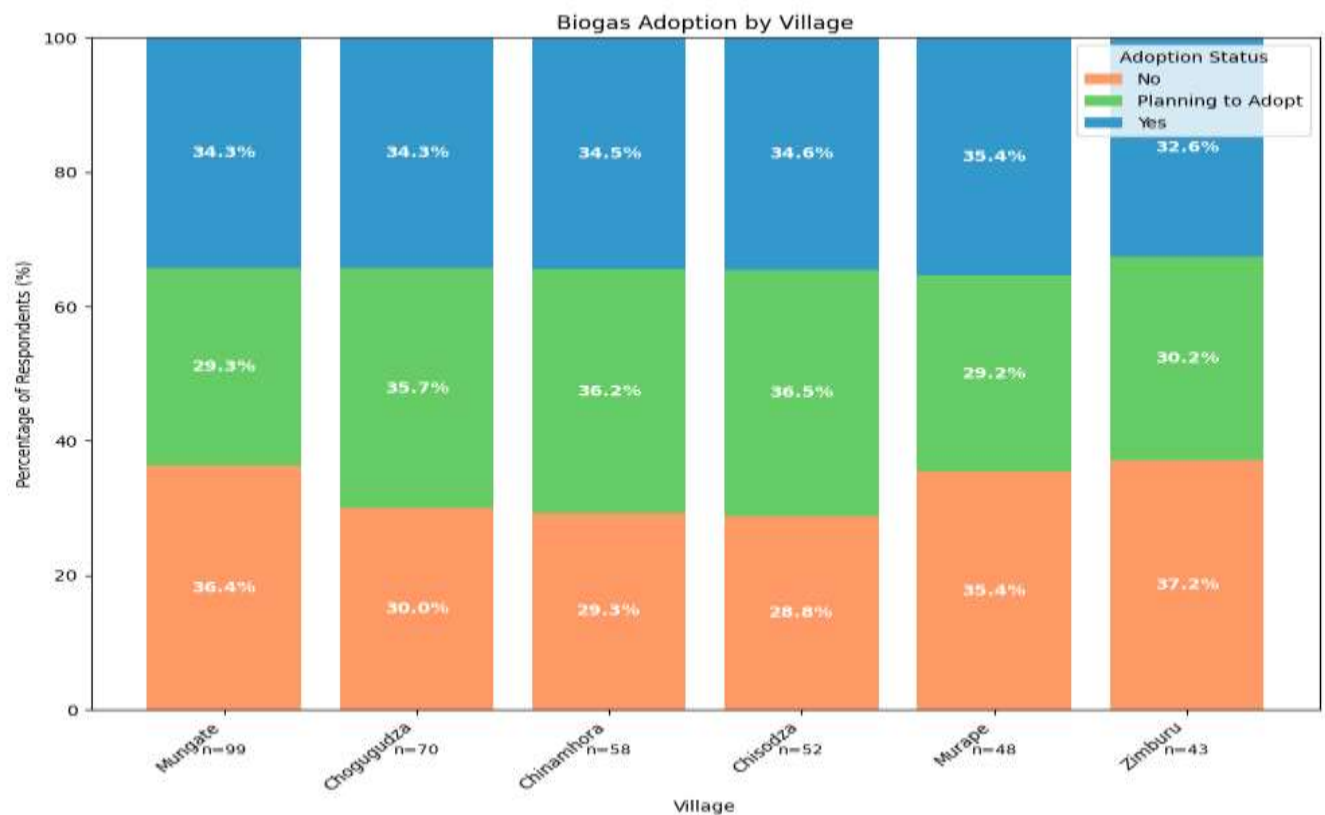


Figure 4.1 Biogas Adoption by Village

Source: Author (2025)

The findings from Figure 4.1 highlight that the six villages in Domboshava have different adoption patterns for biogas. Planning to adopt rates vary from 29.2% in Murape to 36.5% in Chisodza while adoption rates currently range from 32.6% in Zimburu to 35.4% in Murape. The spatial differences can be attributed to localized factors including social cohesion, leadership support and demonstration effects. According to Uhunamure et al. (2021), there is a need for a customized strategy that takes into account complex, context-dependent and regionally diverse drivers when promoting biogas adoption. There is a high combined adoption and planned rate (71.1%) in Chisodza village, indicating especially advantageous circumstances for biogas technology. However, Zimburu has the greatest non-adoption percentage (37.2%), suggesting that this group is experiencing unique obstacles in the adoption of biogas technology

The highlighted spatial patterns represent a variety of interrelated elements that contribute to the distinct adoption settings found in every village. Villages with greater social networks and coherence tend to have higher adoption rates for biogas. According to Wang et al. (2022), social capital and community-level interactions play a significant role in facilitating the adoption of biogas technologies. Although minor distinctions could account for the observed variances, the very uniform adoption distribution among Domboshava communities points to generally similar social networks. Izadi et al. (2024), noted that social capital is critical in the adoption of biogas technology for rural communities. This is critical in highlighting the importance of how social networks have an influence in the adoption of biogas technology by livestock farmers of Domboshava.

Additionally, adoption is also influenced by localized resource access. Kulugomba et al. (2024), highlighted that Malawi's regional discrepancies in the uptake of biogas frequently mirror disparities in the accessibility of vital resources, including building materials, livestock density and water availability. This explains why, despite having a lower planning rate, Murape village has the highest adoption rate at the moment (35.4%), which could be a sign of better resource access that makes the transition from plans to adoption easier. Environmental factors are also a critical determinant of biogas adoption, which can explain the uptake variation among the villages. Spatial adoption patterns may be influenced by topography and local environmental factors. According to Ali et al. (2023) research, factors including soil composition, water table depth and slope gradient produce micro-spatial variations in biogas suitability that impact

village-level adoption patterns. The relatively similar adoption rates among Domboshava livestock farmers indicates generally similar environmental conditions.

According to Rogers (2003), adoption of biogas technology is generally influenced by spatial proximity, with regions close to adoption sites having a higher likelihood of uptake. The comparatively equal adoption rates in Domboshava's villages might be an indication of how developed the diffusion processes are in the area, with knowledge and awareness of technology having gradually expanded throughout the villages. The biogas technology adopted in Domboshava primarily consists of household-scale fixed-dome digesters designed to convert livestock manure into usable energy through anaerobic digestion. At the household level, biogas is mainly utilised for cooking, which remains the primary application, followed by water heating. The biogas is conveyed from the digester to the kitchen through low-pressure piping, allowing households to use biogas in the same manner as conventional stoves. The systems operate independently as stand-alone units, with no connection to the national electricity grid and households do not have access to external gas storage facilities.

Livestock manure is the principal feedstock used in biogas production, with cattle manure being the most common due to the predominance of cattle-rearing in the area. Some households also supplement the feedstock with goat manure while poultry droppings are occasionally incorporated when available.

4.3 Socio-Economic and Demographic Statistics

4.3.1 Descriptive Statistics

Table 4.1: Continuous Variables Descriptive Statistics

Table 4.1 below highlights the descriptive statistics of continuous variables for livestock smallholder farmers in Domboshava.

Variable	Obs	Mean	Std. Dev.	Min	Max
Age of respondent (years)	370	57.22	9.99	41	75
Number of years in school (years)	370	7.65	5.74	0	17
Total arable land owned (ha)	370	1.60	0.87	0.10	3.10
Farming experience (years)	370	22.0	11.5	5	56
Number of Cattle	370	6.14	3.83	0	12
Number of Goats	370	7.07	4.68	0	15
Number of Sheep	370	2.46	1.78	0	5
Number of Chicken	370	74.59	43.26	0	150
Number of Pigs	370	4.74	3.12	0	10.00
Farm Income (US\$)	370	420.44	217.57	38	798
Off-farm income (US\$)	370	391.96	316.56	0	993

Source: Author (2025)

The participants' ages range from 41 to 75 years, as indicated in Table 4.1. The calculated mean age of the participants is 57.22 years, with a standard deviation of 9.99. The ageing farming population indicated by this age profile has important implications for agricultural innovation and technology adoption. The absence of younger farmers under 40 is a concern for the agricultural sector's long-term viability in Domboshava. Planning horizons and risk perceptions in relation to technology investments are strongly influenced by age, with older farmers often exhibiting shorter planning horizons and higher risk aversion (Villacis et al., 2024). There is a significant variation in educational attainment, which is a reflection of the farming community's notable differences in the development of human capital. This can result in uneven distribution of technical knowledge and innovation capacity among livestock farmers in Domboshava.

The land holdings for Domboshava livestock farmers ranges from 0.1 to 3.1 hectares, with an average of 1.60 hectares and a standard deviation of 0.87. This suggests landholdings that are typical of Zimbabwean community farming areas with common grazing areas for livestock production. Furthermore, Domboshava is transforming into a peri-urban region with land-

holdings decreasing in size. Adoption decisions are heavily influenced by land holding size, which has an impact on both the ability to generate enough organic waste for biogas systems and the efficiency with which bio-slurry can be used (Chekol et al., 2022). The high standard deviations for all livestock categories show that there is high variation in the community's ownership of animal assets. The wide variation in livestock holdings can contribute to differences in adoption capacities across livestock farmers. Due to their use as feedstock, Shallo et al. (2020) emphasized livestock holdings, including cattle, as a critical component in the adoption of biogas.

Significant disparity in access to alternate sources of income is indicated by the significant standard deviation of off-farm income of 316.56. According to Bunjamin and Wahab (2021), income diversification greatly influences technology adoption decisions and investment capacity. The relatively low and variable incomes observed can limit the livestock farmers' capacity to invest heavily in technologies including biogas, which often requires start-up costs despite its long-term advantages.

Table 4.2: Categorical Variables Descriptive Statistics

Table 4.2 below highlights the descriptive statistics of categorical variables for livestock smallholder farmers in Domboshava.

Variable	Category	Obs	Percent (%)
Sex of the respondent	Male	172	46.5
	Female	198	53.5
Educational Level	Primary	40	10.8
	Secondary	165	44.6
	Certificate	165	44.6
Access to extension services	Yes	208	56.2
	No	162	43.8
Access to electricity	Yes	199	53.8
	No	171	46.2
Group Membership	Yes	205	55.4
	No	165	44.6
Access to credit	Yes	267	72.2
	No	103	27.8
Access to internet	Yes	132	35.7
	No	238	64.3
Biogas Technology Adoption (Yes/No)	Yes	127	34.3
	No	243	65.7

Source: Author (2025)

Table 4.2 above shows a slight predominance of women in the livestock farming community of Domboshava, with 53.5% of respondents being female and 46.5% being male. The adoption of biogas is significantly impacted by this gender distribution because, in rural Zimbabwe, women are usually primarily in charge of cooking and managing energy requirements. According to Nelson et al. (2021), gender has a major impact on the adoption of energy technologies due to unequal access to resources, knowledge and decision-making authority. The relatively high representation of females in the sample highlights the need for gender-responsive biogas promotion strategies that adequately consider the specific needs and constraints faced by women. The large percentage of respondents with secondary and certificate level education, highlights the possibility of using technology focused educational initiatives to encourage the use of biogas.

From the data, credit availability is comparatively high at 72.2%, although internet service availability is more restricted at 35.7%. The high credit access rate is important and highlights

funding sources that encourage the use of biogas. Credit availability has a major impact on the adoption of renewable energy by addressing financial barriers that frequently prevent investment in sustainable technology (Mungai et al., 2022). Furthermore, the limited availability of internet connectivity may constrain the dissemination of technical knowledge and awareness related to biogas technology and best practices. This challenge is reflected in Table 4.2, where only 35.7% of livestock farmers indicated having access to the internet. According to the data 34.3% adopted biogas technology and 65.7% did not adopt. However, it is important to highlight that among the 65.7% who have not adopted, 32.7% plan to adopt in the future, while 33.0% neither use nor plan to adopt the biogas technology as shown in Figure 4.2 below.

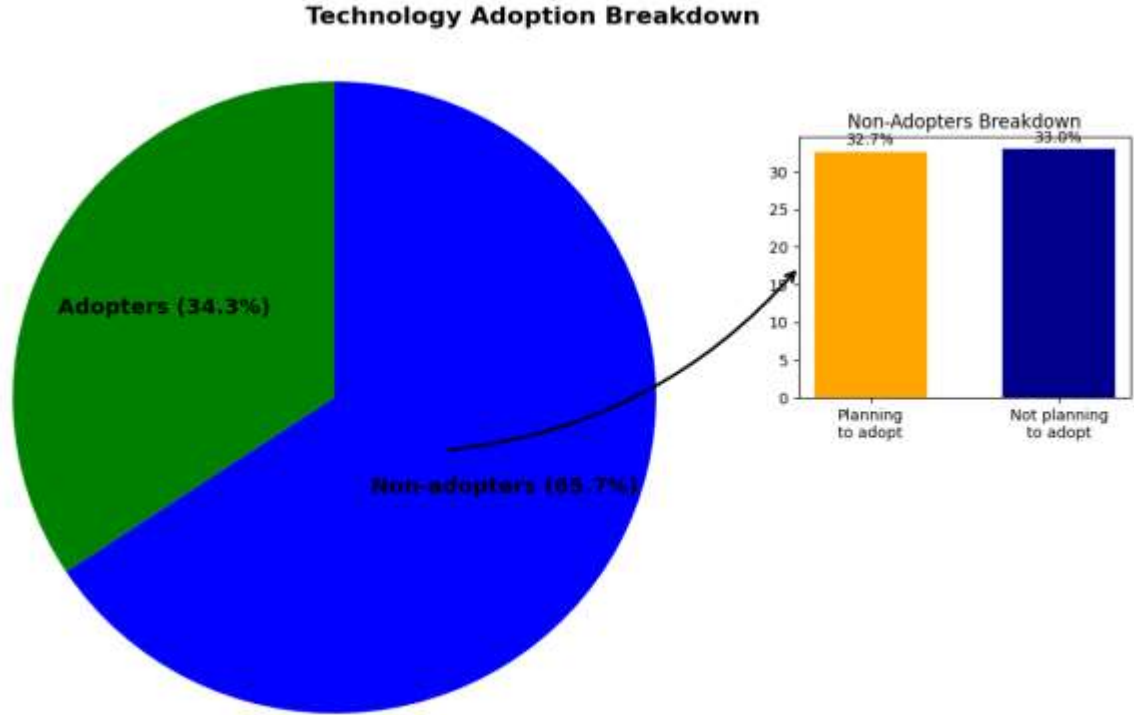


Figure 4.2 Biogas Adoption by Village

Source: Author (2025)

Figure 4.2 illustrates that although approximately two thirds (65.7%) of the livestock farmers have not yet adopted the technology, this group is nearly evenly split between individuals with no plans to adopt (32.7%) and those who express plans to adopt. Furthermore, Figure 4.2

highlights a balanced distribution among non-adopters, indicating that although the current adoption rate stands at 34.3%, the potential adoption rate could increase to approximately 67% after existing adopters are combined with non-adopters who plan to adopt. The study suggests a substantial potential growth trajectory for the biogas technology in Domboshava, Zimbabwe.

4.3.2 Gender Distribution

The pie chart below highlights gender distribution for livestock smallholder farmers in Domboshava. i

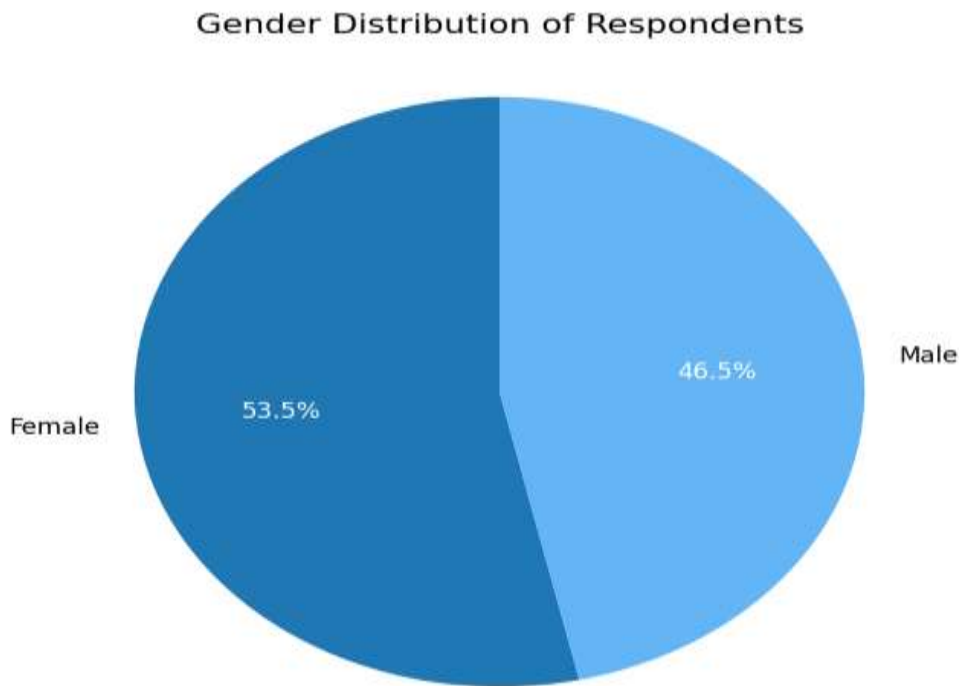


Figure 4.3: Gender Distribution

Source: Author (2025)

Adoption of technology is significantly influenced by gender, particularly in rural areas where gender dynamics can affect how household energy sources are decided. Developing gender-sensitive strategies for promoting biogas is made easier by knowing the respondents' gender distribution. According to Figure 4.3 above, women make up 53.5% of the respondents, compared to 46.5% of men. Despite a slight predominance of female respondents, this gender distribution is significant because it shows a fairly balanced representation. Elasu et al. (2023)

states that gender influences household energy decisions in a number of ways, which can significantly affect Sub-Saharan Africa's adoption of biogas technology. Hence, the balanced gender distribution in this survey provides an opportunity to understand how gender dynamics influence biogas adoption in Domboshava.

Furthermore, according to Ngcobo et al. (2022), women are directly impacted by energy scarcity and frequently bear the majority of the household's energy provision in rural areas. Consequently, the higher percentage of female responders might suggest that they are more interested in biogas and other alternative energy sources as shown in figure 4.4 below:

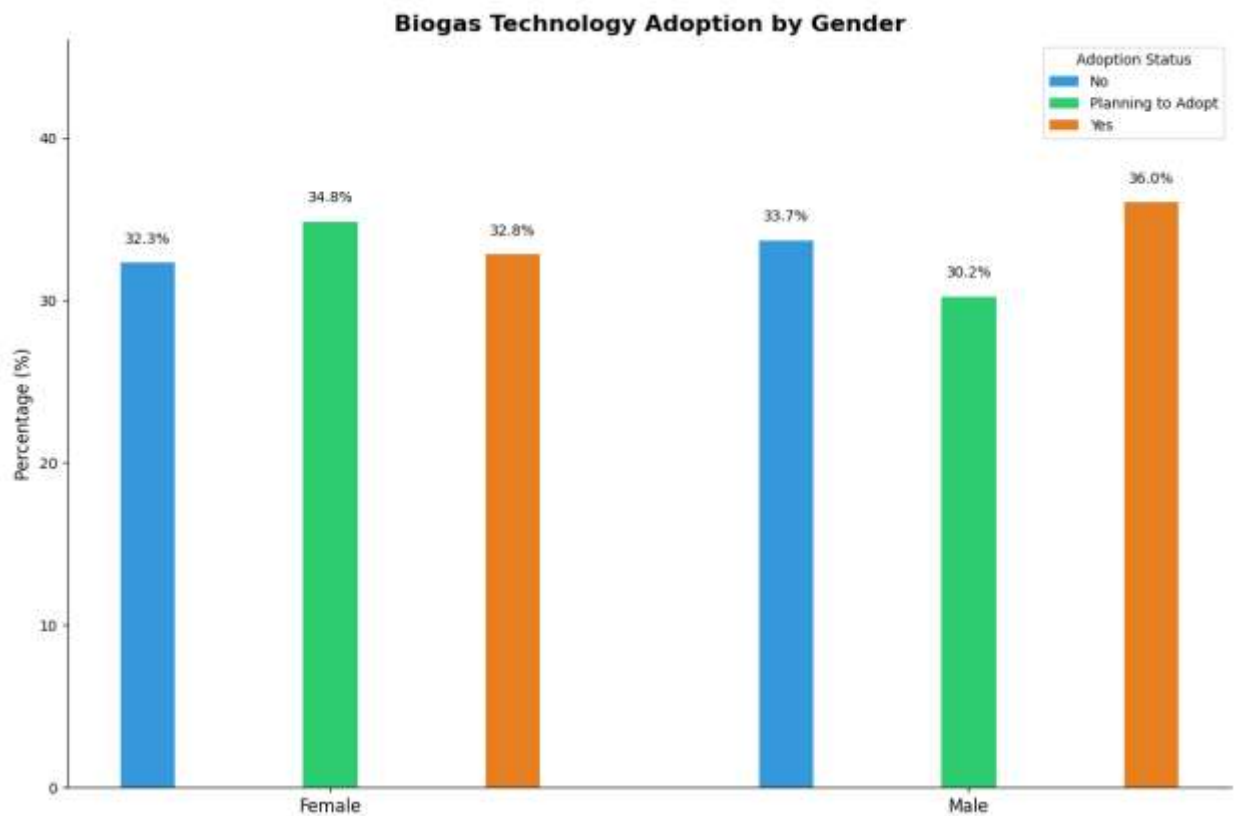


Figure 4.4: Biogas Technology Adoption by Gender

Source: Author 2025

From figure 4.4 above, both genders show similar patterns across the three adoption statuses, but with males having a slightly higher "Yes" adoption rate at 36.0% compared to females at 32.8%, while females have a slightly higher "Planning to Adopt" rate at 34.8% compared to males (30.2%). Furthermore, 33.7% of male respondents neither adopted biogas technology nor

expressed any plans to do so, while 32.3% of female respondents also reported not adopting and not planning to adopt the technology. According to Marambanyika et al. (2020), technology adoption is strongly influenced by gender dynamics, with male-headed households exhibiting higher initial adoption rates since they have more control over household investment decisions. Hence, the findings align with the view that males still control investment decisions, particularly in rural settings, including Domboshava.

However, it's important to note that more women (34.8%) than men (30.2%) indicated the intent to use biogas technology. This shows that women have a stronger inclination to adopt in the future, even though they could encounter more initial obstacles to adoption including installation costs and access to raw materials. This finding is consistent with research by Rasimphi et al. (2022), who noted that women in Sub-Saharan Africa bear the primary responsibility for household energy management and are directly exposed to indoor air pollution from traditional cooking methods, hence they show greater interest in clean cooking technologies. The findings are also complemented by Gleditsch (2019), who noted that in rural Kenya, men prioritized the economic benefits of biogas technology, while women valued it mostly for its health benefits and decreased workload for gathering firewood.

The percentage of respondents who did not use biogas technology is comparable for men (33.7%) and women (32.3%), suggesting that some adoption barriers might not be gender-neutral. These can be financial limitations, technological difficulties or regional elements that have an equal impact on men and women in Domboshava.

4.3.3 Biogas Adoption by Education level

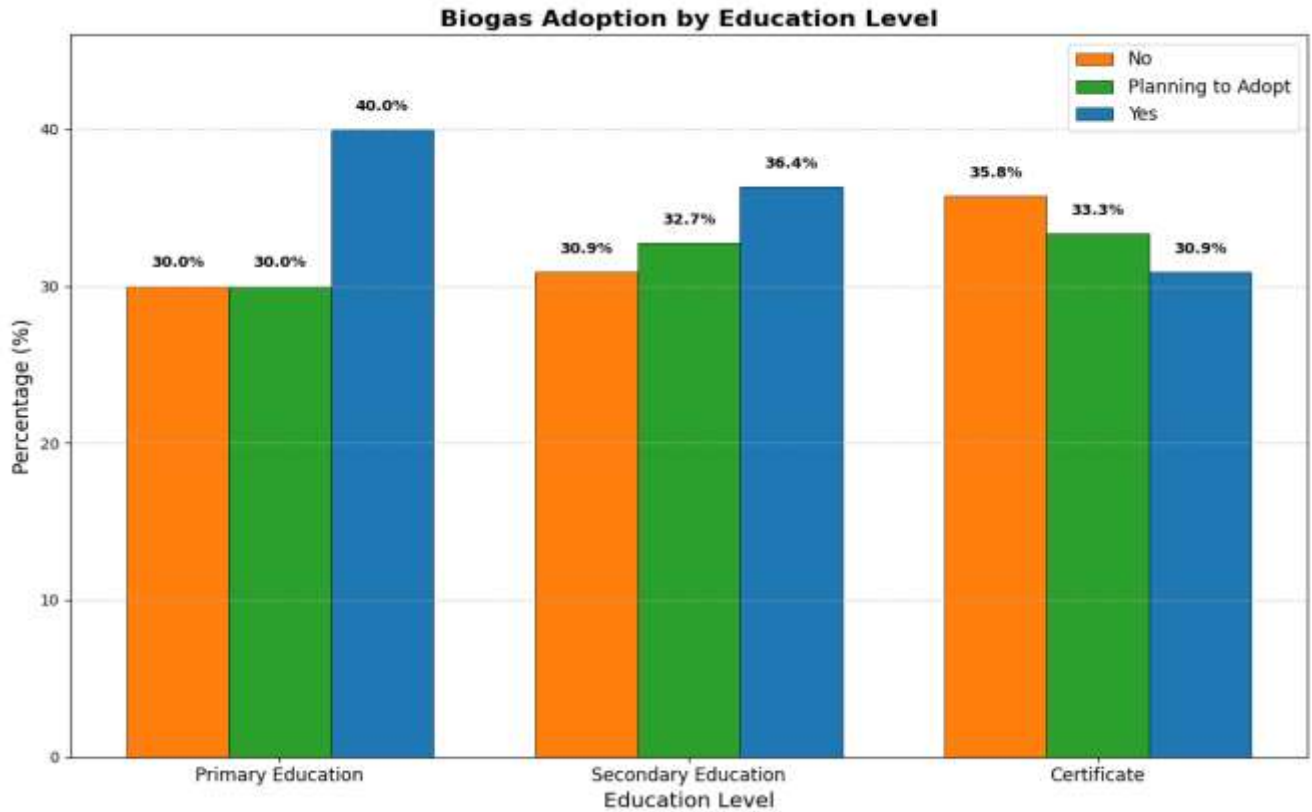


Figure 4.5 Biogas Adoption by Education Level

Source: Author (2025)

From Figure 4.5 above, the respondents with the highest current adoption rate (40.0%) are those with primary education, followed by those with secondary education (36.4%), and the lowest adoption rate (30.9%) are those with certificates. The idea that higher education inevitably results in greater adoption of technology is disproved by this inverse relationship between educational attainment and actual adoption. The findings align with Maramura et al. (2020), who noted that in Zimbabwe, higher formal education did not consistently translate to higher adoption rates, as contextual factors often affected the relationship between education and technology acceptance. The study found that the actual deployment of biogas systems in rural areas, traditional skills and practical knowledge occasionally proved more beneficial than formal education.

According to Dhliwayo et al. (2020), effective biogas promotion initiatives explicitly valued indigenous knowledge alongside formal education, creating hybrid knowledge systems that enhanced adoption across educational levels. According to their study in rural Zimbabwe, initiatives that combined technical biogas information with local expertise in waste management and animal husbandry had greater adoption rates than those that only addressed technical issues. Hence, formal education is not the only critical determinant of biogas technology adoption in rural areas. From the results, higher education is linked to stronger future adoption aspirations and primary education is linked to the highest current adoption rates. The findings imply that educational attainment promotes the adoption of biogas through a variety of mechanisms, including the acquisition of practical skills, the ability to critically evaluate, the costs of economic opportunities and social influence.

4.3.4 Biogas Adoption by Age

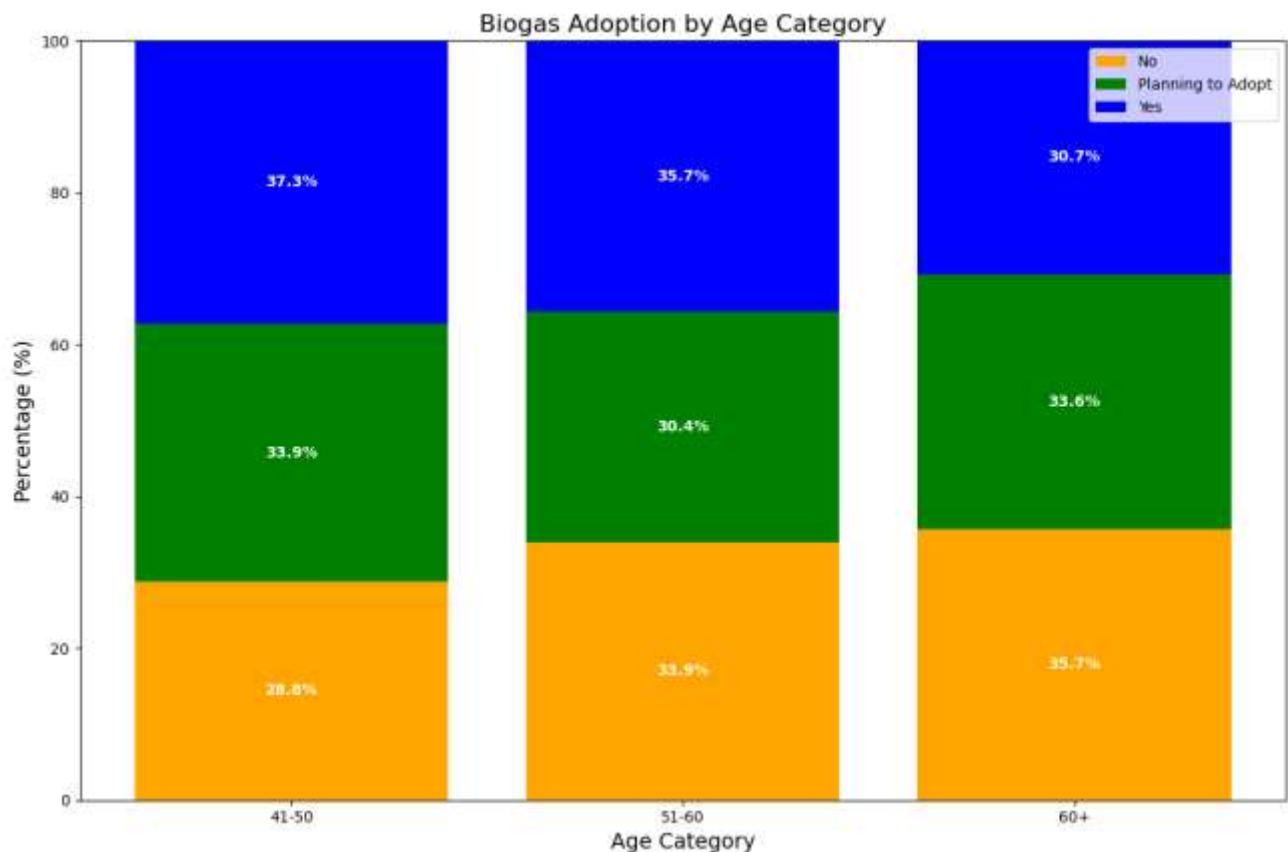


Figure 4.6 Biogas Adoption by Age

Source: Author (2025)

The adoption of biogas is clearly trending downward with age, as seen in Figure 4.6 above. The age group between 41 and 50 has the highest adoption rates (37.3%), followed by the 51 to 60 age group (35.7%), and the 60+ age group (30.7%). The non-adoption rate, on the other hand, increases with age, going from 28.8% in the 41–50 age group to 35.7% in the 60+ age group. According to Maramura et al. (2020), age significantly influences technology adoption decisions among rural households in Zimbabwe, with younger farmers showing greater receptivity to biogas systems due to their longer planning horizons and greater willingness to invest in new technologies. These findings of the study are consistent with their findings. Similar to our results, their study in rural Zimbabwe revealed that farmers under 50 years old were 1.7 times more likely to use biogas technology than those over 60. Getanah (2024), carried out a study in rural Ethiopia and highlighted that while financing constraints were the primary barrier for younger farmers planning biogas adoption, knowledge gaps and operational concerns were more significant for older farmers. Customized support mechanisms that addressed age-specific barriers boosted the conversion rate from planning to adoption.

The study highlights age-based trends that are consistent with new findings on the adoption of renewable energy in Sub-Saharan Africa. According to the data, younger farmers (41–50) are currently adopting more than elderly farmers (60+). This is because they have longer planning horizons, are more risk-tolerant, have easier access to information and are less physically constrained. The high planning to adoption rates in every age group, however, indicate a greater opportunity for increased adoption through age-appropriate interventions. According to the cited studies, these results imply that age affects the adoption of biogas through a variety of channels, including social networks, risk perception, physical capability and economic decision-making.

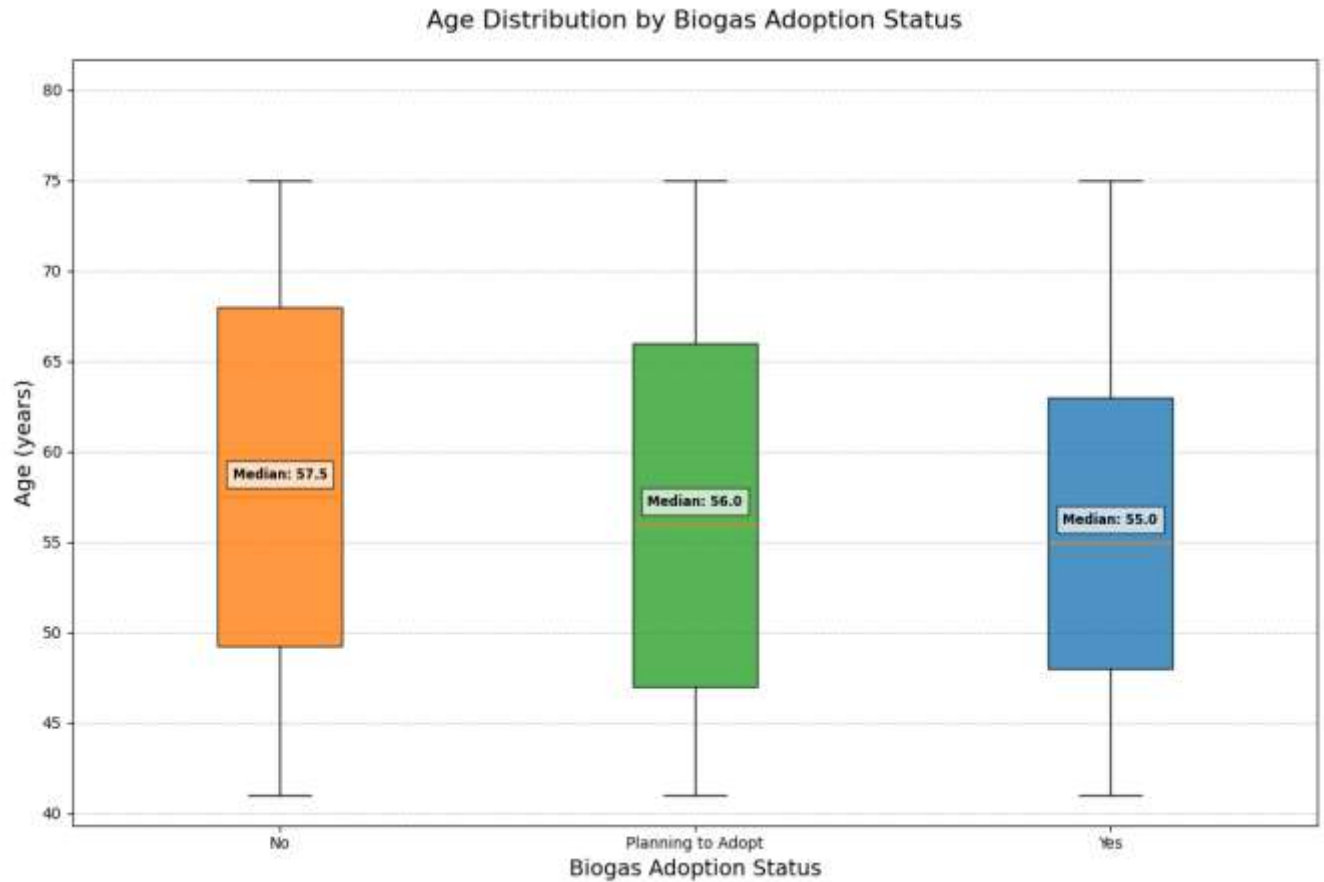


Figure 4.7: Biogas Adoption Status by Age Distribution

Source: Author (2025)

From figure 4.7 above, the gradual rise in the median age between adopters (55 years) and non-adopters (57.5 years) indicates that age affects adoption choices, most likely via a variety of factors including information access, risk perception, investment horizons and physical capability considerations. The significant overlap in age distributions across adoption categories, suggests that age influences technology choices by functioning as a moderating rather than a deterministic factor and interacting with other environmental and socioeconomic factors. According to these findings, age-appropriate interventions that target the particular issues and take advantage of the special opportunities presented by various age cohorts may be able to close adoption gaps and quicken Zimbabwe's transition to renewable energy in rural areas.

The meta-study in Sub-Saharan Africa by Tenaw and Beyene (2021), found that those aged 45–55 were 22 % more likely to own digesters than those over 60, confirming that biogas uptake

declines as farmers grow older. Additionally, the results support the investment horizon theory. According to the investment-horizon theory, households consider how long they believe they will be able to benefit from an investment and compare that to the estimated pay-back duration of a technology. This perceived time is highly age-dependent in the context of clean-energy transitions, including the adoption of biogas technology in Domboshava. The planning to adopt category's median age of 56.0 years places it in the middle of the adopter and non-adopter categories. Given this transitional position, an age-influenced adoption pathway may be possible. The plans to adopt are often preceded by actual adoption, with the lag time positively correlating with age.

4.3.5 Biogas Adoption by Land Area

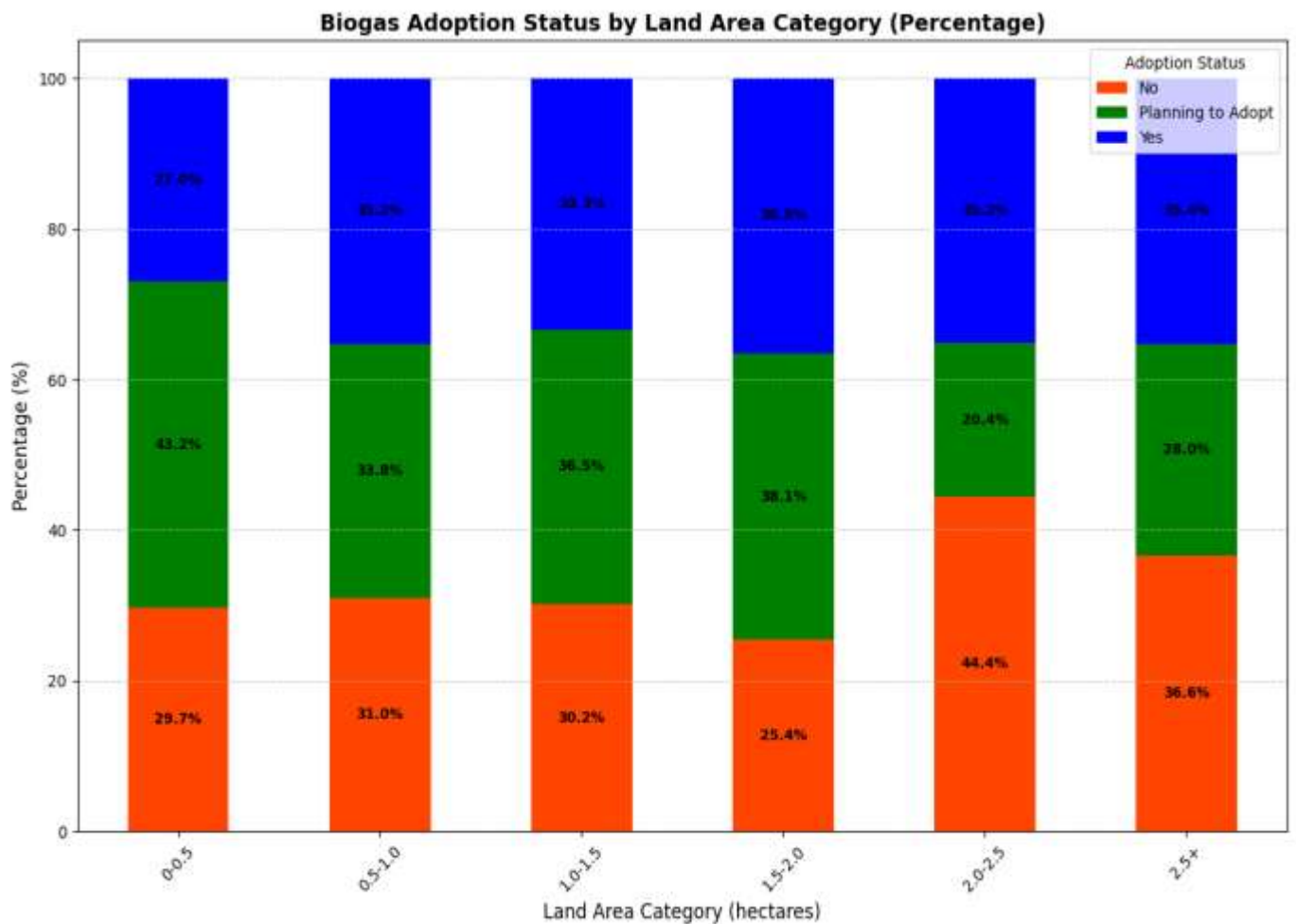


Figure 4.8: Biogas Adoption by land area

Source: Author (2025)

From Figure 4.8 above, biogas adoption varies among land area categories instead of increasing linearly as land holdings rise. The 1.5–2.0 hectare group has the highest adoption rate (36.5%), while the 0-0.5 hectare category has the lowest adoption rate (27.0%). This complex pattern implies that additional socioeconomic and contextual factors regulate the association between land resources and adoption decisions. There is no clear linear trend of rising adoption with increasing land area, according to the data, which reveals significant diversity in adoption rates across all land size categories. Comparable to households with substantially greater land holdings of 2.5+ hectares (35.4%), households with 0.5-1.0 hectares exhibit a high adoption rate (35.2%). This is against the oversimplified notion that higher adoption of technology is correlated with larger land ownership.

The most notable finding is that, in contrast to the more variable planning and non-adoption rates, present adoption rates are very consistent across the majority of land categories, varying from roughly 33% to 37% for land amounts above 0.5 hectares. This means that future adoption plans and non-adoption differ more significantly by land category, even when adoption has reached comparable levels across various land ownership patterns. The graphic shows that households in all land size categories have significantly embraced biogas technology, proving that biogas solutions can work on a variety of farm sizes in rural Zimbabwe.

Marambanyika et al. (2020), in their study in Zimbabwe, found that land holding size influences biogas adoption through multiple, sometimes contradictory pathways, creating non-linear relationships between land area and adoption likelihood. According to their research, adoption rates were frequently greater on medium-sized farms (1-2 hectares) than on smaller or bigger farms. This was due to a complex web of mediating factors that went beyond the availability of resources. Their findings highlight a complex relationship between adoption trends and land size calling into question the oversimplified view that adoption is affected by resource limitations.

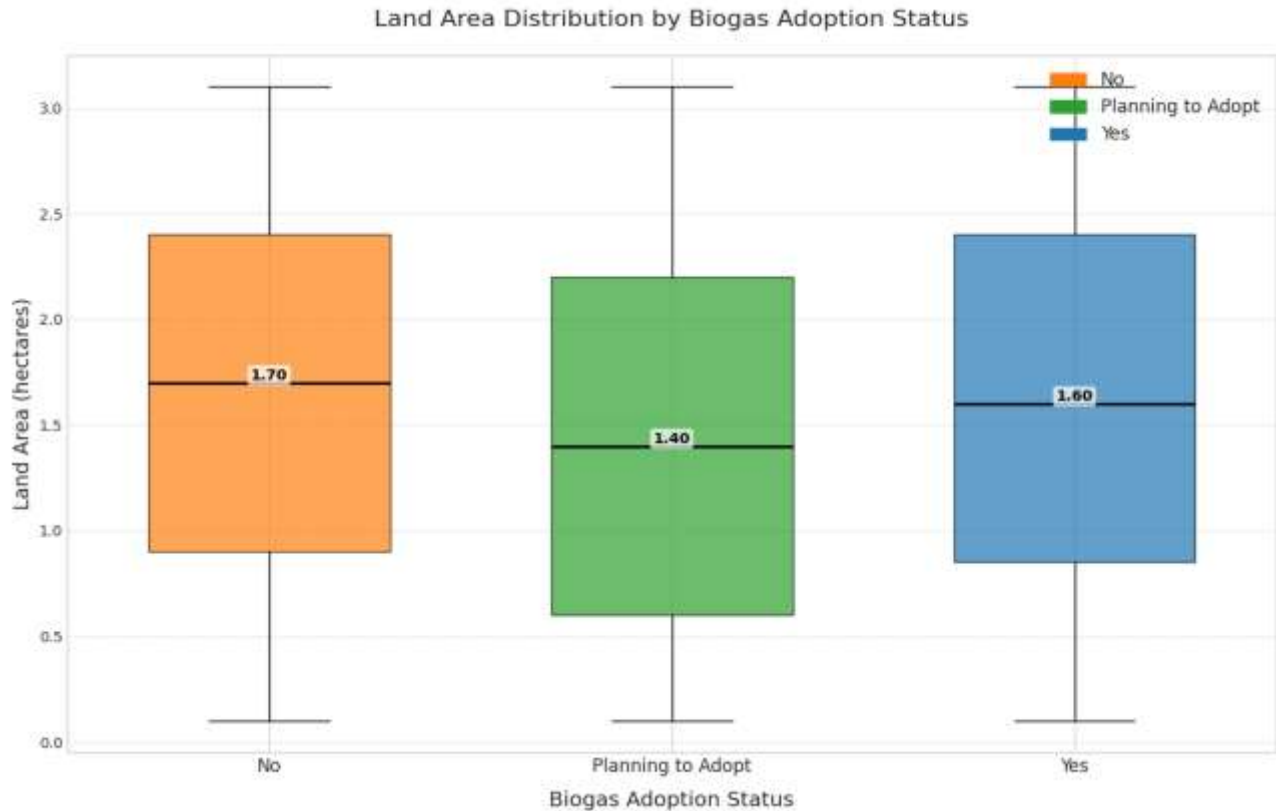


Figure 4.9: Biogas adoption by land area distribution

Source: Author (2025)

From Figure 4.9 above, households that intend to implement biogas technology typically own less land (median 1.40 hectares) than those that have already adopted (median 1.60 hectares) or have not (median 1.70 hectares). This implies a non-linear correlation between land area and the degree of biogas usage. The results indicate that households with larger land holdings prioritize various significant overlaps in land area distributions across all three adoption categories, indicating that while land area may influence adoption decisions, it is not a deterministic factor for the livestock farmers in Domboshava.

The Diffusion theory by Rogers (2003), highlights that an innovation spreads throughout a population and adoption thresholds shift over time. According to the theory, adoption uptake is generally higher in the early phases of diffusion and gradually lower in the later stages as the invention gains traction, standardization and social acceptance. This temporal dimension of the diffusion process is reflected in the land holdings of adopters in the box and whisker plot.

Furthermore, Namirembe et al. (2024), highlighted in their study in Uganda, that the adoption of biogas technology follows the diffusion theory as influenced by socio-economic factors, including land area.

4.3.6 Biogas Adoption by Livestock Ownership

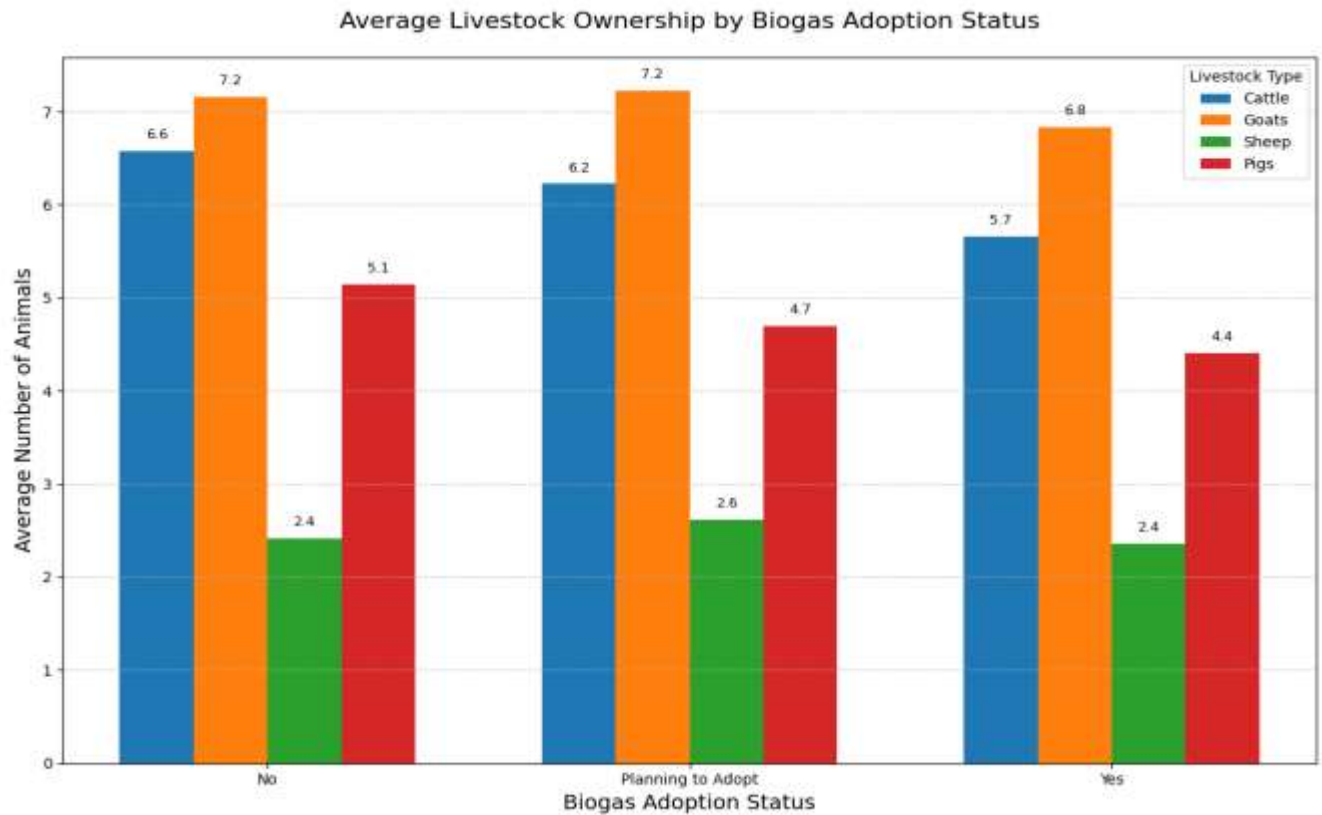


Figure 4.10: Biogas Adoption by livestock ownership

Source: Author (2025)

From Figure 4.10 above, across all adoption categories, goat ownership remains consistently high, with non-adopters and prospective adopters each owning an average of 7.2 goats, whilst current adopters report a slightly lower average of 6.8 goats. Cattle ownership exhibits notable variation across adoption statuses, as shown by non-adopters averaging 6.6 cattle, prospective adopters owning an average of 6.2 and current adopters having the lowest average at 5.7. Sheep constitute the smallest livestock holdings across all groups, with non-adopters and adopters each averaging 2.4 sheep, while those planning to adopt report a slightly higher average of 2.6. Lastly,

pig ownership highlights a clear downward trend shown by non-adopters averaging 5.1 pigs, prospective adopters averaging 4.7 and current adopters averaging 4.4.

The findings in Figure 4.10 confirm the findings by Berhe et al. (2017), which highlighted that cattle ownership was negatively and significantly correlated to the probability of choosing biogas energy, indicating that households with larger herds may prioritize alternative resource allocation strategies or energy preferences. This observation aligns with the energy stacking theory, which posits that households do not necessarily transition linearly from traditional to modern energy sources, but rather adopt a mix of energy options based on contextual needs and circumstances.

The findings highlight patterns that suggest biogas adopters may be optimizing their livestock holdings with efficiency. Specifically, the relatively lower cattle ownership among adopters could reflect a way of utilizing fewer livestock units more efficiently for biogas production, thereby enabling households to meet their energy needs while simultaneously reducing herd size and the associated maintenance costs. Livestock farmers who are planning to adopt biogas technology display distinct transitional characteristics, notably a slightly higher average ownership of sheep compared to both adopters and non-adopters. Yasmin et al. (2022) found that households with more land and livestock that produce dung are more likely to adopt biogas technology, which is consistent with their findings that resource endowments have a significant impact on plans for biogas adoption.

Goat manure's high total nitrogen content and fermentation stability make it an effective feedstock for anaerobic digestion (Haque et al., 2021). Its superior nitrogen composition, relative to other types of livestock manure, enhances its suitability for biogas production. This characteristic can partly explain the consistently high levels of goat ownership observed across all adoption categories.

Figure 4.10 highlights important patterns of the complex relationship between livestock assets and renewable energy adoption in rural settings including Domboshava. The findings suggest that biogas adoption is not only a function of livestock quantity but rather reflects strategic decision-making regarding the composition and management of livestock units.

4.3.7 Biogas Adoption by Off-farm Income

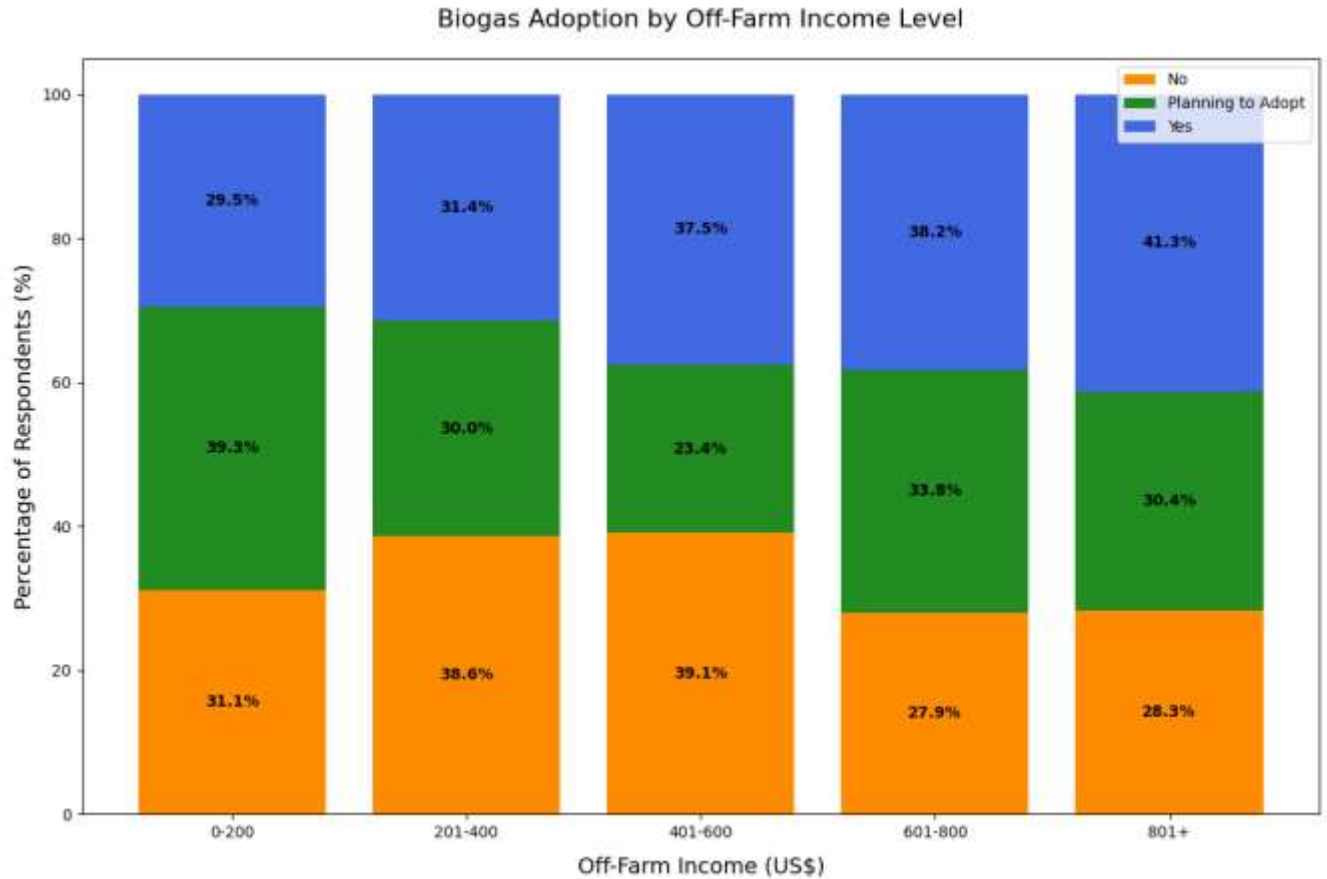


Figure 4.11: Biogas Adoption by Off-farm Income

Source: Author (2025)

Figure 4.11 highlights a positive correlation between off-farm income and biogas adoption rates. As household off-farm income increases from the lowest income bracket of US\$0–200 to the highest US\$801 and above, the proportion of households that have adopted biogas technology rises steadily, increasing from 29.5% to 41.3%. This trend suggests that higher off-farm income enhances the financial capacity of households to invest in renewable energy technologies, including biogas. The lowest income group of US\$0–200 highlights the highest proportion of households planning to adopt at 39.3% while the income group US\$401-600 shows the lowest planning to adopt rate at 23.4%. This pattern suggests that factors beyond income, including perceived need, access to information, or subsidy eligibility, influence plans to adopt biogas technology.

Getaneh et al. (2024) noted that annual household income is a key determinant of biogas adoption, reporting a statistically significant association between income levels and adoption rates. Their study found that 40.6% of biogas adopters belonged to households within the highest annual income bracket and that only households with above-average income levels adopted biogas technologies. These findings underscore the critical role of financial capacity, including off-farm income, in facilitating the uptake of biogas technology. Furthermore, Kulugomba et al. (2024) identified the high installation cost of biogas systems as the most significant obstacle to their adoption. These findings explain why households with higher levels of off-farm income exhibit higher adoption rates of biogas technology. Hence, policies aimed at enhancing off-farm income opportunities combined with targeted subsidy interventions represent the most effective strategy for promoting widespread biogas adoption for livestock farmers in Domboshava.

4.4 Chapter Summary

This chapter examined the adoption and use of biogas technology among livestock farmers in Domboshava, Zimbabwe. It focused on household characteristics including gender, age, education, income, land size and livestock ownership. The results highlight that biogas adoption is strongly influenced by off-farm income and resource availability. Goat ownership remained high across all groups, highlighting its suitability for biogas production. Cattle ownership was lower among adopters, suggesting other external factors influence cattle management. The chapter also revealed diverse usage patterns among adopters. In summary, adoption is shaped by strategic decisions rather than solely by livestock units.

CHAPTER 5

DETERMINANTS OF BIOGAS TECHNOLOGY ADOPTION AMONG LIVESTOCK FARMERS IN DOMBOSHAVA

5.1 Introduction

The socioeconomic elements impacting livestock farmers' adoption of biogas in Domboshava, Zimbabwe, are highlighted in this chapter. The analysis aims to identify key enablers and barriers to adoption at the household level. The findings offer insights that inform targeted policies and programs to promote wider biogas use in rural areas.

5.2 Model Diagnostics

5.2.1 Multicollinearity Diagnostics

The variance inflation factor (VIF) values and the associated tolerance levels were calculated in order to evaluate the existence of multicollinearity among the independent variables. Table 5.1 below displays the findings:

Table 5.1: Multicollinearity Results.

Independent Variable	Variance Inflation Factor (VIF)	Tolerance
Age	1.663	0.602
Off-farm income	3.002	0.333
Land area	1.717	0.582
Gender	1.512	0.661
Livestock units	1.713	0.584
Education	1.498	0.668
Extension	1.532	0.653
Access to credit	1.532	0.653
Energy Costs	1.011	0.989
Mean	1.687	0.636

Source: Author (2025)

From Table 5.1 above, all VIF values range from 1.011 to 3.002, and the corresponding tolerance values ranged from 0.333 to 0.989. These values are well within acceptable thresholds, where a VIF below 10 or a tolerance greater than 0.1 is considered to indicate an absence of serious multicollinearity (Gujarati, 2021). Hence, multicollinearity is not a concern in this model.

Furthermore, the mean VIF of 1.687 and mean tolerance of 0.636 indicate a high degree of overall independence among the predictor variables.

5.2.2 Leverage Diagnostic Plot

The Figure 5.1 below highlights the leverage diagnostic plot for the binary logistic regression.

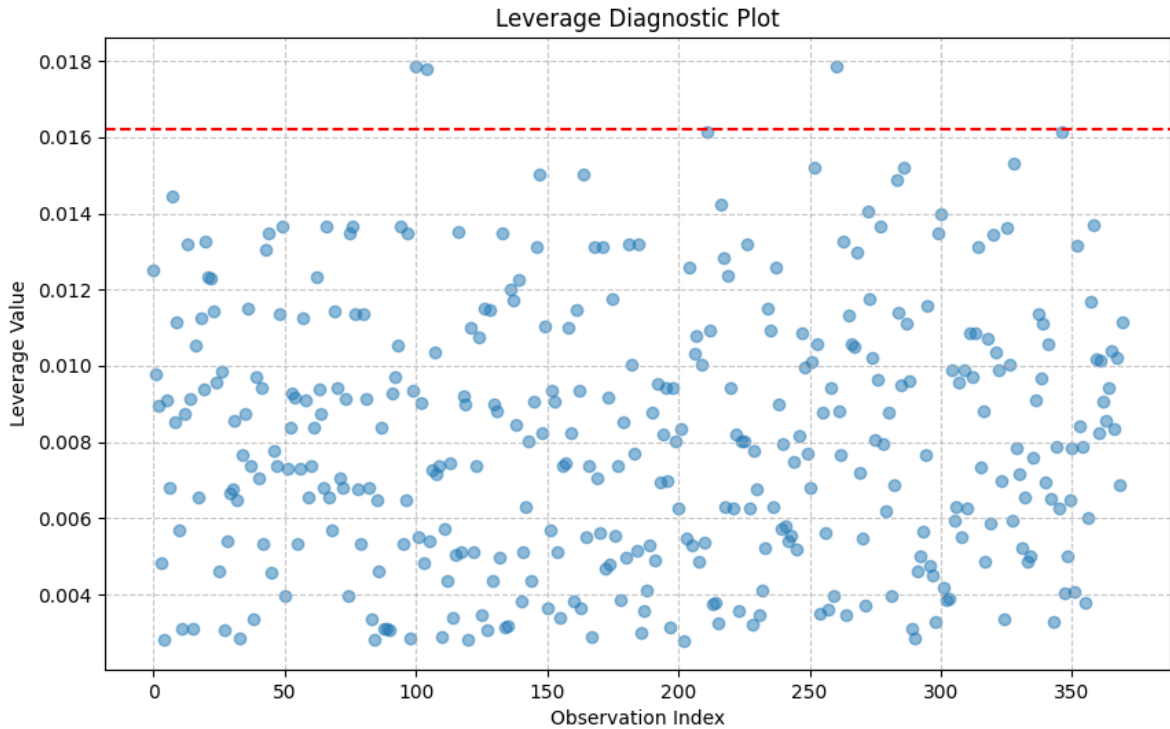


Figure 5.1: Leverage Diagnostic Plot

Source: Author (2025)

Figure 5.1 presents the leverage values for each observation in the dataset. Leverage measures the influence of each data point based on its predictor values. High leverage observations may disproportionately affect the model's parameter estimates. The red dashed line indicates the threshold for high leverage. From Figure 5.1, the threshold is approximately 0.016, indicating that observations exceeding this line may be considered potentially influential. Most of the observations are below the leverage threshold, and only a very small number of observations slightly exceed the threshold. Hence, the distribution of leverage values suggests that the dataset

does not contain highly influential observations and is unlikely to be biased due to leverage-related influence from specific cases.

5.2.3 Residual Diagnostic Plot

The Figure 5.1 below highlights the residual diagnostic plot for the binary logistic regression.

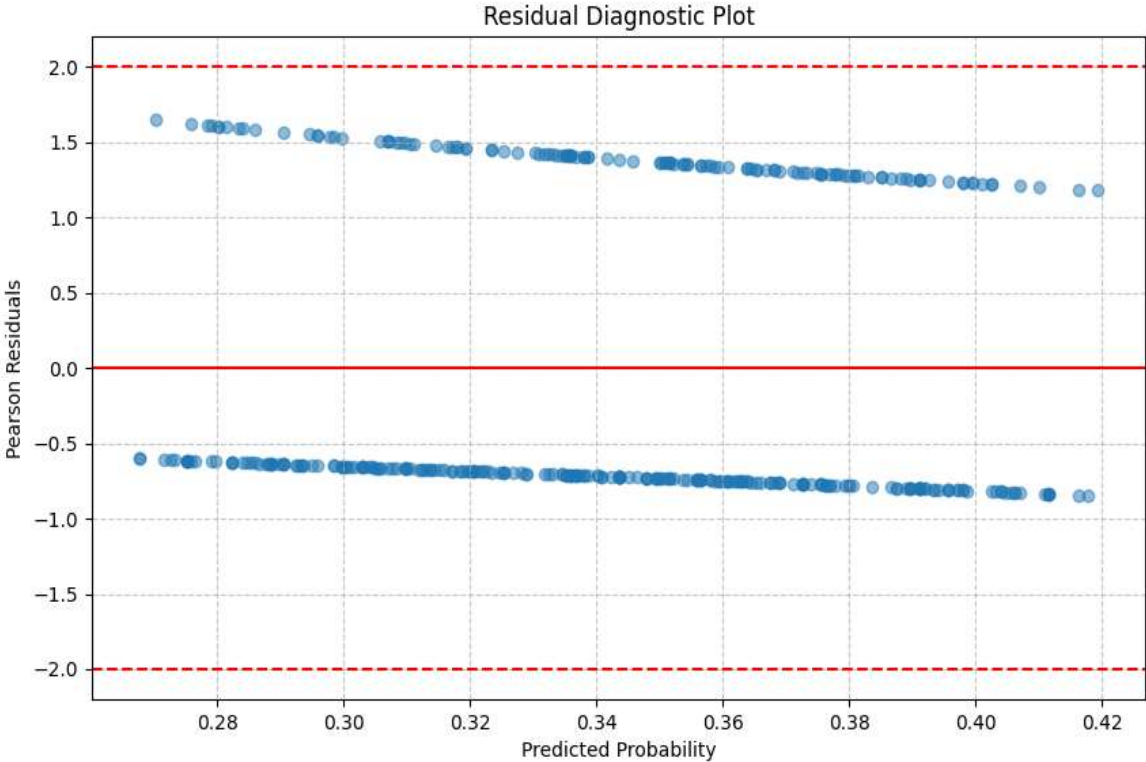


Figure 5.2: Residual Diagnostic Plot

Source: Author (2025)

Figure 5.2 above, highlights the Pearson residuals versus predicted probability plot, which is used to evaluate the logistic regression model fit. The residuals are bounded within the ± 2 horizontal red dashed lines, which highlights the threshold for identifying potential outliers or points of poor fit. All the residual points fall within the threshold and indicate that the model does not have extreme outliers and unusually influential observations. Furthermore, the points are fairly symmetrically distributed around the horizontal red line at zero, which represents good

model prediction. The symmetry highlights that the model does not over-predict or under-predict across the range of predicted probabilities.

5.2.4 Hosmer-Lemeshow Goodness of Fit Test

Table 5.2: Hosmer-Lemeshow Goodness of Fit Test

Model	Chi2 χ^2 (8) value	P value
	10.41	0.237

$p > 0.05$; H_0 : no significant difference between observed and predicted event rates

Author (2025)

Following the failure to reject the null hypothesis, the results from Table 5.2 above demonstrate that the model fits the data well without consistently over- or under-predicting. The relationship between the predictors and the adoption of biogas technology is thus suitably described by the logistic regression model. Hosmer-Lemeshow results align with the Pseudo-R-squared results in table 5.3 below. With a logistic regression pseudo R-squared of 0.4393, the model is estimated to account for 43.93% of the variance in the dependent variable. However, since pseudo R-squared values provide a general sense of model fit estimated using a probability distribution of maximum likelihood, the results cannot be directly compared to R-squared in linear regression.

5.2.5 Heteroscedasticity Test

A major concern in linear regression, where the assumption of homoscedasticity is essential for the validity of statistical inference, is heteroscedasticity, which is the existence of non-constant variance in the regression model's error terms. However, for the binary logistic regression, the model is based on maximum likelihood estimation. Hence, for the binary logistic regression, the assumption of homoscedasticity is not required, because the model is built on the Bernoulli distribution where the variance of the outcome is a function of the mean. Therefore, the model inherently accounts for non-constant variance.

5.3 Binary Logistic Regression Model

Table 5.3: Binary Logistic Regression Estimates

Variable	Marginal Effects (dy/dx)	Standard error (Std.Err.)
Age	-0.002	0.050
Gender	0.249***	0.052
Education	-0.061	0.089
Off-Farm Income	0.296***	0.047
Land area	0.311***	0.051
Access to Credit (0, 1)	0.188***	0.056
Access to Extension (0, 1)	0.177***	0.051
Energy Costs	0.084*	0.044
Livestock Units	0.076*	0.040
Constant	-2.004***	0.236
Pseudo McFadden's R ² :	0.439	
LR chi ² (9):	208.42	
Prob > chi ² :	0.000	
Number of observations	370	

Note: ***p<0.01, **p<0.05, *p<0.1

Dependent Variable: Biogas Adoption (0-NonAdoption; 1-Adoption)

Source: Author (2025)

5.3.1 Gender

Domboshava female livestock farmers are 24.9 percentage points more likely than their male counterparts to adopt biogas technology, according to the statistically significant effect of gender (marginal effect = 0.249, p<0.01). The significant difference indicates the existence of persistent gender-based barriers that limit equitable access to and adoption of agricultural technologies. The finding aligns with descriptive statistics, which indicated that when empowered and included in decision-making processes, women are not only willing but also proactive adopters of clean energy technologies including biogas. This highlights the importance of designing gender-responsive programs that recognize and leverage the unique roles and needs of women in biogas adoption for livestock farmers in Domboshava and Zimbabwe at large.

Pradhan et al. (2024) examined the benefits of biogas adoption in Nepal, highlighting how the technology has brought numerous advantages to local women and the environment. The findings suggested that installing household biogas technologies saves time for women and improves their

respiratory health. Hence, women were more inclined to adopt biogas technology than their male counterparts. Khadka (2020) highlighted that women's perspectives on biogas is based on its health benefits, sustainability and time-saving aspects, which are particularly significant for women in rural communities, including Domboshava. Hence, there is a need for gender-sensitive approaches in biogas promotion strategies in rural communities (Wilkes and Dijk, 2017).

5.3.2 Off-Farm Income

Adoption of biogas is 29.6 percentage points more likely when off-farm income is available ($p < 0.01$). This demonstrates how crucial financial resources are in influencing decisions about the adoption of new technologies. The results indicate that off-farm income serves as a critical enabler of biogas adoption for livestock farmers in Domboshava. Off-farm income provides liquidity, reduces credit constraints and improves risk tolerance, which is essential for adopting capital-intensive systems including biogas. Danso-Abbeam et al. (2020), a study in Ghana, highlighted that non-farm income boosts household welfare and increases the likelihood of adopting improved farming technologies. Furthermore, Bontsa et al. (2023) highlighted that off-farm income plays a critical role in shaping perceptions and willingness to adopt new technologies in the Eastern Cape, South Africa. Households with diverse income sources were more open to risk-taking and long-term investments.

5.3.3 Land area

A marginal effect of 0.311 ($p < 0.01$) indicates that the size of the landholding is the most significant factor in determining the adoption of biogas, with a 31.1 percentage point increase in the likelihood of adopting the technology for every unit increase in land area. Hence, policies aimed at promoting biogas adoption should consider landholding size as a critical factor. Support mechanisms, including subsidies or communal biogas facilities, should be targeted to assist smallholder farmers who may face spatial and resource constraints. Ngcobo et al. (2022) carried out a study in Melani village, South Africa, using binary logistic regression to analyze factors affecting biogas adoption. The results highlighted that land size positively influences biogas adoption as it provides sufficient space for installing digesters and managing livestock waste effectively. Ketuama and Roubík (2024) conducted a study in Cameroon and highlighted that landholding size significantly affects farmers' willingness to pay for small-scale biogas plants.

5.3.4 Access to Credit

The availability of credit significantly increases the probability of biogas adoption by 18.8 percentage points ($p < 0.01$), indicating the importance of financial access in addressing initial capital barriers associated with the adoption of biogas. Access to credit provides households with the necessary capital to invest in biogas systems. Furthermore, credit facilities often come with additional support, including training and maintenance services, which enhance the sustainability of biogas adoption. Hence, initiatives including low-interest loans, subsidies, and partnerships with local cooperatives to facilitate the financing of biogas installations are critical to enhance the adoption of biogas technology in Domboshava. Kulugomba et al. (2024) carried out a study in Malawi and noted that the provision of soft loans and subsidies is essential to make biogas technology affordable for rural communities. The study indicated that without financial support mechanisms, the adoption rate remains low due to the prohibitive upfront investment required. Situmeang et al. (2022) assessed a credit scheme in Indonesia that allowed farmers to access credit with varying interest rates to finance small-scale biogas installations. The findings highlighted that the initiative enabled farmers to build biogas systems, thereby making the technology more accessible.

5.3.5 Access to Extension

The likelihood of biogas adoption increases by a significant 17.7 percentage points when extension services are available ($p < 0.01$). This highlights the critical role of extension services in influencing biogas adoption at the household level, as providing Domboshava livestock farmers with technical support and effective information dissemination can significantly shape their adoption decisions. Therefore, it is important to strengthen and expand agricultural extension services to improve biogas adoption for livestock farmers in Domboshava. Chekol et al. (2022) investigated Ethiopian rural households' adoption patterns of small-scale biogas technology. The results of the study demonstrated that the adoption of biogas technology is positively and significantly impacted by the expansion of extension services. According to this, extension services are essential for spreading knowledge and promoting the use of sustainable energy sources. According to Arowosegbe et al. (2024), agricultural extension agents help Nigeria's agricultural sector become more productive, more sustainable, and more receptive to new technologies. The study indicated that extension serves as a catalyst for the adoption of advanced technologies.

5.3.6 Energy Costs

At the 10% level, the probability of adopting biogas increases by 8.4 percentage points in response to rising energy costs, which is marginally significant ($p < 0.1$). This suggests that while potential energy cost may incentivize adoption, its effect is relatively limited compared to more significant factors. The findings highlight that increasing awareness about the long-term economic benefits of biogas can help shift household perceptions, making energy cost savings a more important factor in adoption decisions. Shallo and Sime (2025) conducted a study in Ethiopia to assess the impact of biogas adoption on annual energy expenditure. The results indicated that biogas technology enhanced household income by decreasing fuel purchases, indicating that energy cost considerations are important in adoption decisions. Sarker et al. (2020) evaluated the economic viability and factors influencing the adoption of biogas technology in Bangladesh. The findings highlighted that factors including energy costs, livestock possession, extension services, education, family size, income and access to credit significantly influenced adoption decisions. The study highlighted the importance of energy costs as a critical determinant of biogas adoption.

5.3.7 Livestock Units

The findings show that the likelihood of adoption is 7.6 percentage points higher for households with more livestock units, which is marginally significant at $p < 0.1$. The findings indicate that livestock organic material is a primary input for biogas generation, highlighting that ownership of sufficient livestock units is both a technical prerequisite and an enabling factor for adoption. The availability of livestock manure directly influences the feasibility and efficiency of biogas systems, making it an essential factor for livestock farmers considering biogas adoption in Domboshava. Czubaszek et al. (2022) highlighted that livestock manure is a key raw material for biogas production, and households with more livestock units had a higher probability of adopting biogas systems. Kulichkova et al. (2020) noted that maintaining livestock is crucial for the sustained use of biogas systems, as it ensures a continuous supply of manure for biogas production for livestock farmers in Eastern and Central Europe. These findings highlight the critical nature of livestock units as an important determinant of biogas adoption.

5.4 Chapter Summary

This chapter provides valuable insights into the factors driving biogas adoption among livestock farmers in Domboshava. The findings highlight the importance of economic and resource-related factors, including landholding size, off-farm income and access to credit, which significantly influence the adoption decision. In contrast, age and education, while commonly associated with technology adoption in general, were found to be non-significant. The results contribute to the broader understanding of biogas adoption and provide policy recommendations aimed at increasing adoption rates. These include improving access to financial resources, supporting extension services and addressing gendered barriers to ensure a more inclusive adoption process.

CHAPTER 6

DETERMINANTS OF PLANS TO ADOPT BIOGAS TECHNOLOGY AMONG LIVESTOCK FARMERS IN DOMBOSHAVA

6.1 Introduction

This chapter employs multinomial logistic regression model to explore how socio-economic factors affect the likelihood of households belonging to various biogas adoption categories, using non-adoption as the baseline reference group. The findings build on the earlier binary logistic regression by providing a more detailed understanding of the adoption process. Key results include the significant predictors for each adoption category relative to non-adoption. These results provide valuable insights for designing targeted interventions to promote biogas technology adoption.

6.2 Model Diagnostics

6.2.1 Multicollinearity Results

Variance Inflation factor (VIF) values and their corresponding tolerance levels were computed. Table 6.1 below displays the findings:

Table 6.1: Multicollinearity Results.

Independent Variable	Variance Inflation Factor (VIF)	Tolerance
Age	1.29	0.775
Off-farm income	1.87	0.535
Land area	2.65	0.377
Gender	1.38	0.725
Livestock units	2.48	0.403
Education	1.54	0.649
Extension	1.76	0.568
Access to credit	1.65	0.606
Energy Costs	1.36	0.735
Mean	1.78	0.597

Source: Author (2025)

From Table 6.1 above, all VIF values range from 1.29 to 2.65 and the corresponding tolerance values ranged from 0.377 to 0.775. These values are well within acceptable thresholds, where a VIF below 10 or a tolerance greater than 0.1 is considered to highlight absence of multicollinearity. Therefore, multicollinearity is not an issue in this model. Furthermore, the mean VIF of 1.78 and mean tolerance of 0.597 indicate a high degree of independence among the explanatory variables.

6.2.2 Leverage Diagnostic Plot

The Figure 6.1 below highlights the Cook's distance leverage diagnostic plot for the binary logistic regression.

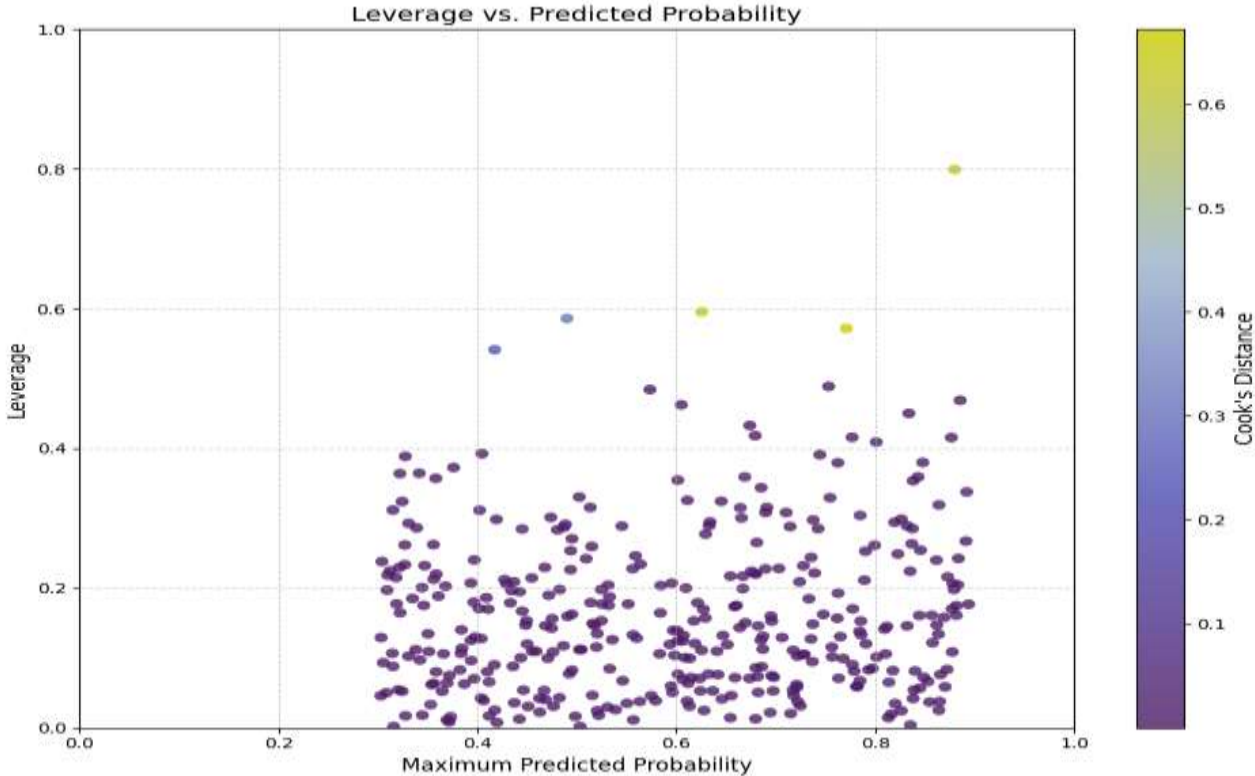


Figure 6.1: Cook's Distance Leverage Diagnostic Plot

Source: Author (2025)

Figure 6.1 above highlights the leverage values of each observation against their predicted probabilities. The leverage calculates how far the predictors for each observation deviate from the dataset's mean predictor values. Cook's distance, which quantifies the impact of every

observation on the model, is represented by the colour gradient. Most high leverage points have relatively low Cook's distance values, as indicated by the Cook's distance colour gradient, suggesting that they have minimal impact on the model's parameter estimates.

6.2.3 Residual Diagnostic Plots

The Figure 6.2 below highlights the residual diagnostic plot for the binary logistic regression.

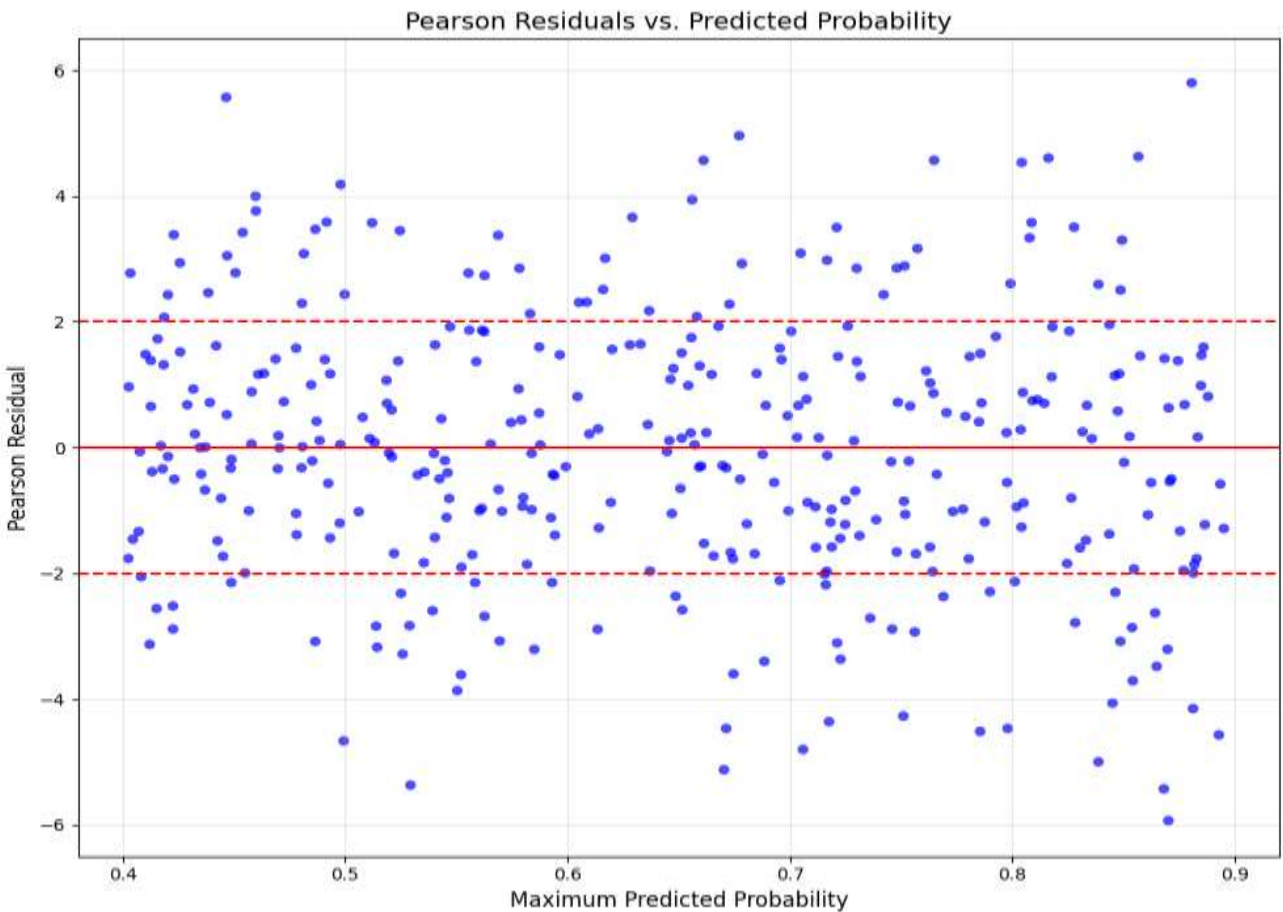


Figure 6.2: Residual Diagnostic Plot

Source: Author (2025)

Figure 6.2 above highlights the Pearson residuals against predicted probabilities. These are the standardized variations between the values that were observed and those that were predicted. Most of the residual points are distributed fairly evenly around the zero threshold across the range of predicted probabilities, highlighting that the model generally fits the data well without systematic bias. Hence, the residuals fall within the ± 2 band, which indicates that the model's

predictions are within an acceptable range of error for most of the observations, with a few outliers that can be observed outside the +/-2 band.

6.2.4 Hosmer-Lemeshow Goodness of Fit Test

Table 6.2: Hosmer-Lemeshow Goodness of Fit Test

Model	Chi2 χ^2 (8) value	P value
Adopters vs Non-Adopters	8.43	0.393
Intending to Adopt vs Non-Adopters	6.74	0.565

$p > 0.05$; H_0 : no significant difference between observed and predicted event rates

Since both p-values are substantially higher than the significance level of 0.05, the results from Table 6.2 above demonstrate that we cannot rule out the null hypothesis of good fit. This shows that the model does a good job of fitting the data for both comparisons.

6.2.5 Heteroscedasticity Analysis for Multinomial Logistic Regression

The multinomial logistic regression utilises the maximum likelihood estimation rather than the estimation method that does not require homoscedasticity for consistency of parameter estimates. Hence, the model assumes categorical outcomes following a multinomial distribution and not normally distributed errors with constant variance. Therefore, the Hosmer-Lemeshow Goodness of fit presents the appropriate results of the model's validity.

6.3 Multinomial Logistic Regression Model

Table 6.3: Multinomial Logistic Regression Estimates

Variables	Intending to Adopt with Non-Adoption as the reference category		Adoption with Non-Adoption as the reference category	
	Dy/dx	Std.Err.	Dy/dx	Std.Err.
Age	0.001	0.013	-0.001	0.681
Gender	0.005	0.167	0.127**	0.026
Education	0.062**	0.157	0.016	0.234
Off-Farm Income	0.072***	0.187	0.143***	0.192
Land area	0.049**	0.141	0.178***	0.163
Access to Credit (0, 1)	0.058**	0.180	0.118***	0.186
Access to Extension (0, 1)	0.117***	0.196	0.084***	0.213
Energy Costs	0.021	0.149	0.063**	0.123
Livestock Units	0.006	0.099	0.059**	0.118
Intercept	-3.126***	0.695	-2.481***	0.782
Pseudo McFadden's R ² :	0.298			
LR chi ² (18):	296.75			
Prob > chi ² :	0.001			
Number of observations	370			

Note: ***p<0.01, **p<0.05, *p<0.1

Source: Author (2025)

6.3.1 Land Area

From Table 6.3 above, land area has a strong positive effect on adoption, significant at 1% for current adopters. Hence, each additional hectare increased adoption probability by 17.8 percentage points with non-adoption as the reference category. Land area has a moderate positive effect on those intending to adopt biogas, significant at 5%. Each additional hectare increases the plans to adopt probability by 4.9 percentage points with non-adoption as the reference category. The stronger effect for current adoption compared to plans to adopt indicates that land constraints primarily affect implementation rather than planning for livestock farmers in Domboshava. Bang and Han (2025) highlighted farm size as a significant determinant of biogas

adoption in South Korea, with the influence less pronounced among those considering adoption. According to Midamba et al. (2021), farmers who own larger tracts of land are more likely to implement sustainable agricultural practices than those who are planning to practice. Therefore, these studies indicate that land area is a critical factor for those already using biogas technology than for those planning to adopt.

6.3.2 Livestock Units

The results highlight that among current adopters, livestock units had a positive effect of 0.059 on their biogas technology adoption, which is significant at the 5% level with non-adoption serving as the reference category. Each additional livestock unit increases adoption probability by 5.9 percentage points. The number of livestock units does not have an effect on those intending to adopt, with non-adopters as the reference category. The result highlights that the actual implementation of biogas adoption by livestock farmers in Domboshava depends on having sufficient animal waste for system operation. According to Nhundu et al. (2023), total livestock units significantly influenced the number of improved technologies adopted by farmers in Zimbabwe. Additionally, Ayal and Mamo (2024) noted that in central Ethiopia, the adoption of climate-smart livestock production technologies is significantly correlated with livestock holdings. These studies indicate the importance of livestock units in the adoption of agricultural technologies, including biogas.

6.3.3 Off-Farm Income

The results highlight off-farm income positive effect of 0.143 on biogas adoption, significant at 1%. Hence, access to off-farm income increased adoption probability by 14.3 percentage points with non-adoption as the reference category for livestock farmers who adopted biogas technology. For those intending to adopt, off-farm income increases plans to adopt probability by 7.2, significant at 1% with non-adoption as the reference category. The results highlight that off-farm income is a key enabler of both biogas adoption plans and actual implementation of the biogas technology. Off-farm income affects both the ability to afford initial installation costs and the capacity to maintain systems over time. According to Rahman et al. (2021), decisions about the adoption of biogas technology in Bangladesh were significantly influenced by the availability of capital derived from off-farm income. Ali et al. (2023) noted that financial capacity through off-farm income is a significant factor in biogas technology adoption in Pakistan. The empirical

studies align with the results from Domboshava, by highlighting the critical role played by off-farm income for those intending to adopt biogas and those already using the technology.

6.3.4 Access to Credit

Access to credit has a positive effect on biogas technology, adoption significant at 1% for current adopters. Credit access increased adoption probability for current users by 11.8 percentage points with non-adopters as the reference category. For those intending to adopt, there is a positive effect of access to credit, significant at 5%. Hence, access to credit increases biogas technology adoption by probability by 5.8 percentage points for those intending to adopt with non-adoption as the reference category. The significant effect on both current adoption and plans highlights the role of financial institutions in promoting renewable energy transitions in Domboshava. According to Shallo and Sime (2025), noted in their study in Ethiopia that access to credit positively and significantly influenced the adoption of biogas technology. The study emphasizes how crucial credit availability is in the African setting. According to Sarker et al. (2020), credit availability had a significant impact on the uptake of biogas technology in Bangladesh, both for those who had already adopted and those who planned to do so.

6.3.5 Access to Extension

Access to extension had a positive effect on biogas technology adoption, significant at 1% for current adopters. Extension access increased adoption probability by 8.4 percentage points with non-adopters as the reference category. Access to extension has a positive effect on those intending to adopt and is significant at 1%. Hence, extension access increases adoption probability by 11.7 percentage points for those intending to adopt biogas technology with non-adopters as the reference category. Therefore, extension services have a slightly higher effect for those intending to adopt than for those who have already adopted the technology for livestock farmers in Domboshava. The results highlight that knowledge dissemination through extension services is critical in the early stages of the adoption decision process. Chekol et al. (2022) highlighted the importance of extension services in educating rural Ethiopian households about the benefits and operation of biogas systems. The study is complemented by the findings from Mukaila et al. (2024), who noted that access to agricultural extension services positively and significantly influenced cassava processors' plans to adopt biogas technology. These results

indicate the importance of information dissemination in biogas technology adoption for those who have adopted and those intending to adopt.

6.3.6 Education

The results highlight that education was not a significant variable in influencing biogas technology adoption for the current adopters. However, education has a positive effect on those intending to adopt and is significant at 5%. Therefore, an additional year of education increases plans to adopt probability by 6.2 percentage points with non-adoption as a reference category. The results indicate that education enhances receptiveness to new technologies and environmental awareness, which increases adoption plans for livestock farmers in Domboshava. Osei-Marfo et al. (2020) highlighted that higher education levels had a significantly direct effect on household heads' plans to adopt biogas technology. Higher education levels were associated with increased plans to adopt. However, Guntoro et al. (2024) noted that education did not significantly influence the willingness to adopt biogas technology for Vietnam pig farmers' adoption. Hence, education affects households differently depending on other socio-economic factors.

6.3.7 Gender

The gender variable had a positive effect on biogas adoption for current users and was significant at 5%. Since males were the base and females the target, the results highlight that being female increased the probability of adoption by 12.7 per cent for current users with non-adoption as the reference category. Gender was not a significant variable for those intending to adopt biogas technology. The results highlight that gender-based constraints operate primarily at the implementation stage rather than the planning stage of biogas technology adoption for livestock farmers in Domboshava. Pradhan et al. (2024) noted that women in Nepal are more likely to embrace clean cooking options, including biogas technology, and have more agency in household decision-making. This is an important observation, since women face direct exposure to indoor air pollution and the health benefits associated with cleaner energy sources. However, Uhunamure (2021) states that households headed by men are more likely than those headed by women to adopt biogas technology in South Africa's Limpopo province. The study highlights male-headed advantage in biogas uptake primarily to differential access to resources, control over investments and structural prerequisites including livestock, land and income. Therefore,

although females are more inclined to adopt biogas technology, social norms and values can affect the likelihood of adopting technologies in the African context, including Domboshava.

6.3.8 Energy Costs

Energy costs have a positive effect on the likelihood to adopt biogas technology for current users and significant at 5%. Hence, higher energy costs increase adoption probability by 6.3 percentage points for current adopters with non-adopters as the reference category. Energy costs are not a significant variable for those intending to adopt biogas technology. The results indicate that immediate economic motivations play a greater role in actual implementation than in any future plans to adopt biogas technology. The results highlight that energy cost savings are a primary factor for actual adopters, however, less prominently in the considerations of potential future adopters. Geddafa et al. (2023), noted that households facing higher energy costs were more likely to adopt biogas technology in rural Ethiopia. Luo et al. (2021) highlighted that the energy costs in Pakistan was a key enabler in households adopting biogas technology. The empirical evidence highlights the critical role of energy cost drivers in shaping the actual uptake of biogas technology as opposed to the planning stages of adoption.

6.4 Chapter Summary

The chapter presented the multinomial logistic regression results, which highlighted that different factors drive current adoption and plans to adopt biogas technology. Socio-economic factors, including income and credit, primarily affect actual implementation, while knowledge and information variables primarily affect future plans. The findings provide for more effective policy interventions that address specific barriers at each stage of the adoption decision process by accelerating the diffusion of biogas technologies in Domboshava and Zimbabwe at large.

CHAPTER 7

EFFECT OF BIOGAS TECHNOLOGY ADOPTION ON LIVELIHOODS FOR DOMBOSHAVA LIVESTOCK FARMERS

7.1 Introduction

This chapter explores the impact of biogas adoption on the livelihoods of livestock farmers in Domboshava, Zimbabwe, using multiple linear regression. Multiple linear regression was utilized over other methods including propensity score matching and endogenous switching regression that are designed primarily to address selection bias and endogeneity when estimating causal effects of a treatment variable. The livelihood index is created through Principal Component Analysis (PCA), combining livelihood indicators. The regression model examines how biogas adoption, among other independent variables, influences the livelihood index. Key assumptions of the model, including homoscedasticity and multicollinearity, are tested for validity. The chapter aims to provide insights into biogas's role in improving rural livelihoods and inform policy recommendations for its wider adoption.

7.2 Model Diagnostics

7.2.1 Principal Component Analysis

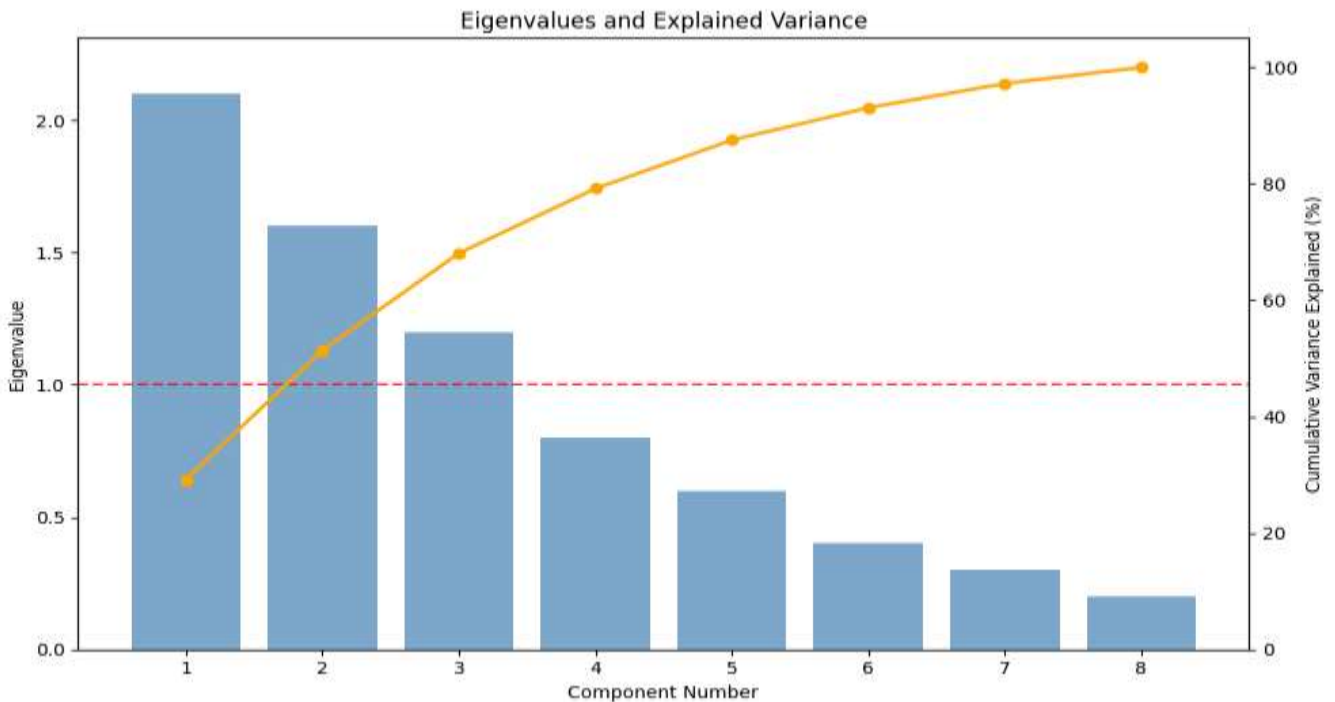


Figure 7.1: Scree Plot of Eigen Values after Principal Component Analysis

Source: Author (2025)

From Figure 7.1, the first component has the highest eigenvalue of approximately 2.1 followed by the second component at 1.4 and the third component at 1.1. The remaining components have eigenvalues less than 1.0, which progressively decreases. The red dashed horizontal line at an eigenvalue of 1.0 represents the Kaiser criterion, which is a common rule of highlighting that components with eigenvalues greater than 1.0 explain more variance than a single original variable and should be retained. Here, the first three components meet this criterion. The three components explain approximately 65% of the total variance of the livelihood index. This captures a substantial portion of the information contained in the original seven variables while achieving significant dimensionality reduction.

Table 7.1 Principal Component Analysis for Deriving the Livelihood Index

The table below highlights the various components of the livelihood index

Variable	PCA1	PCA2	PCA3	Commonality
Health Access	0.38	0.75	0.22	0.76
Number of years in community group	0.85	0.14	-0.10	0.75
Housing Quality	0.82	0.20	0.18	0.74
Environmental Sustainability	0.16	0.23	0.88	0.85
Energy Access	0.29	0.37	0.68	0.68
Agricultural Assets	0.71	-0.12	0.32	0.62
Income	0.35	0.84	0.12	0.84
Eigen Value	2.09	1.41	1.06	
% of Variance	45.80%	30.90%	23.20%	
Cumulative %	45.80%	76.80%	100%	

Source: Author (2025)

Principal Component Analysis (PCA) was used to create a livelihood index for the livestock farmers in Domboshava based on Table 7.1 above. Hence, by analyzing seven indicators across human, social, physical, financial, and environmental capital dimensions, three significant components collectively explaining 65.2% of the total variance were identified. PCA1, with an eigenvalue of 2.09, explains 45.8% of the variance and primarily represents social and physical

assets, including housing quality, number of years in community group and agricultural assets, which load highly on this component. The PCA2, with an eigenvalue of 1.41 and explaining 30.9% of the variance, captures economic and health dimensions, with income and health access highlighting the highest loadings. PCA3, with an eigenvalue of 1.06 and accounting for 23.2% of the variance, reflects environmental sustainability and energy access, as indicated by high loadings on environmental sustainability and energy access. The three components meet the Kaiser criterion of eigenvalues greater than 1.0, cumulatively explaining 100% of the variance and providing a robust basis for constructing a composite livelihood index.

7.2.2 Heteroscedasticity Test

The following modified Wald test was used in the study to determine whether heteroscedasticity was present:

Table 7.2: Breusch Pagan test for heteroscedasticity

Model	Test Statistic (LM)	df	P value
Breusch-Pagan Test	21.35**	27	0.027

*** $p < 0.01$; H_0 : Homoscedastic

Table 2 highlights the existence of heteroscedasticity. The null hypothesis, according to which the model is homoscedastic, is rejected since the Breusch-Pagan test is significant at 5%. To account for heteroscedasticity, the study used multiple linear regression with robust standard errors.

7.2.3 Multicollinearity Test

Table 7.3 Multicollinearity Test Results

Independent Variable	Variance Inflation Factor (VIF)	Tolerance
Age	1.30	0.769
Off-farm income	1.90	0.526
Land area	2.20	0.455
Gender	1.10	0.909
Livestock units	1.80	0.556
Biogas adoption	1.75	0.571
Education	1.40	0.714
Extension	1.70	0.588

Independent Variable	Variance Inflation Factor (VIF)	Tolerance
Access to credit	1.60	0.625
Energy Costs	1.50	0.667
Mean	1.63	0.638

Source: Author (2025)

From Table 7.3 above, all VIF values range from 1.10 to 2.20, and the corresponding tolerance values ranged from 0.455 to 0.909. These values are well within acceptable thresholds, where a VIF below 10 or a tolerance greater than 0.1 is considered to highlight the absence of multicollinearity. Hence, multicollinearity is not an issue for the multiple linear regression model.

7.3 Multiple Linear Regression Results

Table 7.4: Multiple Linear Regression Estimates

The table below highlights the effect of independent variables on the livelihood index

Variable	Coefficient	Robust Standard Error
Age	0.003	0.011
Gender	0.067	0.066
Education	0.178***	0.042
Off-Farm Income	0.195***	0.046
Land area	0.242***	0.055
Access to Credit (0, 1)	0.124**	0.059
Biogas Adoption (0, 1)	0.167**	0.038
Access to Extension (0, 1)	0.156***	0.054
Energy Costs	0.098*	0.051
Livestock Units	0.143***	0.048
Constant	0.124***	0.048
F-Statistic	58.32 (p<0.01)	
R-squared	0.602	
Adjusted R-squared	0.591	
Number of observations	370	

Note: ***p<0.01, **p<0.05, *p<0.1

Dependent Variable: Livelihood Index

Source: Author (2025)

The F-statistic of 58.32 and a p-value of less than 0.01 demonstrate the statistical significance of the regression model. Additionally, the R-squared is 0.602, meaning that the model accounts for about 60.2% of the variance in the livelihood index. The model has significant explanatory

power, as evidenced by the Adjusted R-squared of 0.591, which takes into account the number of predictors.

7.3.1 Effect of Education on Livelihoods

The livelihood index is positively impacted by the education variable, which is significant at 1%. Therefore, when all other factors are held constant, an increase of one unit in educational years results in a 0.178 unit increase in the livelihood index. This indicates the role of education level in enhancing the livelihoods of livestock farmers in Domboshava. Investment in education enhances productivity and economic outcomes. Furthermore, education helps households with skills and knowledge that improve agricultural practices. Tran et al. (2020) highlighted that education is a critical determinant of livelihoods for rural communities in Vietnam. The study noted that education enables households to be receptive to technologies. Moli et al. (2021) conducted a study in Bangladesh and noted that biogas adoption improved the incomes and livelihoods of the rural households in the country. The empirical studies highlight the importance of education and human capital on livelihoods. However, Abera et al. (2021) highlighted that education had a negative impact on key diversification strategies among rural communities in South-Western Ethiopia. Therefore, although education generally has a positive impact on household incomes and livelihoods, its effects can also be negative depending on the specific contextual factors.

7.3.2 Effect of Off-Farm Income on Livelihoods

The livelihood index is positively impacted by the off-farm income variable, which is significant at 1%. Therefore, when all other factors are held constant, a one unit increase in off-farm income corresponds to a 0.195 unit increase in the livelihood index. This highlights how crucial off-farm revenue is to raising the standard of living for livestock farmers in Domboshava. The Sustainable Livelihoods Framework highlights the importance of income diversification as a strategy for rural households to manage risk and improve resilience. Hence, off-farm activities allow households to reduce their dependence on agriculture alone as the source of income. Anang and Apedo (2023) noted that off-farm income enhanced the livelihood support systems for rural communities in northern Ghana. Li and Xu (2023) highlighted that off-farm income significantly reduced the energy poverty for rural households in China by improving their

livelihoods. Therefore, off-farm income is a critical factor for the improvement of livelihoods for livestock farmers in Domboshava.

7.3.3 Effect of Biogas Technology Adoption Income on Livelihoods

Adoption of biogas technology is an independent variable that is significant at 5% and positively affects the livelihood index. Hence, assuming all other factors remain unchanged, implementing biogas technology is linked to a 0.167 unit increase in the livelihood index. The findings demonstrate how crucial biogas technology is to raising Domboshava livestock farmers' standard of living. It is important to note that the coefficient's magnitude is smaller than expected, which may reflect the influence of other underlying factors that limit the full realization of livelihood benefits from biogas adoption. Rahman et al. (2021) highlighted that biogas technology adoption had a positive effect on the incomes and livelihoods in Bangladesh. The results indicated a significant effect on poverty reduction among the adopters. Shallo and Sime (2023) noted that the adoption of biogas technology significantly enhanced both energy security and household incomes in Ethiopia. The study employed a propensity score matching approach to facilitate a comparative analysis between adopters and non-adopters. Hence, empirical studies indicate that biogas adoption contributes to livelihood improvement, although the extent of this impact varies across contexts and among adopting households.

7.3.4 Effect of Land Area on Livelihoods

At 1%, the land area independent variable significantly improves the livelihood index. Therefore, assuming all other factors remain constant, a one unit increase in land area results in a 0.242 unit increase in the livelihood index. The large magnitude of the coefficient in relation to other independent variables indicates that land area is an important component in raising the standard of living for livestock farmers in Domboshava. Coulibaly and Li (2020) indicated that the loss of land by peri-urban farmers in Mali had a significant negative impact on the livelihoods of farmers. Livestock farmers were affected the most due to the nature of farming activities, which require more grazing land. Shackleton (2020) highlighted that mining operations, among other environmental factors, negatively affected the rural farmers in Limpopo province of South Africa. The study recommended the full restoration of land rights for the farmers to improve their livelihoods.

7.3.5 Effect of Access to Credit on Livelihoods

The access to credit variable is significant at 5% and has a positive effect on the livelihood index. Therefore, assuming all other factors remain unchanged, a one unit increase in credit availability results in a 0.124 unit increase in the livelihood index. Access to credit provides a fundamental component of cushioning livestock farmers in Domboshava from various risky factors which affect their livelihoods. Silong and Gadanakis (2020) indicated that credit access was a critical factor in improving the livelihoods for livestock farmers in Domboshava. The study highlighted that credit markets have hugely improved the savings of the livestock farmers in Nigeria. Felkner et al. (2022) indicated that credit access and market access were pivotal livelihood strategies for households in the forest areas of Cambodia. The study posited that access and market access enabled the rural farmers to diversify into non-forest related income generating activities. Hence, access to credit is a critical aspect of livelihood diversification for Domboshava livestock farmers.

7.3.6 Effect of Access to Extension on Livelihoods

Access to extension is significant at 1% and has a positive effect on the livelihood index. Therefore, assuming all other factors remain unchanged, a one unit increase in access to extension results in a 0.156 unit increase in the livelihood index. Access to extension is a key component of knowledge sharing and a facilitator of improving livelihood and income. Loki and Mdoda (2023) investigated how self-reliance and sustainable livelihoods in the Eastern Cape, South Africa, were impacted by access to extension services. The findings highlighted a significant positive effect of extension services on rural households that received regular and reliable visits from extension officers compared to those that did not receive such support. Akter (2020) noted that women's access to extension services in Timor-Leste had a profound effect on their cropping practices and livelihoods. Therefore, vulnerable groups, including women and the youth, can benefit immensely from access to extension services in Domboshava.

7.3.7 Effect of Energy Costs on Livelihoods

Energy costs are significant at 10% and have a positive effect on the livelihood index. Hence, assuming all other factors remain constant, a one unit increase in energy costs results in a 0.098 unit increase in the livelihood index. According to the findings, households with higher energy expenses are more likely to have access to contemporary energy services, a sign of improved

financial status. Empirical studies present divergent findings regarding the impact of energy costs on livelihoods. Kimutai et al. (2025) noted that energy costs are an impediment to the livelihoods of rural communities in Kenya and adopting biogas technologies can reduce energy costs and improve their incomes. However, Palsaniya et al. (2021) noted that higher energy costs can be an indicator of better livelihoods for communities in rural India. Hence, the results posit that households with higher energy costs are likely to be better off than their counterparts.

7.3.8 Effect of Livestock units on Livelihoods

Livestock units are significant at 1% and have a positive effect on the livelihood index. Therefore, assuming all other factors remain unchanged, a one unit increase in livestock units results a 0.143 unit increase in the livelihood index. . Therefore, the number of livestock units is an important predictor of the livelihood status of farmers in Domboshava. Kuchimanchi et al. (2021) examined the effects of livestock rearing on smallholder farmers' livelihoods in Telangana, India. The results indicated that herd size was positively related to the livelihood status of the smallholder farmers'. Ayana et al. (2021), noted that livestock holding size was a critical determinant of livelihood diversification strategy for farmers in Western Ethiopia. The results indicate that farmers who practiced diversified farming, including both livestock and crop production, showed improved livelihood outcomes compared to those engaged in non-diversified agricultural practices. The empirical findings are consistent with evidence highlighting the significance of livestock units in enhancing livelihoods in Domboshava.

7.4 Chapter Summary

The chapter presented the results of the multiple linear regression analysis examining the determinants of the livelihood index. The model exhibited a good fit, with substantial explanatory power. The key predictors, including education, off-farm income, biogas adoption, land size, access to credit, extension services, energy costs and livestock units, were statistically significant. These findings indicate the multidimensional nature of rural livelihoods and the importance of both economic and institutional factors. The results align with existing theoretical frameworks and contribute to empirical knowledge on livelihood enhancement strategies.

CHAPTER 8

FRAMEWORK FOR ENHANCING BIOGAS TECHNOLOGY ADOPTION AND IMPACT AMONG LIVESTOCK FARMERS IN DOMBOSHAVA, ZIMBABWE

8.1 Introduction

This chapter presents a framework aimed at improving biogas technology uptake among livestock farmers in Domboshava, Zimbabwe. Previous chapters have highlighted the key socio-economic, technical and institutional factors affecting biogas technology adoption, indicating a need for a more integrated and context-specific approach. The framework integrates evidence from both primary study findings, key informants and focus group discussions conducted during the study. The framework is informed by empirical findings, stakeholder consultations and relevant theoretical perspectives. It identifies strategic entry points for intervention across policy, finance, capacity-building and community engagement dimensions. Emphasis is placed on aligning the framework with local realities in Domboshava to ensure feasibility and sustainability. The aim is to provide a practical guide for policymakers, development actors and farmers.

8.2 Conceptual Basis for the Framework

The framework is guided by the Diffusion of Innovation theory and the Sustainable Livelihoods approach. These frameworks highlight the need for knowledge dissemination, supportive institutions and an enabling environment to facilitate technological adoption. According to the Diffusion of Innovation theory, time, social structures, and communication channels are all important aspects of innovation that influence how quickly technologies are adopted. The Sustainable Livelihoods approach indicates a livelihood-centric perspective by highlighting the role of access to natural, financial, human, physical and social capital in determining adoption decisions. Focus group discussions further highlighted that community cohesion and social capital facilitated collective problem-solving, including shared maintenance of biogas units. These perspectives are critical to various interventions, including household capacity and policy alignment.

The focus group discussions and key informant interviews were transcribed and analyzed thematically using Nvivo software to identify recurring patterns and themes, which informed the development of the adoption framework. Community cohesion and social capital were identified as key facilitators, with strong networks enabling collective problem-solving and maintenance of biogas units. Policy awareness emerged as another theme, as most farmers were unaware of renewable energy policies, perceiving them as urban-centric. This informed the framework's focus on aligning biogas objectives with national policies and simplifying procedures for smallholders. Institutional coordination was highlighted, with fragmented efforts from government, NGOs and the private sector, leading to the recommendation for dedicated focal persons. Financial constraints, including high installation costs and lack of tailored financing, informed the inclusion of subsidies, microfinance engagement and flexible payment systems. Technical capacity gaps and insufficient knowledge on biogas operation highlighted the need for vocational training, demonstration sites, awareness campaigns, including gender-sensitive messaging. Collectively, these themes anchor the framework and livelihood needs of smallholder livestock farmers in Domboshava.

8.3 Key Factors and Stakeholders Influencing Adoption

8.3.1 Policy and Legal Alignment

Zimbabwe's Renewable Energy Policy (2019) recognizes biogas as a critical energy source, however, its provisions remain general and lack operational directives targeting smallholder livestock farmers. The evidence from this study's findings revealed that, most of livestock farmers were unaware of existing policy frameworks supporting biogas, while focus group discussions noted that farmers often perceived energy-related policies as urban-centric and disconnected from rural realities. Hence, an important element of the framework involves the harmonization of biogas-related objectives within national policies, particularly the Renewable Energy Policy, the Environmental Management Act (Chapter 20:27) and the Zimbabwe Agricultural Policy Framework (2018–2030). This must be done through the development of rural areas by Goromonzi Rural District Council to support household-level biogas installations and the simplification of Environmental Impact Assessment procedures for small-scale digesters. Furthermore, there should be collaboration with the Zimbabwe Energy Regulatory Authority to disseminate biogas technical and safety standards which livestock farmers in both the survey and focus group discussions identified as critical to improving trust, safety and adoption rates.

8.3.2 Institutional Coordination

Institutional coordination emerges as another important aspect of the framework. The fragmentation of government agencies, non-governmental organisations, and the private sector has resulted in fragmented efforts to promote biogas technologies. Livestock farmers' concerns were brought to light by focus groups and key informant interviews regarding the contradictory messages from government agencies, non-governmental organisations (NGOs), and the private sector. This frequently led to misunderstandings regarding technical requirements and available assistance. The framework proposes the establishment of a local Biogas Working Group in Domboshava, comprising representatives from the Agricultural Extension services, Environmental Management Agency, Goromonzi Rural District Council, livestock small-holder farmers, Non-Governmental Organizations and the technology suppliers. This platform should facilitate joint planning, implementation, and monitoring of biogas interventions in Domboshava with clearly defined roles and timelines. In addition, the appointment of biogas technology focal persons in government departments will help mainstream biogas awareness into existing agricultural outreach programs. This aligns with focus group feedback indicating the need for continuous, localized information delivery from trusted sources. Additionally, the supply and upkeep of biogas units in Domboshava may benefit greatly from public-private partnerships established under the Joint Ventures Act.

8.3.4 Financial Mechanisms

Financial means is a fundamental aspect of the framework, given the high initial capital investment associated with biogas technology. The current lack of tailored financial instruments for rural energy solutions in Zimbabwe necessitates the introduction of targeted subsidy schemes that cover installation costs for poor but livestock-owning farmers, which significantly improves their livelihoods. The study survey findings highlight that livestock farmers mentioned prohibitive installation costs as one of the primary barrier to adoption. Focus group discussions reinforced this constraint, with participants noting the absence of financing mechanisms tailored to rural energy solutions, particularly for smallholder livestock farmers in Domboshava. The framework also encourages the mobilization of local financial structures including Village Savings and Loan Associations, to establish biogas specific savings and credit arrangements. Collaborations with rural microfinance, institutions, including Empower Bank and other financial institutions, can further expand access to low-interest loans with flexible repayment

terms. Hence, to ensure long-term sustainability and affordability, the framework also recommends the development of innovative financing models, including flexible biogas payment systems using mobile money platforms including Mpesa in Kenya. Focus group discussions and key informant interviews highlighted that such payment flexibility would reduce default risk while encouraging wider biogas technology uptake.

8.3.5 Technical Capacity

A critical determinant of sustainable biogas technology adoption in Domboshava is the availability of technical capacity and localized extension support. Hence, there is a need to address the shortage of skilled technicians in Domboshava. Smallholder-livestock farmers highlighted challenges related to poor-quality installations, inadequate maintenance support and inconsistencies in system performance, which highlighted the importance of technology-specific considerations. The framework proposes the implementation of certified short courses in biogas construction and maintenance through partnerships with vocational training institutions, including Harare Polytechnic and the Zimbabwe Institution of Engineers. Local artisans trained through these programs constitute a decentralized workforce capable of constructing and servicing digesters at the community level in Domboshava. Extension officers, who already have established networks with livestock farmers, should be capacitated to deliver biogas related extension information during their routine field visits. The establishment of demonstration sites at local schools, clinics and lead farmer homesteads can serve as platforms for hands on learning and technology diffusion.

8.3.6 Awareness and Behavioural Change

Behavioural change and community awareness is important in influencing household decisions regarding biogas technology, as shown in Figure 8.1. A significant number of livestock farmers in Domboshava remain unaware of the benefits or operational requirements of biogas systems. Focus group discussions noted that farmers often relied on informal, untrained labor which resulted in poor-quality installations and frequent system breakdowns. This shortage of qualified personnel significantly undermines both initial adoption and the long-term functionality of biogas systems. Hence, the framework promotes a set of targeted information campaigns utilising local communication channels, including vernacular radio programming, community theatres and visual materials to convey both technical and livelihood benefits. Furthermore,

attention is highlighted to the gendered dynamics of energy use, with messages crafted to highlight how biogas adoption can reduce the domestic burden on women and girls by improving health outcomes and livelihoods. Focus group discussions and key informant interviews recommended adopting lead farmer models, in which early adopters serve as biogas “ambassadors” within their communities to build trust and reduce perceived risks.

8.4 Framework for Enhancing Biogas Adoption in Domboshava

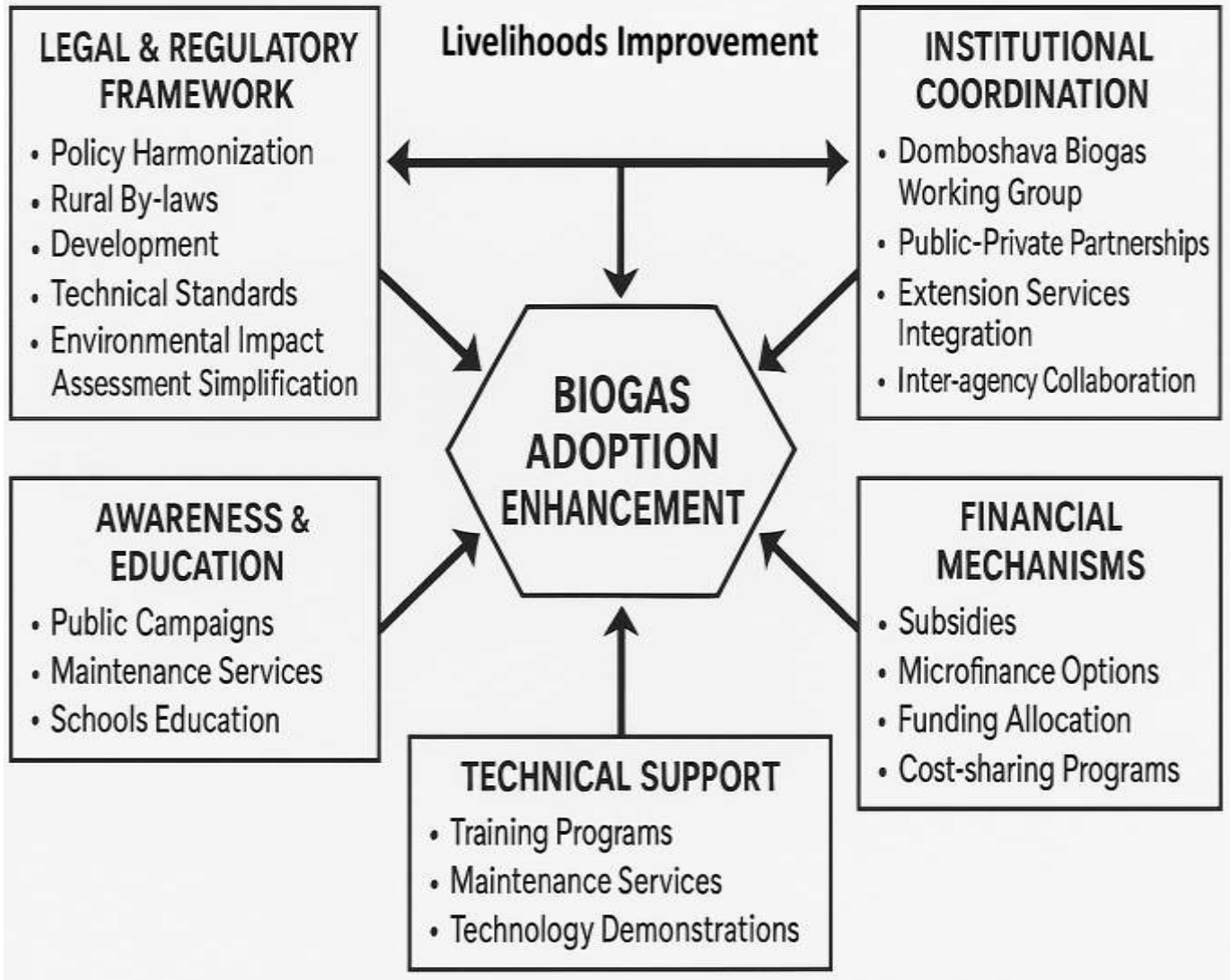


Figure 8.1: Integrated Biogas Adoption Framework

Source: Author (2025)

8.5 Chapter Summary

The proposed framework provides a holistic and practical approach to enhancing biogas technology adoption in Domboshava. It is based on Zimbabwe's policy and regulatory context, informed by local socio-economic realities and designed to be both scalable and sustainable. Hence, by integrating policy reform, institutional coordination, financial innovation, technical capacity building and behaviour change strategies, the framework offers a pathway for unlocking the full potential of biogas technology as a renewable energy solution for rural households in Domboshava and Zimbabwe at large.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter presents an overview of the study by presenting the research objectives and summarizing how they were addressed. It offers the key conclusions drawn from the study's findings, highlighting the implications of biogas technology adoption for rural livelihoods in Zimbabwe and Africa at large. The chapter also provides policy recommendations directed at various stakeholders, including government, development agencies, the private sector and Domboshava livestock farmers. Hence, the chapter aims to enhance the uptake and sustainable use of biogas technology. Furthermore, the chapter outlines future research directions that build upon the current study's findings. The chapter consolidates the study's contributions to knowledge and practice within the context of rural energy transitions and sustainable development.

9.2 Recap of the study's objectives

The study was guided by five objectives, which were addressed through appropriate methodological approaches. The first objective sought to determine the extent of biogas uptake in Domboshava. This was achieved using descriptive analysis by highlighting the determinants and trends of biogas technology adoption among the livestock farmers. The second and third objectives analysed the influence of socio-economic factors on both current adoption and future adoption plans. The objectives were analyzed using binary and multinomial logistic regression models, respectively. The results identified variables including education, off-farm income, livestock ownership and access to extension as key determinants. The fourth objective examined the impact of biogas adoption on livelihoods using a composite livelihood index and multiple linear regression. The results confirmed that adoption significantly enhances household welfare. Lastly, the fifth objective was accomplished through institutional mapping and stakeholder analysis. The results informed the development of a context-specific framework to guide the scaling up of biogas technology in rural Zimbabwe and Africa.

9.3 Conclusion

Objective 1 determined the extent of biogas technology uptake among livestock farmers in Domboshava by examining key socio-economic variables including gender, age, education, income, land size and livestock ownership. The results highlight that biogas adoption remains relatively limited despite the high potential offered by livestock resources in the area. Descriptive analysis demonstrated that only a small proportion of farmers had adopted the technology, although many expressed plans to adopt. However, these plans were constrained by limited financial capacity, inadequate information and infrastructural challenges. Off-farm income and resource availability emerged as strong determinants of adoption, underscoring the central role of economic security in facilitating technological transitions. Goat ownership was consistently high across all categories of farmers, highlighting its suitability as a reliable source of feedstock for biogas production. Overall, these findings reveal substantial awareness gaps and weak extension support, indicating the need for enhanced promotional activities, strengthened capacity-building initiatives and context-specific support mechanisms to improve uptake in Domboshava.

Objective 2 examined the effect of socio-economic factors on biogas technology adoption using binary logistic regression. The analysis identified land size, off-farm income, credit access, gender, livestock units, energy costs and extension services as significant predictors of adoption, demonstrating that biogas uptake is strongly associated with household resource endowment and institutional support. These results highlight that households with financial capacity, stronger institutional connectivity and higher livestock capacity are more likely to adopt biogas technology. Although age and education are commonly linked to technology adoption in the literature, they were found to be statistically insignificant in this context, suggesting that economic and structural factors are more influential than demographic ones. The findings contribute to a clearer understanding of the adoption dynamics in Domboshava and offer policy insights focused on enhancing access to finance, improving extension service delivery and addressing gender-related barriers to promote inclusive adoption pathways.

Objective 3 analysed the influence of socio-economic factors on farmers' plans to adopt biogas technology, drawing on results from the multinomial logistic regression. The analysis indicated

that factors such as off-farm income, land size, credit access, education and extension services shape future intentions, whereas actual adoption is more strongly influenced by tangible considerations including livestock units and high energy costs. The multinomial model demonstrated that many determinants of current adoption equally influence plans to adopt, though practical resource-based variables had a stronger effect on those already using the technology. These distinctions highlight that households planning to adopt are primarily motivated by knowledge and institutional support, while actual adopters respond more directly to economic and energy-related pressures. The findings suggest that with appropriate support mechanisms, a significant number of households could transition from intentions to actual adoption. This objective therefore provides evidence for developing targeted policy interventions that address the specific constraints encountered at each stage of the adoption, thereby promoting wider diffusion of biogas technology in Domboshava and nationally.

Objective 4 assessed the effect of biogas technology adoption on the livelihoods of livestock farmers using a composite livelihood index. The multiple linear regression results highlighted that education, off-farm income, land size, access to credit, extension services, energy costs, livestock units and biogas adoption itself significantly influenced livelihood outcomes. The analysis indicated a strong positive relationship between biogas use and improved household welfare, demonstrating that the technology contributes meaningfully to multidimensional livelihood enhancement. These findings confirm the study's proposition that biogas adoption positively affects rural welfare by improving income, reducing energy expenditure and enhancing overall resilience. The results also highlight the complex, multidimensional nature of rural livelihoods, where economic, institutional and technological factors interact to shape household welfare. Hence, the study aligns with relevant theoretical frameworks and adds empirical depth to existing literature on livelihood improvement strategies in rural settings.

Objective 5 focused on developing a context-specific framework to enhance biogas adoption among livestock farmers in Domboshava. Through institutional mapping and stakeholder analysis, the study formulated an integrated biogas adoption framework tailored to local socio-economic and institutional realities. The framework highlights the need for coordinated

engagement among government departments, NGOs, financial institutions and local communities to strengthen the enabling environment for biogas uptake. Zimbabwe's policy and regulatory context, the framework is designed to be scalable and sustainable while addressing locally identified barriers such as limited financing, inadequate technical knowledge and insufficient extension support. It emphasizes the importance of expanding technical training, promoting financial support mechanisms, and mainstreaming biogas into rural development and energy policy processes. Overall, the proposed framework is firmly grounded in the practical experiences of Domboshava communities, ensuring its relevance, applicability and potential for long-term impact.

9.4 Recommendations

Objective 1: To determine the extent of biogas technology uptake among livestock farmers in Domboshava.

The study recommends that comprehensive awareness campaigns be launched to bridge the prevailing information gap regarding the benefits and operation of biogas systems. These campaigns should be led by local extension officers, NGOs and community-based organizations in Domboshava. Local languages recognized in the constitution of Zimbabwe should be used in radio platforms, demonstration sites and farmer to farmer learning models to improve biogas technology adoption and livelihoods. Targeted micro-financing schemes and revolving community savings groups should be promoted to reduce financial entry barriers for low income households and those planning to adopt biogas technology in Domboshava. Furthermore, involving women's groups and the youth in biogas education and maintenance training, promotes gender inclusive energy access and intergenerational knowledge transfer.

Objective 2: To analyse the effect of socio-economic factors on biogas technology adoption among Domboshava livestock farmers

Enhancing access to affordable credit through formal banks, including Empower Bank Zimbabwe and Zimbabwe Women's Microfinance Bank, is critical. Informal credit facilities in Domboshava, including village savings groups, provide the means to access the biogas technology. These financial products should be tailored to Domboshava rural contexts with low-interest rates and a long pay-back period. Extension services should be uplifted through biogas technology, technical knowledge and frequency of contact with the adopters. This can be

achieved by equipping agricultural extension officers with renewable energy modules and incentivizing performance based outreach. Gender sensitive policy design by the Ministry of Women's Affairs, Community, Small and Medium Enterprises Development is essential to address structural barriers limiting female-headed households' access to biogas.

Objective 3: To analyse the effect of socio-economic factors on the plans to adopt biogas technology among Domboshava livestock farmers.

All stakeholders should develop a phased biogas adoption roadmap by targeting potential adopters with context-specific education, motivational seminars, and success stories from current Domboshava biogas users. Domboshava Village Energy Committees, supported by Goromonzi Rural District Council and traditional leaders, should be formed to coordinate training and serve as information hubs. The results highlight that local schools and tertiary institutions in Domboshava offering renewable energy programmes should take a more active role in biogas awareness and technical support, helping to build a sustained knowledge network that reinforces adoption and effective use within the community.

Objective 4: To analyse the effect of biogas technology adoption on the livelihoods of livestock farmers in Domboshava, using a composite livelihood index.

The study recommends integrating biogas promotion activities into national livelihood strategies, including the Zimbabwe National Development Strategy 1 and 2. This will help mainstream its development potential into national growth policies. All stakeholders should scale up livelihood enhancement programs that include biogas as a core component alongside government initiatives, including nutrition, water and health interventions. Ensuring that biogas technology adopters in Domboshava record and reflect biogas benefits, including cooking conditions and income savings, can help track welfare benefits and guide future plans. Hence, these feedback mechanisms can ensure that interventions remain adaptive and grounded in lived experiences for households in Domboshava.

Objective 5: To develop a context-specific framework for the improvement of biogas adoption among livestock farmers in Domboshava.

The integrated biogas adoption framework can be adopted at the ward and district levels through participatory planning processes involving all key stakeholders. The integrated biogas

framework can serve as an important tool for multi-stakeholder coordination, including government departments. Stakeholder platforms and policy dialogue forums should be held regularly to evaluate the implementation of the integrated biogas framework and refine it based on evolving needs for Domboshava households. Additionally, the local monitoring and evaluation system should track the integrated biogas framework's impact and foster accountability among all stakeholders in Domboshava.

9.5 Future research direction

The study provided insights into the determinants of biogas adoption and its impact on livelihoods in Domboshava. However, other critical issues remain unexplored. Firstly, the cross-sectional nature of the study means there is a need to track dynamic changes in adoption behaviour and livelihood outcomes over time. To evaluate the socioeconomic effects and long-term sustainability of biogas technology, future research should take longitudinal designs into account. Furthermore, the study was geographically confined to Domboshava. Hence, expanding the research to include other rural contexts across Zimbabwe and Southern Africa would enhance external validity and enable comparative analysis. Furthermore, other qualitative methodologies, including ethnographic studies and participatory rural appraisals, can complement quantitative findings. Further research should explore the gendered implications of biogas technology adoption and its transformative potential for women and youth empowerment in rural energy transitions. Lastly, there is a need to incorporate the role of artificial intelligence access in adopting biogas technology in rural areas.

9.6 Contribution to the Body of Knowledge

This study makes several important contributions to the existing body of knowledge on renewable energy adoption, rural livelihoods and smallholder agricultural systems in Sub-Saharan Africa. Firstly, it provides one of the few empirical analyses of biogas technology uptake among livestock-based households in Zimbabwe, generating context-specific quantitative evidence on the socio-economic determinants of adoption, plans to adopt and the livelihood impacts of biogas use. Furthermore, by integrating binary and multinomial logistic regression with a composite livelihood index, the study advances methodological approaches for analyzing both current and prospective adoption behaviour, thereby filling a gap in the literature that has traditionally focused on either adopters or non-adopters only. The development of a context-

specific biogas adoption framework focused on local institutional, socio-economic and policy realities contributes a theoretically informed yet practical tool for guiding biogas promotion efforts in similar rural contexts. Finally, the findings enrich global discourses on clean energy transitions by demonstrating how smallholder livestock farmers in resource-constrained settings can leverage biogas to enhance energy security, reduce environmental pressure and improve multidimensional livelihoods.

REFERENCES

- Abba, Z.Y.I., Balta-Ozkan, N. and Hart, P., 2022. A holistic risk management framework for renewable energy investments. *Renewable and Sustainable Energy Reviews*, 160, p.112305. <https://doi.org/10.1016/j.rser.2022.112305>
- Abbas, T., Ali, G., Adil, S.A., Bashir, M.K. and Kamran, M.A., 2017. Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. *Renewable energy*, 107, pp.431-439. <https://doi.org/10.1016/j.renene.2017.01.060>
- Abdallah, F.D.M., 2018. Statistical Modelling of Categorical Outcome with More than Two Nominal Categories. *Am J Appl Math Stat*, 6, pp.262-265. <https://doi.org/10.12691/ajams-6-6-7>
- Abera, A., Yirgu, T. and Uncha, A., 2021. Determinants of rural livelihood diversification strategies among Chewakaresettlers' communities of southwestern Ethiopia. *Agriculture & Food Security*, 10(1), p.30. <https://doi.org/10.1186/s40066-021-00305-w>
- Aboagye, B., Gyamfi, S., Ofori, E.A. and Djordjevic, S., 2021. Status of renewable energy resources for electricity supply in Ghana. *Scientific African*, 11, p.e00660. <https://doi.org/10.1016/j.sciaf.2020.e00660>
- Adnan, N., Nordin, S.M., Rahman, I. and Noor, A., 2017. Adoption of green fertilizer technology among paddy farmers: A possible solution for Malaysian food security. *Land use policy*, 63, pp.38-52. <https://doi.org/10.1016/j.landusepol.2017.01.022>
- Ahmad, M., Khan, I., Khan, M.Q.S., Jabeen, G., Jabeen, H.S. and Işık, C., 2023. Households' perception-based factors influencing biogas adoption: Innovation diffusion framework. *Energy*, 263, p.126155. <https://doi.org/10.1016/j.energy.2022.126155>
- Ahmad, M. and Wu, Y., 2022. Household-based factors affecting uptake of biogas plants in Bangladesh: Implications for sustainable development. *Renewable Energy*, 194, pp.858-867. <https://doi.org/10.1016/j.renene.2022.05.135>
- Al-Rahmi, W.M., Yahaya, N., Alamri, M.M., Alyoussef, I.Y., Al-Rahmi, A.M. and Kamin, Y.B., 2021. Integrating innovation diffusion theory with technology acceptance model: Supporting students' attitude towards using a massive open online courses (MOOCs) systems. *Interactive Learning Environments*, 29(8), pp.1380-1392. <https://doi.org/10.1080/10494820.2019.1629599>
- Almeida, F., 2018. Strategies to perform a mixed methods study. *European Journal of Education Studies*. <https://doi.org/10.5281/zenodo.1406214>
- Ajzen, I., 2020. The theory of planned behavior: Frequently asked questions. *Human Behavior and Emerging Technologies*, 2(4), pp.314-324. <https://doi.org/10.1002/hbe2.195>

- Akbulut, A., Arslan, O., Arat, H. and Erbaş, O., 2021. Important aspects for the planning of biogas energy plants: Malatya case study. *Case Studies in Thermal Engineering*, 26, p.101076. <https://doi.org/10.1016/j.csite.2021.101076>
- Akter, S., Erskine, W., Spycykerelle, L., Branco, L.V. and Imron, J., 2020. The impact of women's access to agricultural extension on cropping practices in Timor-Leste. *Food Security*, 12(2), pp.449-463. <https://doi.org/10.1007/s12571-020-01007-0>
- Alam, M.Z., Kousar, S. and Rehman, C.A., 2019. Role of entrepreneurial motivation on entrepreneurial intentions and behaviour: theory of planned behaviour extension on engineering students in Pakistan. *Journal of Global Entrepreneurship Research*, 9(1), pp.1-20. <https://doi.org/10.1186/s40497-019-0175-1>
- Alexander, S., Harris, P. and McCabe, B.K., 2019. Biogas in the suburbs: an untapped source of clean energy?. *Journal of cleaner production*, 215, pp.1025-1035. <https://doi.org/10.1016/j.jclepro.2019.01.118>
- Ali, S., Poulouva, P., Akbar, A., Javed, H.M.U. and Danish, M., 2020. Determining the influencing factors in the adoption of solar photovoltaic technology in Pakistan: A decomposed technology acceptance model approach. *Economies*, 8(4), p.108. <https://doi.org/10.3390/economies8040108>
- Ali, S., Yan, Q., Razaq, A., Khan, I. and Irfan, M., 2023. Modeling factors of biogas technology adoption: a roadmap towards environmental sustainability and green revolution. *Environmental Science and Pollution Research*, 30(5), pp.11838-11860. <https://doi.org/10.1007/s11356-022-22894-0>
- Ali, S., Yan, Q., Irfan, M. and Chen, Z., 2022. Evaluating barriers on biogas technology adoption in China: the moderating role of awareness and technology understanding. *Frontiers in Environmental Science*, 10, p.887084. <https://doi.org/10.3389/fenvs.2022.887084>
- Aliyu, A.K., Modu, B. and Tan, C.W., 2018. A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, 81, pp.2502-2518. <https://doi.org/10.1016/j.rser.2017.06.055>
- Alola, A.A., Bekun, F.V. and Sarkodie, S.A., 2019. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Science of the Total Environment*, 685, pp.702-709. <https://doi.org/10.1016/j.scitotenv.2019.05.139>
- Amir, S.M., Khan, S., Abro, A.A., Inamullah, E. and Mehmood, T., 2022. Transforming the Livelihood of Rural Households: A Case of Successful Adoption of Biogas Technology in Khyber Pakhtunkhwa, Pakistan. *Sarhad Journal of Agriculture*, 38(330). <https://dx.doi.org/10.17582/journal.sja/2022/38.3.885.893>

- Amuzu-Sefordzi, B., Martinus, K., Tschakert, P. and Wills, R., 2018. Disruptive innovations and decentralized renewable energy systems in Africa: A socio-technical review. *Energy research & social science*, 46, pp.140-154. <https://doi.org/10.1016/j.erss.2018.06.014>
- Anang, B.T. and Apedo, C.K., 2023. The influence of off-farm work on farm income among smallholder farm households in northern Ghana. *Cogent Economics & Finance*, 11(1), p.2196861. <https://doi.org/10.1080/23322039.2023.2196861>
- Anditi, C., Musango, J.K., Smit, S. and Ceschin, F., 2022. Addressing gender dimensions in energy innovations: A gender analysis framework for informal urban settlements in Africa. *Energy Research & Social Science*, 88, p.102476. <https://doi.org/10.1016/j.erss.2021.102476>
- Ansah, I.G.K., Gardebroek, C. and Ihle, R., 2019. Resilience and household food security: a review of concepts, methodological approaches and empirical evidence. *Food Security*, 11(6), pp.1187-1203. <https://doi.org/10.1007/s12571-019-00968-1>
- Apfel, D. and Herbes, C., 2021. What Drives Senegalese SMEs to Adopt Renewable Energy Technologies? Applying an Extended UTAUT2 Model to a Developing Economy. *Sustainability*, 13(16), p.9332. <https://doi.org/10.3390/su13169332>
- Arneth, A., Shin, Y.J., Leadley, P., Rondinini, C., Bukvareva, E., Kolb, M., Midgley, G.F., Oberdorff, T., Palomo, I. and Saito, O., 2020. Post-2020 biodiversity targets need to embrace climate change. *Proceedings of the National Academy of Sciences*, 117(49), pp.30882-30891. <https://doi.org/10.1073/pnas.2009584117>
- Arowosegbe, O.B., Alomaja, O.A. and Tiamiyu, B.B., 2024. The role of agricultural extension workers in transforming agricultural supply chains: enhancing innovation, technology adoption, and ethical practices in Nigeria. *World Journal of Advanced Research and Reviews*, 23(3), pp.2585-2602. <https://doi.org/10.30574/wjarr.2024.23.3.2962>
- Awasthi, M.K., Sarsaiya, S., Wainaina, S., Rajendran, K., Kumar, S., Quan, W., Duan, Y., Awasthi, S.K., Chen, H., Pandey, A. and Zhang, Z., 2019. A critical review of organic manure biorefinery models toward sustainable circular bioeconomy: Technological challenges, advancements, innovations, and future perspectives. *Renewable and Sustainable Energy Reviews*, 111, pp.115-131. <https://doi.org/10.1016/j.rser.2019.05.017>
- Ayal, D.Y. and Mamo, B., 2024. Farmer's climate smart livestock production adoption and determinant factors in HidebuAbote District, Central Ethiopia. *Scientific reports*, 14(1), p.10027. <https://doi.org/10.1038/s41598-024-59967-8>
- Ayana, G.F., Megento, T.L. and Kussa, F.G., 2021. The extent of livelihood diversification on the determinants of livelihood diversification in AssosaWereda, Western Ethiopia. *GeoJournal*, pp.1-25. <https://doi.org/10.1007/s10708-021-10379-5>

- Balgah, R.A., Mbue, I.N. and Ngwa, K.A., 2018. The impacts of renewable energy on livelihoods: A case study of biogas adoption in Cameroon. *Int. J. Dev. Sustain*, 7, pp.220-239.
- Bang, J. and Han, J.W., 2025. Factors Influencing Farmers' Motivation to Adopt Smart Farm Technology in South Korea. *arXiv preprint arXiv:2504.01795*. <https://doi.org/10.48550/arXiv.2504.01795>
- Baurzhan, S. and Jenkins, G.P., 2016. Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?. *Renewable and Sustainable Energy Reviews*, 60, pp.1405-1418. <https://doi.org/10.1016/j.rser.2016.03.016>
- Bekchanov, M., Mondal, M.A.H., de Alwis, A. and Mirzabaev, A., 2019. Why adoption is slow despite promising potential of biogas technology for improving energy security and mitigating climate change in Sri Lanka?. *Renewable and Sustainable Energy Reviews*, 105, pp.378-390. <https://doi.org/10.1016/j.rser.2019.02.010>
- Belotti, F. and Iardi, G., 2018. Consistent inference in fixed-effects stochastic frontier models. *Journal of Econometrics*, 202(2), pp.161- 177. <https://doi.org/10.1016/j.jeconom.2017.09.005>
- Berhe, M., Hoag, D., Tesfay, G. and Keske, C., 2017. Factors influencing the adoption of biogas digesters in rural Ethiopia. *Energy, sustainability and society*, 7, pp.1- 11. <https://doi.org/10.1186/s13705-017-0112-5>
- Bharadwaj, B., Malakar, Y., Herington, M. and Ashworth, P., 2022. Context matters: unpacking decision-making, external influences and spatial factors on clean cooking transitions in Nepal. *Energy Research & Social Science*, 85, p.102408. <https://doi.org/10.1016/j.erss.2021.102408>
- Bibi, A., Zhang, X. and Umar, M., 2021. The imperativeness of biomass energy consumption to the environmental sustainability of the United States revisited. *Environmental and Ecological Statistics*, 28(4), pp.821-841. <https://doi.org/10.1007/s10651-021-00500-9>
- Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N.J., Moore, M.L., Morrison, T.H. and Brown, K., 2018. The dark side of transformation: latent risks in contemporary sustainability discourse. *Antipode*, 50(5), pp.1206- 1223. <https://doi.org/10.1111/anti.12405>
- Bößner, S., Devisscher, T., Suljada, T., Ismail, C.J., Sari, A. and Mondamina, N.W., 2019. Barriers and opportunities to bioenergy transitions: An integrated, multi-level perspective analysis of biogas uptake in Bali. *Biomass and Bioenergy*, 122, pp.457-465. <https://doi.org/10.1016/j.biombioe.2019.01.002>

- Bonokwane, L.P. and Ololade, O.O., 2022. Socio-economic factors affecting smallholder farmers' willingness to adopt biodigester technology in South Africa. *Journal of Energy in Southern Africa*, 33(1), pp.10-20. <https://doi.org/10.17159/2413-3051/2022/v33i1a8860>
- Bond, T. and Templeton, M.R., 2011. History and future of domestic biogas plants in the developing world. *Energy for Sustainable development*, 15(4), pp.347- 354. <https://doi.org/10.1016/j.esd.2011.09.003>
- Bontsa, N.V., Mushunje, A. and Ngarava, S., 2023. Factors influencing the perceptions of smallholder farmers towards adoption of digital technologies in Eastern Cape Province, South Africa. *Agriculture*, 13(8), p.1471. <https://doi.org/10.3390/agriculture13081471>
- Brandt, U.S. and Svendsen, G.T., 2022. Is the annual UNFCCC COP the only game in town?: Unilateral action for technology diffusion and climate partnerships. *Technological Forecasting and Social Change*, 183, p.121904. <https://doi.org/10.1016/j.techfore.2022.121904>
- Broska, L.H., 2021. It's all about community: On the interplay of social capital, social needs, and environmental concern in sustainable community action. *Energy Research & Social Science*, 79, p.102165. <https://doi.org/10.1016/j.erss.2021.102165>
- Budiman, I., 2021. The complexity of barriers to biogas digester dissemination in Indonesia: challenges for agriculture waste management. *Journal of Material Cycles and Waste Management*, 23(5), pp.1918-1929. <https://doi.org/10.1007/s10163-021-01263-y>
- Bullough, A., Guelich, U., Manolova, T.S. and Schjoedt, L., 2022. Women's entrepreneurship and culture: gender role expectations and identities, societal culture, and the entrepreneurial environment. *Small Business Economics*, 58(2), pp.985- 996. <https://doi.org/10.1007/s11187-020-00429-6>
- Burke, M., Davis, W.M. and Diffenbaugh, N.S., 2018. Large potential reduction in economic damages under UN mitigation targets. *Nature*, 557(7706), pp.549- 553. <https://doi.org/10.1038/s41586-018-0071-9>
- Butscher, S., Hubenschmid, S., Müller, J., Fuchs, J. and Reiterer, H., 2018, April. Clusters, trends, and outliers: How immersive technologies can facilitate the collaborative analysis of multidimensional data. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-12). <https://doi.org/10.1145/3173574.3173664>
- Cafer, A., Green, J. and Goreham, G., 2022. A community resilience framework for community development practitioners building equity and adaptive capacity. In *Community Development for Times of Crisis* (pp. 56-74). Routledge. <http://dx.doi.org/10.1080/15575330.2019.1575442>

- Cantarero, M.M.V., 2020. Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. *Energy Research & Social Science*, 70, p.101716. <https://doi.org/10.1016/j.erss.2020.101716>
- Carley, S. and Konisky, D.M., 2020. The justice and equity implications of the clean energy transition. *Nature Energy*, 5(8), pp.569-577. <https://doi.org/10.1038/s41560-020-0641-6>
- Cergibozan, R., 2022. Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. *Renewable Energy*, 183, pp.617- 626. <https://doi.org/10.1016/j.renene.2021.11.056>
- Chadambuka, P. and Helliker, K., 2022. Two sides of the stream: the politics of belonging between foreign ex-farm workers and A1 farmers on a fast track farm in Zimbabwe. *African Identities*, pp.1- 16. <https://doi.org/10.1080/14725843.2022.2077699>
- Chambers, R. and Conway, G., 1992. *Sustainable rural livelihoods: practical concepts for the 21st century*. Institute of Development Studies (UK).
- Chanakira, M. and Dzapasi, Y., 2022. Access to Affordable, Reliable, Sustainable and Modern Energy for All? An Assessment of Gender and Energy Access in Peri-Urban Zimbabwe. *Alexandria Journal for Veterinary Sciences*, 72(2). <https://doi.org/10.2478/jgp-2021-0003>
- Chanza, N., 2018. Limits to climate change adaptation in Zimbabwe: Insights, experiences and lessons. *Limits to climate change adaptation*, pp.109-127. https://doi.org/10.1007/978-3-319-64599-5_6
- Chanza, N. and Gundu-Jakarasi, V., 2020. Deciphering the climate change conundrum in Zimbabwe: an exposition. *Global Warming and Climate Change*, pp.1- 25. <https://doi.org/10.5772/intechopen.84443>
- Chekol, F., Tsegaye, A., Mazengia, T. and Hiruy, M., 2022. Small scale biogas technology adoption behaviours of rural households and its effect on major crop yields in East GojjamZone of Ethiopia: propensity score matching approach. *Cogent Engineering*, 9(1), p.2133343. <https://doi.org/10.1080/23311916.2022.2133343>
- Chiaromonti, D. and Goumas, T., 2019. Impacts on industrial-scale market deployment of advanced biofuels and recycled carbon fuels from the EU Renewable Energy Directive II. *Applied Energy*, 251, p.113351. <https://doi.org/10.1016/j.apenergy.2019.113351>
- Chigumira, G., Dube, C., Mudzonga, E., Chiwunze, G. and Matsika, W., 2019. *Enhancing Natural Resources Management in Zimbabwe* (No. 2374-2020- 962). <https://doi.org/10.22004/ag.econ.305818>

- Clancy, J., Barnett, A., Cecelski, E., Pachauri, S., Dutta, S., Oparaocha, S. and Kooijman, A., 2019. Gender in the transition to sustainable energy for all: From evidence to inclusive policies.
- Clemens, H., Bailis, R., Nyambane, A. and Ndung'u, V., 2018. Africa Biogas Partnership Program: A review of clean cooking implementation through market development in East Africa. *Energy for Sustainable Development*, 46, pp.23- 31. <https://doi.org/10.1016/j.esd.2018.05.012>
- Cole, S.A. and Fernando, A.N., 2021. 'Mobile'izing agricultural advice technology adoption diffusion and sustainability. *The Economic Journal*, 131(633), pp.192- 219. <https://doi.org/10.1093/ej/ueaa084>
- Coulibaly, B. and Li, S., 2020. Impact of agricultural land loss on rural livelihoods in peri-urban areas: Empirical evidence from Sebougou, Mali. *Land*, 9(12), p.470. <https://doi.org/10.3390/land9120470>
- Creamer, E.G., 2017. *An introduction to fully integrated mixed methods research*. sage publications. <http://dx.doi.org/10.4135/9781071802823>
- Crossland, M., Paez Valencia, A.M., Pagella, T., Mausch, K., Harris, D., Dilley, L. and Winowiecki, L., 2021. Women's changing opportunities and aspirations amid male outmigration: Insights from Makueni County, Kenya. *The European Journal of Development Research*, 33, pp.910-932. <https://doi.org/10.1057/s41287-021-00362-8>
- Cudjoe, D., Yuan, Q. and Han, M.S., 2020. An assessment of the influence of awareness of benefits and perceived difficulties on waste sorting intention in Beijing. *Journal of Cleaner Production*, 272, p.123084. <https://doi.org/10.1016/j.jclepro.2020.123084>
- Czubaszek, R., Wysocka-Czubaszek, A. and Banaszuk, P., 2022. Importance of feedstock in a small-scale agricultural biogas plant. *Energies*, 15(20), p.7749. <https://doi.org/10.3390/en15207749>
- Dahunsi, S.O., Fagbiele, O.O. and Yusuf, E.O., 2020. Bioenergy technologies adoption in Africa: a review of past and current status. *Journal of Cleaner Production*, 264, p.121683. <https://doi.org/10.1016/j.jclepro.2020.121683>
- Daoud, J.I., 2017, December. Multicollinearity and regression analysis. In *Journal of Physics: Conference Series* (Vol. 949, No. 1, p. 012009). IOP Publishing. <https://doi.org/10.1088/1742-6596/949/1/012009>
- Danso-Abbeam, G., Dagunga, G. and Ehiakpor, D.S., 2020. Rural non-farm income diversification: implications on smallholder farmers' welfare and agricultural technology adoption in Ghana. *Heliyon*, 6(11). <https://doi.org/10.1016/j.heliyon.2020.e05393>

- Das, A., 2021. Logistic regression. In *Encyclopedia of Quality of Life and Well-Being Research* (pp. 1-2). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-69909-7_1689-2
- David, L.O., Nwulu, N.I., Aigbavboa, C.O. and Adepoju, O.O., 2022. Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. *Journal of Cleaner Production*, 363, p.132522. <https://doi.org/10.1016/j.jclepro.2022.132522>
- Davis, F.D., 1985. *A technology acceptance model for empirically testing new end-user information systems: Theory and results* (Doctoral dissertation, Massachusetts Institute of Technology).
- Dawadi, S., Shrestha, S. and Giri, R.A., 2021. Mixed-methods research: A discussion on its types, challenges, and criticisms. *Journal of Practical Studies in Education*, 2(2), pp.25-36. <https://doi.org/10.46809/jpse.v2i2.20>
- de Souza Mendonça, A.K., Barni, G.D.A.C., Moro, M.F., Bornia, A.C., Kupek, E. and Fernandes, L., 2020. Hierarchical modeling of the 50 largest economies to verify the impact of GDP, population and renewable energy generation in CO2 emissions. *Sustainable Production and Consumption*, 22, pp.58- 67. <https://doi.org/10.1016/j.spc.2020.02.001>
- De Vries, H., Tummers, L. and Bekkers, V., 2018. The diffusion and adoption of public sector innovations: A meta-synthesis of the literature. *Perspectives on Public Management and Governance*, 1(3), pp.159-176. <https://doi.org/10.1093/ppmgov/gvy001>
- Di Giulio, G.M., Bedran-Martins, A.M.B., da Penha Vasconcellos, M., Ribeiro, W.C. and Lemos, M.C., 2018. Mainstreaming climate adaptation in the megacity of São Paulo, Brazil. *Cities*, 72, pp.237-244. <https://doi.org/10.1016/j.cities.2017.09.001>
- Dhliwayo, N., Chanza, N. and De Wit, A., 2020. Beyond climatic intervention: The social dimension of a biogas project in Sogwala village, Zimbabwe. *Journal of Energy in Southern Africa*, 31(4), pp.43-56. <https://doi.org/10.17159/2413-3051/2020/v31i4a8924>
- Donner, M., Gohier, R. and de Vries, H., 2020. A new circular business model typology for creating value from agro-waste. *Science of the Total Environment*, 716, p.137065. <https://doi.org/10.1016/j.scitotenv.2020.137065>
- Dooley, E., 2020. An ethnographic look into farmer discussion groups through the lens of social learning theory. *Sustainability*, 12(18), p.7808. <https://doi.org/10.3390/su12187808>
- Dutta, B. and Hwang, H.G., 2021. Consumers purchase intentions of green electric vehicles: The influence of consumers technological and environmental considerations. *Sustainability*, 13(21), p.12025. <https://doi.org/10.3390/su132112025>

- Ederer, P., Baltenweck, I., Blignaut, J.N., Moretti, C. and Tarawali, S., 2023. Affordability of meat for global consumers and the need to sustain investment capacity for livestock farmers. *Animal Frontiers*, 13(2), pp.45-60. <https://doi.org/10.1093/af/vfad004>
- Efthymiou, M. and Papatheodorou, A., 2019. EU Emissions Trading scheme in aviation: Policy analysis and suggestions. *Journal of Cleaner Production*, 237, p.117734. <https://doi.org/10.1016/j.jclepro.2019.117734>
- Elahi, E., Khalid, Z. and Zhang, Z., 2022. Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Applied Energy*, 309, p.118459. <https://doi.org/10.1016/j.apenergy.2021.118459>
- Elasu, J., Ntayi, J.M., Adaramola, M.S., Buyinza, F., Ngoma, M. and Atukunda, R., 2023. Gender role differentiation in household fuel transition decision-making: Implications for education and training in Uganda. *Frontiers in Sustainability*, 4, p.1034589. <https://doi.org/10.3389/frsus.2023.1034589>
- Emetere, M.E., Agubo, O. and Chikwendu, L., 2021. Erratic electric power challenges in Africa and the way forward via the adoption of human biogas resources. *Energy Exploration & Exploitation*, 39(4), pp.1349-1377. <https://doi.org/10.1177/01445987211003678>
- Fatoki, O., 2022. Determinants of intention to purchase photovoltaic panel system: an integration of technology acceptance model and theory of planned behaviour. *International Journal of Energy Economics and Policy*, 12(3), pp.432-440. <https://doi.org/10.32479/ijeep.12931>
- Feiz, R., Metson, G.S., Wretman, J. and Ammenberg, J., 2022. Key factors for site-selection of biogas plants in Sweden. *Journal of Cleaner Production*, 354, p.131671. <https://doi.org/10.1016/j.jclepro.2022.131671>
- Felkner, J.S., Lee, H., Shaikh, S., Kolata, A. and Binford, M., 2022. The interrelated impacts of credit access, market access and forest proximity on livelihood strategies in Cambodia. *World Development*, 155, p.105795. <https://doi.org/10.1016/j.worlddev.2021.105795>
- Fetters, M.D. and Rubinstein, E.B., 2019. The 3 Cs of content, context, and concepts: a practical approach to recording unstructured field observations. *The Annals of Family Medicine*, 17(6), pp.554-560. <https://doi.org/10.1370/afm.2453>
- Gangi, F., Daniele, L.M., D'Angelo, E., Varrone, N. and Coscia, M., 2023. The impact of board gender diversity on banks' environmental policy: The moderating role of gender inequality in national culture. *Corporate Social Responsibility and Environmental Management*, 30(3), pp.1273-1291. <https://doi.org/10.1002/csr.2418>

- Geddafa, T., Melka, Y. and Sime, G., 2023. Cost-benefit analysis and financial viability of household biogas plant investment in South Ethiopia. *Sustainable Energy Research*, 10(1), p.20. <https://doi.org/10.1186/s40807-023-00089-6>
- Getaneh, A., Eba, K. and Tucho, G.T., 2024. Assessment of Biomass Energy Potential for Biogas Technology Adoption and Its Determinant Factors in Rural District of LimmuKossa, Jimma, Ethiopia. *Energies*, 17(9), p.2176. <https://doi.org/10.3390/en17092176>
- Gill, J.C., Mankelow, J. and Mills, K., 2019. The role of Earth and environmental science in addressing sustainable development priorities in Eastern Africa. *Environmental Development*, 30, pp.3-20. <https://doi.org/10.1016/j.envdev.2019.03.003>
- Gebrekidan, S., Tiki, L. and Mulatu, Y., 2018. Indigenous knowledge on highland bamboo (Yushania alpina) management and utilization practices in Kokosa Woreda, South East Ethiopia. *Scientific Research and Essays*, 13(11), pp.111- 122. <https://doi.org/10.5897/SRE2017.6552>
- Giaccalone, M., Panarello, D. and Mattera, R., 2018. Multicollinearity in regression: an efficiency comparison between L p-norm and least squares estimators. *Quality & Quantity*, 52, pp.1831-1859. <https://doi.org/10.1007/s11135-017-0571-y>
- Gleditsch, H.H., 2019. *Women and renewable energy: implications of the implementation of biogas on women in rural Kenya* (Master's thesis, Norwegian University of Life Sciences, Ås).
- Granić, A. and Marangunić, N., 2019. Technology acceptance model in educational context: A systematic literature review. *British Journal of Educational Technology*, 50(5), pp.2572-2593. <https://doi.org/10.1111/bjet.12864>
- Gujarati, D.N., 2021. *Basic econometrics*. Sage Publications.
- Guntoro, B., Surya, N.H.Q.A.R., Thu, N.T.A. and Van Vui, N., 2024. Factors Affecting the Willingness to Adopt Biogas System at Small Pig Farms in Mekong Delta, Vietnam. *Pakistan Journal of Agricultural Research*, 37(4), pp.320- 330. <https://dx.doi.org/10.17582/journal.pjar/2024/37.4.320.330>
- Guta, D.D., 2018. Determinants of household adoption of solar energy technology in rural Ethiopia. *Journal of Cleaner Production*, 204, pp.193- 204. <https://doi.org/10.1016/j.jclepro.2018.09.016>
- Gutsa, I., 2017. *Climate change and the livelihoods of elderly female headed households in Gutsa village, Goromonzi District, Zimbabwe* (Doctoral dissertation, University of the Witwatersrand, Faculty of Humanities, School of Social Sciences).

- Guttentag, D. and Smith, S.L., 2022. The diffusion of Airbnb: a comparative look at earlier adopters, later adopters, and non-adopters. *Current issues in tourism*, 25(20), pp.3225-3244. <https://doi.org/10.1080/13683500.2020.1782855>
- Halcomb, E.J. and Hickman, L., 2015. Mixed methods research. Faculty of Science. *Medicine and Health-Papers: part A*, 2656. <http://dx.doi.org/10.7748/ns.29.32.41.e8858>
- Haque, M.A., Kabir, A.A., Hashem, M.A., Azad, M.A.K., Bhuiyan, M.K.J. and Rahman, M.M., 2021. Efficacy of Biogas Production from Different Types of Livestock Manures. *International Journal of Smart Grid*, 5(4), pp.158- 166. <https://doi.org/10.20508/ijsmartgrid.v5i4.215.g177>
- He, K., Zhang, J. and Zeng, Y., 2020. Households' willingness to pay for energy utilization of crop straw in rural China: Based on an improved UTAUT model. *Energy Policy*, 140, p.111373. <https://doi.org/10.1016/j.enpol.2020.111373>
- Hendren, K., Newcomer, K., Pandey, S.K., Smith, M. and Sumner, N., 2023. How qualitative research methods can be leveraged to strengthen mixed methods research in public policy and public administration?. *Public Administration Review*, 83(3), pp.468- 485. <https://doi.org/10.1111/puar.13528>
- Higuera-Castillo, E., Liébana-Cabanillas, F.J., Muñoz-Leiva, F. and Molinillo, S., 2019. The role of collectivism in modeling the adoption of renewable energies: A cross-cultural approach. *International Journal of Environmental Science and Technology*, 16(4), pp.2143-2160. <https://doi.org/10.1007/s13762-019-02235-4>
- Ho, C.W. and Wu, C.C., 2021. Exploring Intention toward using an electric scooter: Integrating the technology readiness and acceptance into norm activation model (TRAM). *Energies*, 14(21), p.6895. <https://doi.org/10.3390/en14216895>
- Hou, J. and Hou, B., 2019. Farmers' adoption of low-carbon agriculture in China: An extended theory of the planned behavior model. *Sustainability*, 11(5), p.1399. <https://doi.org/10.3390/su11051399>
- Hua, L. and Wang, S., 2019. Antecedents of consumers' intention to purchase energy-efficient appliances: An empirical study based on the technology acceptance model and theory of planned behavior. *Sustainability*, 11(10), p.2994. <https://doi.org/10.3390/su11102994>
- Huang, M.T. and Zhai, P.M., 2021. Achieving Paris Agreement temperature goals requires carbon neutrality by middle century with far-reaching transitions in the whole society. *Advances in Climate Change Research*, 12(2), pp.281- 286. <https://doi.org/10.1016/j.accre.2021.03.004>

- Husband, G., 2020. Ethical data collection and recognizing the impact of semi-structured interviews on research respondents. *Education Sciences*, 10(8), p.206.
<https://doi.org/10.3390/educsci10080206>
- Hyman, J. and Bailis, R., 2018. Assessment of the Cambodian national biodigester program. *Energy for Sustainable Development*, 46, pp.11- 22.
<https://doi.org/10.1016/j.esd.2018.06.008>
- Il Islam, D., Rahman, A., Sarker, N.I., Sarker, S.R. and Jianchao, L., 2021. Factors Influencing Rice Farmers' Risk Attitudes and Perceptions in Bangladesh amid Environmental and Climatic Issues. *Polish Journal of Environmental Studies*, 30(1).
<https://doi.org/10.15244/pjoes/120365>
- Ikonya, S.N., 2018. Adoption of biogas technology as an alternative energy source in gakawa location, Nyeri County, Kenya. *Unpublished master's thesis, Kenyatta University*.
- Ingwani, E., 2019. Are peri-urban land transactions a disaster in the making? A case of Domboshava, Zimbabwe. *Jamba: Journal of Disaster Risk Studies*, 11(3), pp.1- 6.
<http://dx.doi.org/10.4102/jamba.v11i3.708>
- Issifu, A.K., Darko, F.D. and Paolo, S.A., 2022. Climate change, migration and farmer–herder conflict in Ghana. *Conflict Resolution Quarterly*, 39(4), pp.421- 439.
<https://doi.org/10.1002/crq.21346>
- Izadi, N., Saadi, H. and Kooshki, L., 2024. Analysis of smallholder farmers' dynamics of knowledge sharing, skill transfer, and participation in using biogas (application of social network analysis). *Sustainable Futures*, 8, p.100271.
<https://doi.org/10.1016/j.sftr.2024.100271>
- Jabeen, G., Yan, Q., Ahmad, M., Fatima, N., Jabeen, M., Li, H. and Qamar, S., 2020. Household- based critical influence factors of biogas generation technology utilization: a case of Punjab province of Pakistan. *Renewable Energy*, 154, pp.650- 660.
<https://doi.org/10.1016/j.renene.2020.03.049>
- Jacobs, D., 2016. *Renewable energy policy convergence in the EU: the evolution of feed-in tariffs in Germany, Spain and France*. Routledge.
<https://doi.org/10.4324/9781315605340>
- Jan, I. and Akram, W., 2018. Willingness of rural communities to adopt biogas systems in Pakistan: Critical factors and policy implications. *Renewable and Sustainable Energy Reviews*, 81, pp.3178-3185. <https://doi.org/10.1016/j.rser.2017.03.141>
- Janas, M. and Zawadzka, A., 2018. Assessment of environmental impact of agricultural biogas plants. *Acta Innovations*, (27), pp.24-30.
<http://dx.doi.org/10.32933/ActaInnovations.27.3>

- Jayashankar, P., Nilakanta, S., Johnston, W.J., Gill, P. and Burres, R., 2018. IoT adoption in agriculture: the role of trust, perceived value and risk. *Journal of Business & Industrial Marketing*. <http://dx.doi.org/10.1108/JBIM-01-2018-0023>
- Johnson, R.A. and Bhattacharyya, G.K., 2019. *Statistics: principles and methods*. John Wiley & Sons.
- Kaifa, J. and Parawira, W., 2019. A Study of Biogas Production in Zimbabwe: Lessons for Southern Africa. *Adv Biotech & Micro*,13(3): 555865. <https://doi.org/10.19080/AIBM.2019.13.555865>
- Kajau, G. and Madyira, D.M., 2019. Analysis of the Zimbabwe biodigester status. *Procedia Manufacturing*, 35, pp.561-566. <https://doi.org/10.1016/j.promfg.2019.05.079>
- Kamusoko, R., Jingura, R.M., Chikwambi, Z. and Parawira, W., 2022. Biogas: microbiological research to enhance efficiency and regulation. In *Handbook of biofuels* (pp. 485-497). Academic Press. <https://doi.org/10.1016/B978-0-12-822810-4.00025-7>
- Kapoor, R., Ghosh, P., Kumar, M., Sengupta, S., Gupta, A., Kumar, S.S., Vijay, V., Kumar, V., Vijay, V.K. and Pant, D., 2020. Valorization of agricultural waste for biogas based circular economy in India: A research outlook. *Bioresource Technology*, 304, p.123036. <https://doi.org/10.1016/j.biortech.2020.123036>
- Karlsson, N.P., Hoveskog, M., Halila, F. and Mattsson, M., 2019. Business modelling in farm-based biogas production: towards network-level business models and stakeholder business cases for sustainability. *Sustainability Science*, 14, pp.1071-1090. <https://doi.org/10.1007/s11625-018-0584-z>
- Kasilingam, D.L., 2020. Understanding the attitude and intention to use smartphone chatbots for shopping. *Technology in Society*, 62, p.101280. <https://doi.org/10.1016/j.techsoc.2020.101280>
- Kelebe, H.E., 2018. Returns, setbacks, and future prospects of bio-energy promotion in northern Ethiopia: the case of family-sized biogas energy. *Energy, Sustainability and Society*, 8(1), pp.1-14. <https://doi.org/10.1186/s13705-018-0171-2>
- Kemausuor, F., Adaramola, M.S. and Morken, J., 2018. A review of commercial biogas systems and lessons for Africa. *Energies*, 11(11), p.2984. <https://doi.org/10.3390/en11112984>
- Ketuama, C.T. and Roubík, H., 2024. Economic viability and factors affecting farmers' willingness to pay for adopting small-scale biogas plants in rural areas of Cameroon. *Renewable Energy*, 230, p.120895. <https://doi.org/10.1016/j.renene.2024.120895>
- Khadka, G., 2020. Relevance of Biogas in Rural Area: Women Perspectives. *PatanPragya*, 6(1), pp.117-126. <https://doi.org/10.3126/pragya.v6i1.34407>

- Khairunnessa, F., Vazquez-Brust, D.A. and Yakovleva, N., 2021. A review of the recent developments of green banking in Bangladesh. *Sustainability*, 13(4), p.1904. <https://doi.org/10.3390/su13041904>
- Khan, S.A.R., Zhang, Y., Kumar, A., Zavadskas, E. and Streimikiene, D., 2020. Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. *Sustainable development*, 28(4), pp.833-843. <https://doi.org/10.1002/sd.2034>
- Khan, E.U. and Martin, A.R., 2016. Review of biogas digester technology in rural Bangladesh. *Renewable and Sustainable Energy Reviews*, 62, pp.247- 259. <https://doi.org/10.1016/j.rser.2016.04.044>
- Kimutai, S.K., Kimutai, I.K. and Manirambona, E., 2025. Impact of biogas adoption on household energy use and livelihood improvement in Kenya: an overview on a roadmap toward sustainability. *International Journal of Energy Sector Management*, 19(3), pp.551-568. <https://doi.org/10.1108/IJESM-07-2024-0053>
- Knowles, M.S., Holton III, E.F., Swanson, R.A., SWANSON, R. and Robinson, P.A., 2020. The adult learner: The definitive classic in adult education and human resource development. <https://doi.org/10.4324/9780429299612>
- Kooij, H.J., Oteman, M., Veenman, S., Sperling, K., Magnusson, D., Palm, J. and Hvelplund, F., 2018. Between grassroots and treetops: Community power and institutional dependence in the renewable energy sector in Denmark, Sweden and the Netherlands. *Energy Research & Social Science*, 37, pp.52-64. <https://doi.org/10.1016/j.erss.2017.09.019>
- Kuchimanchi, B.R., De Boer, I.J., Ripoll-Bosch, R. and Oosting, S.J., 2021. Understanding transitions in farming systems and their effects on livestock rearing and smallholder livelihoods in Telangana, India. *Ambio*, 50, pp.1809- 1823. <https://doi.org/10.1007/s13280-021-01523-z>
- Kulichkova, G.I., Ivanova, T.S., Köttner, M., Volodko, O.I., Spivak, S.I., Tsygankov, S.P. and Blume, Y.B., 2020. Plant feedstocks and their biogas production potentials. *The Open Agriculture Journal*, 14(1). <http://dx.doi.org/10.2174/1874331502014010219>
- Kulugomba, R., Mapoma, H.W., Gamula, G., Blanchard, R. and Mlatho, S., 2024. Opportunities and barriers to biogas adoption in Malawi. *Energies*, 17(11), p.2591. <https://doi.org/10.3390/en17112591>
- Lade, S.J., Donges, J.F., Fetzer, I., Anderies, J.M., Beer, C., Cornell, S.E., Gasser, T., Norberg, J., Richardson, K., Rockström, J. and Steffen, W., 2018. Analytically tractable climate-carbon cycle feedbacks under 21st century anthropogenic forcing. *Earth System Dynamics*, 9(2), pp.507-523. <https://doi.org/10.5194/esd-9-507-2018>

- Lauer, M., Hansen, J.K., Lamers, P. and Thrän, D., 2018. Making money from waste: The economic viability of producing biogas and biomethane in the Idaho dairy industry. *Applied Energy*, 222, pp.621- 636.
<https://doi.org/10.1016/j.apenergy.2018.04.026>
- Lavery, M.R., Acharya, P., Sivo, S.A. and Xu, L., 2019. Number of predictors and multicollinearity: What are their effects on error and bias in regression?. *Communications in Statistics-Simulation and Computation*, 48(1), pp.27- 38.
<https://doi.org/10.1080/03610918.2017.1371750>
- Li, Q., Wang, J., Wang, X. and Wang, Y., 2022. The Impact of Training on Beef Cattle Farmers' Installation of Biogas Digesters. *Energies*, 15(9), p.3039.
<https://doi.org/10.3390/en15093039>
- Li, Y., Qing, C., Guo, S., Deng, X., Song, J. and Xu, D., 2023. When my friends and relatives go solar, should I go solar too? Evidence from rural Sichuan province, China. *Renewable Energy*, 203, pp.753-762. <https://doi.org/10.1016/j.renene.2022.12.119>
- Li, Y. and Xu, Y., 2023. Does off-farm work alleviate rural households' energy poverty in China? Comparative analysis based on livelihood patterns. *Journal of Cleaner Production*, 427, p.139144. <https://doi.org/10.1016/j.jclepro.2023.139144>
- Loeb, S., Dynarski, S., McFarland, D., Morris, P., Reardon, S. and Reber, S., 2017. Descriptive Analysis in Education: A Guide for Researchers. NCEE 2017-4023. *National Center for Education Evaluation and Regional Assistance*.
- Loki, O. and Mdoda, L., 2023. Assessing the contribution and impact of access to extension services toward sustainable livelihoods and self-reliance in Eastern Cape Province, South Africa. *African Journal of Food, Agriculture, Nutrition and Development*, 23(4), pp.23000-23025. <http://dx.doi.org/10.18697/ajfand.119.22990>
- Lu, J. and Gao, X., 2021. Biogas: Potential, challenges, and perspectives in a changing China. *Biomass and Bioenergy*, 150, p.106127.
<https://doi.org/10.1016/j.biombioe.2021.106127>
- Lund, B.D., Omame, I., Tijani, S. and Agbaji, D., 2020. Perceptions toward artificial intelligence among academic library employees and alignment with the diffusion of innovations' adopter categories. *College & Research Libraries*, 81(5), p.865.
<https://doi.org/10.5860/crl.81.5.865>
- Luo, B., Khan, A.A., Ali, M.A.S. and Yu, J., 2021. An evaluation of influencing factors and public attitudes for the adoption of biogas system in rural communities to overcome energy crisis: A case study of Pakistan. *Science of The Total Environment*, 778, p.146208. <https://doi.org/10.1016/j.scitotenv.2021.146208>

- Ketuama, C.T. and Roubík, H., 2024. Economic viability and factors affecting farmers' willingness to pay for adopting small-scale biogas plants in rural areas of Cameroon. *Renewable Energy*, 230, p.120895.
<https://doi.org/10.1016/j.renene.2024.120895>
- Knierim, A., Kernecker, M., Erdle, K., Kraus, T., Borges, F. and Wurbs, A., 2019. Smart farming technology innovations—Insights and reflections from the German Smart-AKIS hub. *NJAS- Wageningen Journal of Life Sciences*, 90, p.100314.
<https://doi.org/10.1016/j.njas.2019.100314>
- Kulichkova, G.I., Ivanova, T.S., Köttner, M., Volodko, O.I., Spivak, S.I., Tsygankov, S.P. and Blume, Y.B., 2020. *Plant feedstocks and their biogas production potentials. Open Agric J* 14: 219–234. <http://dx.doi.org/10.2174/1874331502014010219>
- Kulugomba, R., Mapoma, H.W., Gamula, G., Blanchard, R. and Mlatho, S., 2024. Opportunities and barriers to biogas adoption in Malawi. *Energies*, 17(11), p.2591.
<https://doi.org/10.3390/en17112591>
- Maćkowiak, B., Matějka, F. and Wiederholt, M., 2023. Rational inattention: A review. *Journal of Economic Literature*, 61(1), pp.226-273. <https://doi.org/10.1257/jel.20211524>
- Majchrzak, M., Szczypa, P. and Adamowicz, K., 2022. Supply of Wood Biomass in Poland in Terms of Extraordinary Threat and Energy Transition. *Energies*, 15(15), p.5381.
<https://doi.org/10.3390/en15155381>
- Makate, M., Nelson, N. and Makate, C., 2018. Farm household typology and adoption of climate-smart agriculture practices in smallholder farming systems of southern Africa. *African Journal of Science, Technology, Innovation and Development*, 10(4), pp.421-439. <http://dx.doi.org/10.1080/20421338.2018.1471027>
- Marambanyika, T., Sakarombe, S., Musasa, T. and Defe, R., 2020. Biogas Technology Adoption as an Alternative Source of Energy in Domboshava Communal Area of Zimbabwe: Benefits and Challenges. *Journal of Geographical Research*, 3(3), pp.23- 32.
<https://doi.org/10.30564/jgr.v3i3.2151>
- Maramura, T.C., Maziriri, E.T., Chuchu, T., Mago, D. and Mazivisa, R., 2020. Renewable energy access challenge at household level for the poor in rural Zimbabwe: is biogas energy a remedy?. *International Journal of Energy Economics and Policy*, 10(4), pp.282-292. <https://doi.org/10.32479/ijeep.8801>
- Marie, M., Yirga, F., Alemu, G. and Azadi, H., 2021. Status of energy utilization and factors affecting rural households' adoption of biogas technology in north-western Ethiopia. *Heliyon*, 7(3), p.e06487.<https://doi.org/10.1016/j.heliyon.2021.e06487>

- Masukujjaman, M., Alam, S.S., Siwar, C. and Halim, S.A., 2021. Purchase intention of renewable energy technology in rural areas in Bangladesh: Empirical evidence. *Renewable Energy*, 170, pp.639- 651. <https://doi.org/10.1016/j.renene.2021.01.125>
- Mateescu, C. and Dima, A.D., 2022. Critical analysis of key barriers and challenges to the growth of the biogas sector: a case study for Romania. *Biomass Conversion and Biorefinery*, 12(12), pp.5989-6002. <https://doi.org/10.1007/s13399-020-01054-9>
- Meidiana, C., Hidayah, A. and Wijayanti, W.P., 2020, June. Factors Influencing the Biogas Acceptance in Rural Area. In *IOP Conference Series: Earth and Environmental Science* (Vol. 520, No. 1, p. 012006). IOP Publishing. <https://doi.org/10.1088/1755-1315/520/1/012006>
- Meinshausen, M., Lewis, J., McGlade, C., Gütschow, J., Nicholls, Z., Burdon, R., Cozzi, L. and Hackmann, B., 2022. Realization of Paris Agreement pledges may limit warming just below 2 C. *Nature*, 604(7905), pp.304-309. <https://doi.org/10.1038/s41586-022-04553-z>
- Mendieta, O., Castro, L., Vera, E., Rodríguez, J. and Escalante, H., 2021. Toward the Adoption of Anaerobic Digestion Technology through Low-Cost Biodigesters: A Case Study of Non-Centrifugal Cane Sugar Producers in Colombia. *Water*, 13(18), p.2566. <https://doi.org/10.3390/w13182566>
- Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S., 2016. Factors affecting households' decisions in biogas technology adoption, the case of Ofla and Mecha Districts, northern Ethiopia. *Renewable Energy*, 93, pp.215- 227. <https://doi.org/10.1016/j.renene.2016.02.066>
- Mengistu, B., Paulos, M., Agonafir, N., Ameha, A., Legesse, H., Dankenbring, E., Sylla, M. and Miller, N.P., 2021. Barriers to the uptake of community-based curative child health services in Ethiopia. *BMC Public Health*, 21(1), p.1551. <https://doi.org/10.1186/s12889-021-11558-2>
- Midamba, D.C., Kwesiga, M. and Ouko, K.O., 2024. Determinants of adoption of sustainable agricultural practices among maize producers in Northern Uganda. *Cogent Social Sciences*, 10(1), p.2286034. <https://doi.org/10.1080/23311886.2023.2286034>
- Mishra, P., Pandey, C.M., Singh, U., Gupta, A., Sahu, C. and Keshri, A., 2019. Descriptive statistics and normality tests for statistical data. *Annals of cardiac anaesthesia*, 22(1), p.67. https://doi.org/10.4103/aca.ACA_157_18
- Mittal, S., Ahlgren, E.O. and Shukla, P.R., 2018. Barriers to biogas dissemination in India: A review. *Energy Policy*, 112, pp.361-370. <https://doi.org/10.1016/j.enpol.2017.10.027>

- Mohammed, L., Niesten, E. and Gagliardi, D., 2020. Adoption of alternative fuel vehicle fleets—a theoretical framework of barriers and enablers. *Transportation Research Part D: Transport and Environment*, 88, p.102558. <https://doi.org/10.1016/j.trd.2020.102558>
- Moli, D.R.R., Hafeez, A.G., Majumder, S., Mitra, S. and Hasan, M., 2021. Does biogas technology adoption improve the livelihood and income level of rural people?. *International Journal of Green Energy*, 18(10), pp.1081- 1090. <https://doi.org/10.1080/15435075.2021.1891907>
- Monika, G., Deepak, P., Yogeshvari, J. and Rajababu, V., 2020. Biogas: An Effective and Common Energy Tool—Part II. *Biofuel Production Technologies: Critical Analysis for Sustainability*, pp.105-121. https://doi.org/10.1007/978-981-13-8637-4_4
- Mukaila, R., Umaru, I.I., Otekunrin, O.A., Omeje, E.E., Awoyelu, F.E., Onah, O.G., Okorie, O.J., Onyia, C.C. and Ezinwa, G.S., 2024. Adoption of biogas technology by cassava processors: Implication for environmental sustainability. *World Development Sustainability*, 4, p.100132. <https://doi.org/10.1016/j.wds.2024.100132>
- Mukeshimana, M.C., Zhao, Z.Y., Ahmad, M. and Irfan, M., 2021. Analysis on barriers to biogas dissemination in Rwanda: AHP approach. *Renewable Energy*, 163, pp.1127- 1137. <https://doi.org/10.1016/j.renene.2020.09.051>
- Mukono, S.N. and Mwiinga, P.C., 2021. Environmental aspects of water use in arid regions: The Lake Kariba case. In *Management of River Basins and Dams*: (pp. 75-81). CRC Press. <http://dx.doi.org/10.1201/9781003211006-11>
- Mukoro, V., Sharmina, M. and Gallego-Schmid, A., 2022. A review of business models for access to affordable and clean energy in Africa: Do they deliver social, economic, and environmental value?. *Energy Research & Social Science*, 88, p.102530. <https://doi.org/10.1016/j.erss.2022.102530>
- Munafò, M.R., Tilling, K., Taylor, A.E., Evans, D.M. and Davey Smith, G., 2018. Collider scope: when selection bias can substantially influence observed associations. *International journal of epidemiology*, 47(1), pp.226- 235. <https://doi.org/10.1093/ije/dyx206>
- Murray, C., 2002. Livelihoods research: transcending boundaries of time and space. *Journal of Southern African Studies*, 28(3), pp.489- 509. <https://doi.org/10.1080/0305707022000006486>
- Mustafa, S., Zhang, W., Sohail, M.T., Rana, S. and Long, Y., 2023. A moderated mediation model to predict the adoption intention of renewable wind energy in developing countries. *Plosone*, 18(3), p.e0281963. <https://doi.org/10.1371/journal.pone.0281963>

- Mutami, C., 2015. Smallholder agriculture production in Zimbabwe: A survey. *Consilience*, (14), pp.140-157.
- Mutate, C.T., Kanjanda, A.J. and Mehta, G., 2023. The Use of Biogas Energy for Electrical Power Generation in ZimbabweA Study. In *Recent advances in Power Systems: Select Proceedings of EPREC 2022* (pp. 265-275). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-6605-7_19
- Muvhiiwa, R., Hildebrandt, D., Chimwani, N., Ngubevana, L. and Matambo, T., 2017. The impact and challenges of sustainable biogas implementation: moving towards a bio-based economy. *Energy, Sustainability and Society*, 7, pp.1-11. <https://doi.org/10.1186/s13705-017-0122-3>
- Namirembe, G., Mukwaya, P.I., Mugagga, F. and Kisira, Y., 2024. Insights into home biogas technology adoption dynamics through the lens of the diffusion of innovation theory in Uganda. *Energy for Sustainable Development*, 80, p.101425. <https://doi.org/10.1016/j.esd.2024.101425>
- Ndiritu, S.W. and Engola, M.K., 2020. The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya. *Renewable Energy*, 161, pp.593-605. <https://doi.org/10.1016/j.renene.2020.07.082>
- Ndlela, N.W. and Davidson, I.E., 2022, August. Reliability and security analysis of the southern Africa power pool regional grid. In *2022 IEEE PES/IAS PowerAfrica* (pp. 1-5). IEEE. <https://doi.org/10.1109/PowerAfrica53997.2022.9905389>
- Nelson, H., Chen, C.F. and Li, J., 2021. Equity in renewable energy technology adoption in China: a review of the social-psychological and demographic barriers. *Current Sustainable/Renewable Energy Reports*, 8, pp.91-100. <https://doi.org/10.1007/s40518-021-00175-7>
- Nevzorova, T. and Kutcherov, V., 2019. Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. *Energy Strategy Reviews*, 26, p.100414. <https://doi.org/10.1016/j.esr.2019.100414>
- Nevzorova, T. and Karakaya, E., 2020. Explaining the drivers of technological innovation systems: The case of biogas technologies in mature markets. *Journal of Cleaner Production*, 259,p.120819. <https://doi.org/10.1016/j.jclepro.2020.120819>
- Ngcobo, L., Obi, A., Mamphweli, S. and Zantsi, S., 2022. Adoption and perceptions of biogas: Empirical evidence from rural households of Melani village in Raymond Mhlaba municipality. *African Journal of Science, Technology, Innovation and Development*, 14(2), pp.350-358. <https://dx.doi.org/10.1080/20421338.2020.1819684>

- Nhubu, T., Muzenda, E., Mbohwa, C. and Agbenyeku, E.O., 2020. Comparative assessment of composting and anaerobic digestion of municipal biodegradable waste in Harare, Zimbabwe. *Environmental Progress & Sustainable Energy*, 39(4), p.e13376. <https://doi.org/10.1002/ep.13376>
- Nhundu, T., Mutandwa, E., Stark, J., Chamboko, T. and Vambe, A.T., 2023. Determinants of smallholder livestock farmers' adoption decisions of improved fodder technologies in Insiza District. *African Journal of Science, Technology, Innovation and Development*, 15(7), pp.805-816. <https://doi.org/10.1080/20421338.2023.2196199>
- Nikolakis, W. and Grafton, R.Q., 2015. Putting Indigenous water rights to work: The sustainable livelihoods framework as a lens for remote development. *Community Development*, 46(2), pp.149-163. <https://doi.org/10.1080/15575330.2015.1009922>
- Nygaard, I. and Bolwig, S., 2018. The rise and fall of foreign private investment in the jatropha biofuel value chain in Ghana. *Environmental Science & Policy*, 84, pp.224- 234. <https://doi.org/10.1016/j.envsci.2017.08.007>
- O'Connor, S., Ehimen, E., Pillai, S.C., Black, A., Tormey, D. and Bartlett, J., 2021. Biogas production from small-scale anaerobic digestion plants on European farms. *Renewable and Sustainable Energy Reviews*, 139, p.110580. <https://doi.org/10.1016/j.rser.2020.110580>
- Obaideen, K., Abdelkareem, M.A., Wilberforce, T., Elsaid, K., Sayed, E.T., Maghrabie, H.M. and Olabi, A.G., 2022. Biogas role in achievement of the sustainable development goals: Evaluation, Challenges, and Guidelines. *Journal of the Taiwan Institute of Chemical Engineers*, 131, p.104207. <https://doi.org/10.1016/j.jtice.2022.104207>
- Obileke, K., Nwokolo, N., Makaka, G., Mukumba, P. and Onyeaka, H., 2021. Anaerobic digestion: Technology for biogas production as a source of renewable energyA review. *Energy & Environment*, 32(2), pp.191- 225. <https://doi.org/10.1177/0958305X20923117>
- Obuobi, B., Zhang, Y., Adu-Gyamfi, G., Nketiah, E., Grant, M.K., Adjei, M. and Cudjoe, D., 2022. Fruits and vegetable waste management behavior among retailers in Kumasi, Ghana. *Journal of Retailing and Consumer Services*, 67, p.102971. <https://doi.org/10.1016/j.jretconser.2022.102971>
- Onyutha, C., 2019. African food insecurity in a changing climate: The roles of science and policy. *Food and Energy Security*, 8(1), p.e00160. <https://doi.org/10.1002/fes3.160>
- Oribhabor, C.B. and Anyanwu, C.A., 2019. Research sampling and sample size determination: a practical application. *Journal of Educational Research (Fudjer)*, 2(1), pp.47-57.

- Ortiz, W., Terrapon-Pfaff, J. and Dienst, C., 2017. Understanding the diffusion of domestic biogas technologies. Systematic conceptualisation of existing evidence from developing and emerging countries. *Renewable and Sustainable Energy Reviews*, 74, pp.1287-1299. <https://doi.org/10.1016/j.rser.2016.11.090>
- Osei-Marfo, M., de Vries, N. and Awuah, E., 2020. Dynamics of household heads' intentions to adopt biogas technology in Ghana. <http://dx.doi.org/10.9734/jenrr/2020/v4i230125>
- Palsaniya, D.R., Kumar, S., Das, M.M., Kumar, T.K., Kumar, S., Chaudhary, M., Chand, K., Rai, S.K., Ahmed, A., Sahay, C.S. and Choudhary, M., 2021. Integrated multi-enterprise agricultural system for sustaining livelihood, energy use and resource recycling: a case study from semi-arid tropics of central India. *Agroforestry Systems*, 95(8), pp.1619-1634. <https://doi.org/10.1007/s10457-021-00670-2>
- Pandey, R., Jha, S.K., Alatalo, J.M., Archie, K.M. and Gupta, A.K., 2017. Sustainable livelihood framework-based indicators for assessing climate change vulnerability and adaptation for Himalayan communities. *Ecological indicators*, 79, pp.338-346. <https://doi.org/10.1016/j.ecolind.2017.03.047>
- Patinvoh, R.J. and Taherzadeh, M.J., 2019. Challenges of biogas implementation in developing countries. *Current Opinion in Environmental Science & Health*, 12, pp.30-37. <https://doi.org/10.1016/j.coesh.2019.09.006>
- Peltonen-Sainio, P., Sorvali, J. and Kaseva, J., 2020. Winds of change for farmers: Matches and mismatches between experiences, views and the intention to act. *Climate Risk Management*, 27, p.100205. <https://doi.org/10.1016/j.crm.2019.100205>
- Pilloni, M., Hamed, T.A. and Joyce, S., 2020. Assessing the success and failure of biogas units in Israel: Social niches, practices, and transitions among Bedouin villages. *Energy Research & Social Science*, 61, p.101328. <https://doi.org/10.1016/j.erss.2019.101328>
- Plonsky, L. and Ghanbar, H., 2018. Multiple regression in L2 research: A methodological synthesis and guide to interpreting R2 values. *The Modern Language Journal*, 102(4), pp.713-731. <https://doi.org/10.1111/modl.12509>
- Pörtner, H.O., Roberts, D.C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R.A., Betts, R., Kerr, R.B., Biesbroek, R. and Birkmann, J., 2022. *Climate change 2022: Impacts, adaptation and vulnerability* (p. 3056). Geneva, Switzerland::IPCC. <http://dx.doi.org/10.1017/9781009325844>.
- Pradhan Shrestha, R., Jirakiattikul, S., Chapagain, B., Katuwal, H., Gyawali, S. and Shrestha, M., 2024. Biogas adoption and its impact on women and the community: evidence from Nepal. *International Journal of Environmental Studies*, 81(2), pp.537-553. <https://doi.org/10.1080/00207233.2024.2323296>

- Purwanto, P., 2018. Evaluation of Livestock Waste Management to Energy Biogas (Case Study: Jetak Village, Getasan Sub District). In *E3S Web of Conferences* (Vol. 73, p. 07013). EDP Sciences. <https://doi.org/10.1051/e3sconf/20187307013>
- Puzzolo, E., Pope, D., Stanistreet, D., Rehfuess, E.A. and Bruce, N.G., 2016. Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. *Environmental research*, 146, pp.218- 234. <https://doi.org/10.1016/j.envres.2016.01.002>
- Quandt, A., 2018. Measuring livelihood resilience: The household livelihood resilience approach (HLRA). *World Development*, 107, pp.253- 263. <https://doi.org/10.1016/j.worlddev.2018.02.024>
- Rahman, M.S., Majumder, M.K. and Sujon, M.H.K., 2021. Adoption determinants of biogas and its impact on poverty in Bangladesh. *Energy Reports*, 7, pp.5026- 5033. <https://doi.org/10.1016/j.egy.2021.08.027>
- Rahman, M.M., Tabash, M.I., Salamzadeh, A., Abduli, S. and Rahaman, M.S., 2022. Sampling techniques (probability) for quantitative social science researchers: a conceptual guidelines with examples. *Seeu Review*, 17(1), pp.42- 51. <https://doi.org/10.2478/seeur-2022-0023>
- Rahman, M.S., Sujon, M.H.K., Acharjee, D.C., Rasha, R.K. and Rahman, M., 2022. Intensity of adoption and welfare impacts of drought-tolerant rice varieties cultivation in Bangladesh. *Heliyon*, 8(5), p.e09490. <https://doi.org/10.1016/j.heliyon.2022.e09490>
- Rasapoor, M., Young, B., Brar, R., Sarmah, A., Zhuang, W.Q. and Baroutian, S., 2020. Recognizing the challenges of anaerobic digestion: Critical steps toward improving biogas generation. *Fuel*, 261, p.116497. <https://doi.org/10.1016/j.fuel.2019.116497>
- Rasimphi, T.E., Tinarwo, D., Ravhengani, S., Sambo, C. and Mhlanga, P., 2022. Biogas technology implementation in rural areas: a case study of Vhembe District in Limpopo Province, South Africa. In *Handbook of Biofuels* (pp. 501-509). Academic Press. <https://doi.org/10.1016/B978-0-12-822810-4.00026-9>
- Raza, S.A., Qazi, W., Khan, K.A. and Salam, J., 2021. Social isolation and acceptance of the learning management system (LMS) in the time of COVID-19 pandemic: an expansion of the UTAUT model. *Journal of Educational Computing Research*, 59(2), pp.183- 208. <https://doi.org/10.1177/0735633120960421>
- Reichenberg, L., Hedenus, F., Odenberger, M. and Johnsson, F., 2018. Tailoring large-scale electricity production from variable renewable energy sources to accommodate baseload generation in Europe. *Renewable energy*, 129, pp.334- 346. <https://doi.org/10.1016/j.renene.2018.05.014>

- Rezaei, R. and Ghofranfarid, M., 2018. Rural households' renewable energy usage intention in Iran: Extending the unified theory of acceptance and use of technology. *Renewable energy*, 122, pp.382-391. <https://doi.org/10.1016/j.renene.2018.02.011>
- Rhein, F.E. and Rhein, F.E., 2021. B2B innovation adoption and diffusion. *The Dynamics of Green Innovation in B2B Industries: A Systems Approach to Explain the Diffusion of Bioplastics*, pp.35-56. <https://doi.org/10.1007/978-3-658-32148-2>
- Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432-448). Routledge. <http://dx.doi.org/10.4324/9780203710753-35>
- Rogers, E.M., 2003. The innovation-decision process. *Diffusion of innovations*, 5, pp.168-218.
- Romanello, M., McGushin, A., Di Napoli, C., Drummond, P., Hughes, N., Jamart, L., Kennard, H., Lampard, P., Rodriguez, B.S., Arnell, N. and Ayeb-Karlsson, S., 2021. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *The Lancet*, 398(10311), pp.1619-1662. [https://doi.org/10.1016/S0140-6736\(21\)02429-6](https://doi.org/10.1016/S0140-6736(21)02429-6)
- Ronaghi, M.H. and Forouharfar, A., 2020. A contextualized study of the usage of the Internet of things (IoTs) in smart farming in a typical Middle Eastern country within the context of Unified Theory of Acceptance and Use of Technology model (UTAUT). *Technology in Society*, 63, p.101415. <https://doi.org/10.1016/j.techsoc.2020.101415>
- Roopnarain, A. and Adeleke, R., 2017. Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renewable and Sustainable Energy Reviews*, 67, pp.1162-1179. <https://doi.org/10.1016/j.rser.2016.09.087>
- Roopnarain, A., Ndaba, B., Bello-Akinosho, M., Bamuza-Pemu, E., Mukhuba, M., Nkuna, R. and Adeleke, R., 2020. Biogas technology in Africa: an assessment of feedstock, barriers, socio-economic impact and the way forward. *Biogas Production: From Anaerobic Digestion to a Sustainable Bioenergy Industry*, pp.415-445. https://doi.org/10.1007/978-3-030-58827-4_18
- Roy, A.D., Prakash, O., Kumar, A., Kaviti, A.K. and Pandey, A., 2018. Design and Selection Criteria of Biogas Digester. *Low Carbon Energy Supply: Trends, Technology, Management*, pp.91-112. https://doi.org/10.1007/978-981-10-7326-7_6
- Ruwa, T.L., Ruwa, T. and Abbasoglu, S., 2018. Exploration And Modelling Of Renewable Energy Sources And Mini-Grid Installation Opportunities In Zimbabwe.
- Sari, A.I. and Purnomo, S.H., 2022, March. Public acceptance of livestock biogas technology as an environmentally friendly alternative energy. In *IOP Conference Series: Earth and*

Environmental Science (Vol. 1001, No. 1, p. 012033). IOP Publishing.
<https://doi.org/10.1088/1755-1315/1001/1/012033>

- Sarkar, B., Mridha, B., Pareek, S., Sarkar, M. and Thangavelu, L., 2021. A flexible biofuel and bioenergy production system with transportation disruption under a sustainable supply chain network. *Journal of Cleaner Production*, 317, p.128079.
<https://doi.org/10.1016/j.jclepro.2021.128079>
- Sarker, S.A., Wang, S., Adnan, K.M. and Sattar, M.N., 2020. Economic feasibility and determinants of biogas technology adoption: evidence from Bangladesh. *Renewable and Sustainable Energy Reviews*, 123, p.109766. <https://doi.org/10.1016/j.rser.2020.109766>
- Sayed, E.T., Wilberforce, T., Elsaid, K., Rabaia, M.K.H., Abdelkareem, M.A., Chae, K.J. and Olabi, A.G., 2021. A critical review on environmental impacts of renewable energy systems and mitigation strategies: Wind, hydro, biomass and geothermal. *Science of the total environment*, 766, p.144505. <https://doi.org/10.1016/j.scitotenv.2020.144505>
- Scoones, I., 2021. Pastoralists and peasants: perspectives on agrarian change. *The Journal of Peasant Studies*, 48(1), pp.1-47. <https://doi.org/10.1080/03066150.2020.1802249>
- Scoones, I., Mavedzenge, B., & Murimbarimba, F. (2019). Young people and land in Zimbabwe: livelihood challenges after land reform. *Review of African Political Economy*, 46(159), 117-134. <https://doi.org/10.1080/03056244.2019.1610938>
- Seboka, A.D., 2019. Domestic biogas digester as a means of wood fuel consumption reduction in the rural households of Wondo Genet, Southern Ethiopia. *Biofuels*, 10(3), pp.411-417. <https://doi.org/10.1080/17597269.2018.1558841>
- Sehgal, K., 2018. Current state and future prospects of global biogas industry. *Biogas: Fundamentals, Process, and Operation*, pp.449-472. https://doi.org/10.1007/978-3-319-77335-3_18
- Shackleton, R.T., 2020. Loss of land and livelihoods from mining operations: A case in the Limpopo Province, South Africa. *Land use policy*, 99, p.104825.
<https://doi.org/10.1016/j.landusepol.2020.104825>
- Shah, S.A.A., Zhou, P., Walasai, G.D. and Mohsin, M., 2019. Energy security and environmental sustainability index of South Asian countries: A composite index approach. *Ecological Indicators*, 106, p.105507. <https://doi.org/10.1016/j.ecolind.2019.105507>
- Shah, Z.A., Dar, M.A., Dar, E.A., Obianefo, C.A., Bhat, A.H., Ali, M.T., Alatawi, H.A., Ghamry, H.I., Shukry, M. and Sayed, S., 2022. A multinomial approach to sustainable and improved agricultural technologies vis-a-vis socio-personal determinants in apple (*Malus domestica*) cultivation. *Journal of King Saud University-Science*, 34(7), p.102286. <https://doi.org/10.1016/j.jksus.2022.102286>

- Shallo, L., Ayele, M. and Sime, G., 2020. Determinants of biogas technology adoption in southern Ethiopia. *Energy, Sustainability and Society*, 10, pp.1- 13. <https://doi.org/10.1186/s13705-019-0236-x>
- Shallo, L. and Sime, G., 2023. Biogas Technology Adoption and Impacts on Rural Household Energy Expenditure in South Ethiopia. <https://doi.org/10.21203/rs.3.rs-3219842/v1>
- Shallo, L. and Sime, G., 2025. Impacts of Biogas Technology Adoption on Rural Household Energy Expenditure in South Ethiopia. *The Scientific World Journal*, 2025(1), p.2846569. <https://doi.org/10.1155/tswj/2846569>
- Shang, L., Heckelei, T., Gerullis, M.K., Börner, J. and Rasch, S., 2021. Adoption and diffusion of digital farming technologies-integrating farm-level evidence and system interaction. *Agricultural systems*, 190, p.103074. <https://doi.org/10.1016/j.agsy.2021.103074>
- Sharma, G.D., Shah, M.I., Shahzad, U., Jain, M. and Chopra, R., 2021. Exploring the nexus between agriculture and greenhouse gas emissions in BIMSTEC region: The role of renewable energy and human capital as moderators. *Journal of Environmental Management*, 297, p.113316. <https://doi.org/10.1016/j.jenvman.2021.113316>
- Sharma, L.R., 2023. Choosing Appropriate Probability Sampling Designs in Research. *Health*, 2, pp.4-21.
- Shrestha, N., 2020. Detecting multicollinearity in regression analysis. *American Journal of Applied Mathematics and Statistics*, 8(2), pp.39-42. <https://doi.org/10.12691/ajams-8-2-1>
- Silaen, M., Taylor, R., Bößner, S., Anger-Kraavi, A., Chewpreecha, U., Badinotti, A. and Takama, T., 2020. Lessons from Bali for small-scale biogas development in Indonesia. *Environmental Innovation and Societal Transitions*, 35, pp.445- 459. <https://doi.org/10.1016/j.eist.2019.09.003>
- Silong, A.K.F. and Gadanakis, Y., 2020. Credit sources, access and factors influencing credit demand among rural livestock farmers in Nigeria. *Agricultural Finance Review*, 80(1), pp.68-90. <https://doi.org/10.1108/AFR-10-2018-0090>
- Silva, A.G., Canavari, M. and Sidali, K.L., 2017. A Technology Acceptance Model of common bean growers' intention to adopt Integrated Production in the Brazilian Central Region. *Die Bodenkultur: Journal of Land Management, Food and Environment*, 68(3), pp.131-143. <https://doi.org/10.1515/boku-2017-0012>
- Singhasene, N. and Iamsomboon, N., 2022. Renewable Energy Adoption Guideline in Thailand for Sustainable Development of New Alternative Energy: Government and Private Sectors. *J. Legal Ethical & Regul. Issues*, 25, p.1.

- Situmeang, R., Mazancová, J. and Roubík, H., 2022. Technological, Economic, Social and Environmental Barriers to Adoption of Small-Scale Biogas Plants: Case of Indonesia. *Energies*, 15(14), p.5105. <https://doi.org/10.3390/en15145105>
- Slámová, M., Kruse, A., Belčáková, I. and Dreer, J., 2021. Old but not old fashioned: Agricultural landscapes as european heritage and basis for sustainable multifunctional farming to earn a living. *Sustainability*, 13(9), p.4650. <https://doi.org/10.3390/su13094650>
- Sobczak, A., Chomać-Pierzecka, E., Kokieli, A., Różycka, M., Stasiak, J. and Soboń, D., 2022. Economic Conditions of Using Biodegradable Waste for Biogas Production, Using the Example of Poland and Germany. *Energies*, 15(14), p.5239. <https://doi.org/10.3390/en15145239>
- Surroop, D., Bundhoo, Z.M. and Raghoo, P., 2019. Waste to energy through biogas to improve energy security and to transform Africa's energy landscape. *Current opinion in green and sustainable chemistry*, 18, pp.79-83. <https://doi.org/10.1016/j.cogsc.2019.02.010>
- Tagne, R.F.T., Dong, X., Anagho, S.G., Kaiser, S. and Ulgiati, S., 2021. Technologies, challenges and perspectives of biogas production within an agricultural context. The case of China and Africa. *Environment, Development and Sustainability*, 23, pp.14799-14826. <https://doi.org/10.1007/s10668-021-01272-9>
- Tagwi, A. and Chipfupa, U., 2022. Participation of Smallholder Farmers in Modern Bioenergy Value Chains in Africa: Opportunities and Constraints. *BioEnergy Research*, pp.1-15. <https://doi.org/10.1007/s12155-022-10451-z>
- Tagwi, A., 2022. The Impacts of Climate Change, Carbon Dioxide Emissions (CO₂) and Renewable Energy Consumption on Agricultural Economic Growth in South Africa: ARDL Approach. *Sustainability*, 14(24), p.16468. <https://doi.org/10.3390/su142416468>
- Takman, J. and Andersson-Sköld, Y., 2021. A framework for barriers, opportunities, and potential solutions for renewable energy diffusion: Exemplified by liquefied biogas for heavy trucks. *Transport Policy*, 110, pp.150-160. <https://doi.org/10.1016/j.tranpol.2021.05.021>
- Talevi, M., Pattanayak, S.K., Das, I., Lewis, J.J. and Singha, A.K., 2022. Speaking from experience: Preferences for cooking with biogas in rural India. *Energy Economics*, 107, p.105796. <https://doi.org/10.1016/j.eneco.2021.105796>
- Tamilmani, K., Rana, N.P. and Dwivedi, Y.K., 2021. Consumer acceptance and use of information technology: A meta-analytic evaluation of UTAUT2. *Information Systems Frontiers*, 23, pp.987-1005. <https://doi.org/10.1007/s10796-020-10007-6>

- Taneja, G., Pal, B.D., Joshi, P.K., Aggarwal, P.K. and Tyagi, N.K., 2019. Farmers' preferences for climate-smart agriculture assessment in the Indo-Gangetic Plain. *Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions*, pp.91- 111. https://doi.org/10.1007/978-981-10-8171-2_5
- Tanveer, A., Zeng, S., Irfan, M. and Peng, R., 2021. Do perceived risk, perception of self-efficacy, and openness to technology matter for solar PV adoption? An application of the extended theory of planned behavior. *Energies*, 14(16), p.5008. <https://doi.org/10.3390/en14165008>
- Tanyanyiwa, V.I., 2019. The Impact of Climate Change and Variability on Small-Scale Peri-Urban Horticultural Farmers in Domboshawa, Zimbabwe. In *Intellectual, Scientific, and Educational Influences on Sustainability Research* (pp. 46-69). IGI Global. <https://doi.org/10.4018/978-1-6684-3686-8.ch076>
- Targetti, Stefano, Lena L. Schaller, and Jochen Kantelhardt. "A fuzzy cognitive mapping approach for the assessment of public-goods governance in agricultural landscapes." *Land use policy* 107(2021):103972. <https://doi.org/10.1016/j.landusepol.2019.04.033>
- Tembo, A., Rahman, M.M. and Jerin, T., 2022. Barriers to development and adoption of biogas in Mokambo peri-urban of Mufulira, Zambia: how does local government fail to provide renewable energy?. *Biofuels*, pp.1- 12. <https://doi.org/10.1080/17597269.2022.2156055>
- Tenaw, D. and Beyene, A.D., 2021. Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. *Renewable and Sustainable Energy Reviews*, 143, p.110897. <https://doi.org/10.1016/j.rser.2021.110897>
- Thapa, S., Morrison, M. and Parton, K.A., 2021. Willingness to pay for domestic biogas plants and distributing carbon revenues to influence their purchase: A case study in Nepal. *Energy Policy*, 158, p.112521. <https://doi.org/10.1016/j.enpol.2021.112521>
- Theis, S., Lefore, N., Meinzen-Dick, R. and Bryan, E., 2018. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values*, 35, pp.671-684. <https://doi.org/10.1007/s10460-018-9862-8>
- Thrän, D., Schaubach, K., Majer, S. and Horschig, T., 2020. Governance of sustainability in the German biogas sector Adaptive management of the Renewable Energy Act between agriculture and the energy sector. *Energy, Sustainability and Society*, 10, pp.1-18. <https://doi.org/10.1186/s13705-019-0227-y>

- Tolessa, A., 2024. Current status and future prospects of small-scale household biodigesters in Sub-Saharan Africa. *Journal of Energy*, 2024(1), p.5596028. <https://doi.org/10.1155/2024/5596028>
- Torma, G. and Aschemann-Witzel, J., 2023. Social acceptance of dual land use approaches: Stakeholders' perceptions of the drivers and barriers confronting agrivoltaics diffusion. *Journal of Rural Studies*, 97, pp.610-625. <https://doi.org/10.1016/j.jrurstud.2023.01.014>
- Tran, T.A., Tran, T.Q., Tran, N.T. and Nguyen, H.T., 2020. The role of education in the livelihood of households in the Northwest region, Vietnam. *Educational Research for Policy and Practice*, 19, pp.63-88. <https://doi.org/10.1007/s10671-018-9242-6>
- Tsertsidis, A., Kolkowska, E. and Hedström, K., 2019. Factors influencing seniors' acceptance of technology for ageing in place in the post-implementation stage: A literature review. *International journal of medical informatics*, 129, pp.324- 333. <https://doi.org/10.1016/j.ijmedinf.2019.06.027>
- Tsvuura, G., Mutsau, S. and Mbawuya, K.D., 2021. Zimbabwe's E-Government Readiness and Adoption of Cloud-Based Records Management in the Fourth Industrial Revolution . In *Handbook of Research on Information and Records Management in the Fourth Industrial Revolution* (pp. 272-292). IGI Global. <https://doi.org/10.4018/978-1-7998-7740-0.ch018>
- Tundup, S., Roshini, P.S., Kumar, A., Sahoo, A. and Paramasivan, B., 2021. Evaluating the scientific contributions of biogas technology on rural development through scientometric analysis. *Environmental Technology & Innovation*, 24, p.101879. <https://doi.org/10.1016/j.eti.2021.101879>
- Uamusse, M.M., Tussupova, K., Persson, K.M. and Berndtsson, R., 2019. Mini-grid hydropower for rural electrification in mozambique: Meeting local needs with supply in a nexus approach. *Water*, 11(2), p.305. <https://doi.org/10.3390/w11020305>
- Uhunamure, S.E., Nethengwe, N.S. and Tinarwo, D., 2021. Development of a Comprehensive Conceptual Framework for Biogas Technology Adoption in South Africa. *Resources*, 10(8), p.76. <https://doi.org/10.3390/resources10080076>
- Verma, P. and Sinha, N., 2018. Integrating perceived economic wellbeing to technology acceptance model: The case of mobile based agricultural extension service. *Technological forecasting and social change*, 126, pp.207- 216. <https://doi.org/10.1016/j.techfore.2017.08.013>
- Villacis, A.H., Bloem, J.R. and Mishra, A.K., 2023. Aspirations, risk preferences, and investments in agricultural technologies. *Food Policy*, 120, p.102477. <https://doi.org/10.1016/j.foodpol.2023.102477>

- Wadoux, A.M.C., Román-Dobarco, M. and McBratney, A.B., 2021. Perspectives on data-driven soil research. *European Journal of Soil Science*, 72(4), pp.1675- 1689.
<https://doi.org/10.1111/ejss.13071>
- Waheed Iqbal, M., Ashraf, M.Q., Ahmed Khan, S. and Khan, R., 2018. Factors Affecting Intention to Use of Small-scale Renewable Energy Technologies in District Sialkot, Pakistan. *European Online Journal of Natural and Social Sciences*, 7(2), pp.pp-292.
- Wahyudi, J., 2017. The Determinant Factors of Biogas Technology Adoption in Cattle Farming: Evidences from Pati, Indonesia. *International Journal of Renewable Energy Development*, 6(3). <https://doi.org/10.14710/ijred.6.3.235-240>
- Wall, W.P., Khalid, B., Urbański, M. and Kot, M., 2021. Factors influencing consumer's adoption of renewable energy. *Energies*, 14(17), p.5420.
<https://doi.org/10.3390/en14175420>
- Wang, Z., Ali, S., Akbar, A. and Rasool, F., 2020. Determining the influencing factors of biogas technology adoption intention in Pakistan: The moderating role of social media. *International Journal of Environmental Research and Public Health*, 17(7), p.2311. <https://doi.org/10.3390/ijerph17072311>
- Wang, A., He, K. and Zhang, J., 2022. The influence of clan social capital on collective biogas investment. *China Agricultural Economic Review*, 14(2), pp.349-366.
<https://doi.org/10.1108/CAER-01-2021-0010>
- Wassie, Y.T. and Adaramola, M.S., 2019. Potential environmental impacts of small-scale renewable energy technologies in East Africa: A systematic review of the evidence. *Renewable and Sustainable Energy Reviews*, 111, pp.377-391.
<https://doi.org/10.1016/j.rser.2019.05.037>
- Weigel, M. and Demissie, A., 2021. Achieving the SDGs in Africa Through South-South Cooperation on Climate Change with China. *The Palgrave Handbook of Development Cooperation for Achieving the 2030 Agenda: Contested Collaboration*, pp.605-623.
https://doi.org/10.1007/978-3-030-57938-8_28
- Wenga, T., Chinyama, S.R., Gwenzi, W. and Jamro, I.A., 2023. Quantification of bio-wastes availability for bioenergy production in Zimbabwe. *Scientific African*, 20, p.e01634.
<https://doi.org/10.1016/j.sciaf.2023.e01634>
- Wilkes, A. and Dijk, S.V., 2017. Gender Issues in Biogas Promotion and Use in Kenya: A preliminary review.
- Williams, N.B., Quilliam, R.S., Campbell, B., Raha, D., Baruah, D.C., Clarke, M.L., Sarma, R., Haque, C., Borah, T. and Dickie, J., 2022. Challenging perceptions of socio-cultural rejection of a taboo technology: Narratives of imagined transitions to domestic toilet-

- linked biogas in India. *Energy Research & Social Science*, 92, p.102802.
<https://doi.org/10.1016/j.erss.2022.102802>
- Winqvist, E., Rikkonen, P., Pyysiäinen, J. and Varho, V., 2019. Is biogas an energy or a sustainability product?-Business opportunities in the Finnish biogas branch. *Journal of cleaner production*, 233, pp.1344-1354. <https://doi.org/10.1016/j.jclepro.2019.06.181>
- World Bank, (2023). Country Economic Update: Electrifying Zimbabwe's Growth Through Reliable and Universal Energy Access. World Bank Publications. Washington, DC:USA.
- Wu, J. and Song, S., 2021. Older adults' online shopping continuance intentions: Applying the technology acceptance model and the theory of planned behavior. *International Journal of Human-Computer Interaction*, 37(10), pp.938-948.
<https://doi.org/10.1080/10447318.2020.1861419>
- Xue, S., Song, J., Wang, X., Shang, Z., Sheng, C., Li, C., Zhu, Y. and Liu, J., 2020. A systematic comparison of biogas development and related policies between China and Europe and corresponding insights. *Renewable and Sustainable Energy Reviews*, 117, p.109474.
<https://doi.org/10.1016/j.rser.2019.109474>
- Yang, L., Liu, M., Min, Q. and Li, W., 2018. Specialization or diversification? The situation and transition of households' livelihood in agricultural heritage systems. *International Journal of Agricultural Sustainability*, 16(6), pp.455-471.
<https://doi.org/10.1080/14735903.2018.1537669>
- Yang, Y., Zheng, S., Ai, Z. and Jafari, M.M.M., 2021. On the prediction of biogas production from vegetables, fruits, and food wastes by ANFIS-and LSSVM-based models. *BioMed Research International*, 2021(1), p.9202127. <https://doi.org/10.1155/2021/9202127>
- Yarkoni, T., 2022. The generalizability crisis. *Behavioral and Brain Sciences*, 45, p.e1.
<https://doi.org/10.1017/S0140525X20001685>
- Yasmin, N. and Grundmann, P., 2019. Adoption and diffusion of renewable energy—the case of biogas as alternative fuel for cooking in Pakistan. *Renewable and Sustainable Energy Reviews*, 101, pp.255-264. <https://doi.org/10.1016/j.rser.2018.10.011>
- Yasmin, I., Akram, W., Adeel, S. and Chandio, A.A., 2022. Non-adoption decision of biogas in rural Pakistan: use of multinomial logit model. *Environmental Science and Pollution Research*, 29(35), pp.53884-53905. <https://doi.org/10.1007/s11356-022-19539-7>
- Zareei, S., 2018. Project scheduling for constructing biogas plant using critical path method. *Renewable and Sustainable Energy Reviews*, 81, pp.756-759.
<https://doi.org/10.1016/j.rser.2017.08.025>

- Zeng, S., Tanveer, A., Fu, X., Gu, Y. and Irfan, M., 2022. Modeling the influence of critical factors on the adoption of green energy technologies. *Renewable and Sustainable Energy Reviews*, 168, p.112817. <https://doi.org/10.1016/j.rser.2022.112817>
- Zeng, Y., Zhang, J. and He, K., 2019. Effects of conformity tendencies on households' willingness to adopt energy utilization of crop straw: Evidence from biogas in rural China. *Renewable Energy*, 138, pp.573-584. <https://doi.org/10.1016/j.renene.2019.02.003>
- Zeren, F. and Akkuş, H.T., 2020. The relationship between renewable energy consumption and trade openness: New evidence from emerging economies. *Renewable Energy*, 147, pp.322-329. <https://doi.org/10.1016/j.renene.2019.09.006>
- Zerssa, G., Feyssa, D., Kim, D.G. and Eichler-Löbermann, B., 2021. Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture*, 11(3), p.192. <https://doi.org/10.3390/agriculture11030192>

APPENDICES

1. HOUSEHOLDQUESTIONNAIRE

Introduction

Greetings. I am Admire Chawarika, a PhD student pursuing my studies in Agriculture at the University of South Africa. I am working on a research project for my degree programme that examines the **Determinants of Biogas adoption and its impact on livelihoods: Evidence from Domboshava, Zimbabwe**. The study's main objective is identify the factors affecting biogas adoption in Domboshava and formulate policy framework for the uptake of this renewable source of energy. As a critical part of this research, I am reaching out to you, members of Domboshava community who have been randomly selected to represent the broader population. Your honest and thoughtful responses will contribute significantly to our understanding of biogas adoption dynamics and how it shapes the livelihoods of households in Domboshava. I would like to assure you that any information you provide in this questionnaire is entirely confidential and will be used solely for the purposes of this study. Your responses will not be attributed to you by name, ensuring your privacy and anonymity throughout the research process. Your participation is highly appreciated, and I thank you in advance for taking the time to assist us in this endeavor.

Section A: Questionnaire Identification

A1	DateofInterview _____	A5	Ward _____
A2	Enumerator Code _____	A6	Village _____
A4	District _____	A7	

C3. What is the household head's farming experience..... (years)

C4. Crops grown in the last Agricultural Season

Crop(s)	Area(ha)	Output (kg)	Monetary Value (US\$)	Output retained (kg)	Output Sold(kg)	Final Monetary Value (US\$)
Sweet potatoes						
Maize						
Millet						
Groundnuts						
Sunflower						
Soybean						
Dry beans						
Rapoko						
Sorghum						
Cotton						
Cassava						
Cowpea						
Roundnuts						
Watermelon						
Other(_____)						
Other(_____)						
Other(_____)						
Other(_____)						
Other(_____)						

Section D: Livestock Ownership

D1. Does the household own any livestock? 0=No 1=Yes

D2. If Yes, indicate the type and number of livestock kept by the household.

Type of livestock	Do you own this type of livestock 0=No, 1=Yes	If Yes, indicate the number
Goats		
Sheep		
Cattle		
Donkeys		
Chicken		
Pig		
Rabbit		
Turkeys		
Ducks		
Guinea fowls		
Other(____)		
Other(____)		
Other(____)		

Section E: Agricultural Asset Ownership

Type of asset	Number owned	Current value (US\$)
Wheelbarrow		
Hand hoes		
Tractor		
Trailer		
Knapsack sprayer		
Cultivator		
Planter		
Harrow		
Cart		
Lorry/Truck		
Pick		
Machete		
Axe		
Plough		
Spade/shovel		
Waterpump/handpump		

Section F: Group Membership

F1: Could you list any groups or organizations you are currently a member of, whether they are community-based, professional, or recreational?

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F2: How long have you been a member of the groups you listed, and have there been any changes in your affiliations recently?

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Section G: Access to Finance and Internet Services

G1. Does household have access to credit?

0=No 1=Yes

G2. If Yes, What Type of Credit is utilized?

1. Bank loans
2. Microfinance loans
3. Credit cards
4. Informal loans from friends or family
5. Other (please specify): _____

G3. Does household have access to internet services?

0=No 1=Yes

Section H: Energy Sources

H1. What is the primary source of energy used in your household for cooking and heating purposes?

1. Electricity
2. Natural Gas
3. LPG (Liquid Petroleum Gas)

4. Firewood

5. Other (Please Specify): _____

H2. How would you describe the affordability of your current energy source in relation to your household budget?

1. Highly Affordable
2. Moderately Affordable
3. Slightly Affordable
4. Not Affordable
5. Not Sure

H3. How accessible is your current energy source in terms of availability and proximity?

1. Highly Accessible
2. Moderately Accessible
3. Limited Accessibility
4. Inaccessible
5. Not Sure

H4. How much importance do you place on the environmental impact of your current energy source, including factors like pollution and carbon emissions?

1. Very Important
2. Moderately Important
3. Slightly Important
4. Not Important
5. Not Sure

H5. Do you believe that there is a benefit to using biogas as a source of local energy production?

0=No 1=Yes

Section I: Income and Livelihood Impact

II. Are you currently using biogas technology using feedstock from livestock?

- A. Yes

- B. No
- C. Planning to adopt in the future

If Yes,

I2. How would you describe the overall trend in your livestock farming income before and after adopting biogas technology?

- 1. Increased significantly
- 2. Increased moderately
- 3. Remained stable
- 4. Decreased moderately
- 5. Decreased significantly

I3. Could you provide a numerical estimate, in US dollars, reflecting the potential impact on your annual income as a livestock farmer due to the adoption of biogas? Please indicate whether this figure is expected to be positive or negative, taking into account the possibility that the costs might outweigh the benefits.

US\$.....

I4. Can you identify any new income streams or opportunities that have emerged as a result of adopting biogas technology? If Yes, Specify the numerical figure in US\$.

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I5. If there has been a decrease or increase in income due to biogas adoption, can you identify any specific changes to your income?

- 1. Lower energy costs
- 2. Higher energy costs
- 3. Higher market prices for products
- 4. Low market prices for products
- 5. Other (please specify):_____

I6. If there has been an increase in income due to biogas adoption, how have you utilized the additional funds generated?

- A. Invested in livestock expansion
- B. Improved living conditions

- C. Education and skill development
- D. Repaid debts
- E. Other (please specify): _____

Section J: Environmental Sustainability of Adopting Biogas

J1. How has biogas adoption influenced the management of livestock waste on your farm?

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J2. How has the implementation of biogas influenced your use of firewood?

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J3. Have you experienced any cost savings in terms of feed, waste disposal, or other aspects of livestock farming due to the use of biogas? **If Yes**, state the actual cost saving in US\$.

(Please specify in US\$): _____

J4. What percentage reduction in the use of chemical fertilizers and pesticides have you experienced on your farm since implementing biogas technology?

- A. No reduction
- B. 1-25%
- C. 26-50%
- D. 51-75%
- E. 76-100% (Complete reduction)

J5. Have you noticed any changes in soil health and fertility since incorporating biogas technology into your farming practices? If yes, please describe the observed changes.

- A. No changes
- B. Minimal soil health
- C. Enhanced soil fertility
- D. Other (please specify): _____

Section K: Challenges in Adopting Biogas

K1. Have there been any challenges or obstacles in the process of adopting biogas technology? If Yes, list the challenges below.

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K2. What operational challenges, if any, did you face in integrating biogas technology into your daily livestock farming activities? If yes, list below.

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K3. Were there any challenges related to community perceptions, social acceptance, or cooperation in adopting biogas technology on your farm? If Yes, list below.

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K4. How did you address or mitigate the challenges you encountered in adopting biogas technology on your farm?

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Section L: Recommendations and Future Outlook

L1.Based on your experience, what recommendations or suggestions do you have to enhance the positive effects of biogas adoption on livestock farming?

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L2.In your opinion, what support services or resources would be most beneficial for other livestock farmers considering the adoption of biogas technology?

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L3. How can community or peer engagement be improved to facilitate a smoother transition to biogas technology among livestock farmers?

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L4. What practices or policies do you believe should be key for ensuring environmental sustainability?

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2. KEY INFORMANT QUESTIONNAIRE

Introduction

Greetings. I am Admire Chawarika, a PhD student pursuing my studies in Agriculture at the University of South Africa. I am working on a research project for my degree programme that examines the **Determinants of Biogas adoption and its impact on livelihoods: Evidence from Domboshava, Zimbabwe**. The study's main objective is identify the factors affecting biogas adoption in Domboshava and formulate policy framework for the uptake of this renewable source of energy. As a critical part of this research, I am reaching out to you as a Key Informant to share your valuable experience and knowledge on biogas adoption determinants and impact in Domboshava. Your honest and thoughtful responses will contribute significantly to our understanding of biogas adoption dynamics and how it shapes the livelihoods of households in Domboshava. I would like to assure you that any information you provide in this questionnaire is entirely confidential and will be used solely for the purposes of this study. Your responses will not be attributed to you by name, ensuring your privacy and anonymity throughout the research process. Your participation is highly appreciated, and I thank you in advance for taking the time to assist us in this endeavor.

Section A: Questionnaire Identification

A1	Date of Interview _____	A5	Ward _____
A2	Name (Optional) _____	A6	Village _____
A3	Enumerator Code _____	A7	Institution/Capacity _____
A4	District _____		

Section B: Introduction and Background

B1. Can you please introduce yourself, including your role, expertise, and experience related to sustainable energy or rural livelihoods?

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B2. From your perspective, what are the prevailing socioeconomic conditions and challenges in Domboshava, Zimbabwe, that may influence the adoption of biogas technology?

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B3. Have you collaborated with local community members, leaders, or organizations in Domboshava, and how has this engagement shaped your understanding of the community's dynamics?

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B4. From your perspective, what are some of the significant challenges and opportunities that researchers and practitioners may encounter when studying or implementing renewable energy projects in rural areas like Domboshava?

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B5. In your interactions with the community, have you observed any prevailing perceptions or attitudes towards sustainable energy solutions, and how might these impact the acceptance of biogas technology?

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SECTION C: Biogas Adoption Factors

C1. How would you assess the level of awareness and understanding of biogas technology among the local community in Domboshava?

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C2. What are the major barriers or challenges hindering the widespread adoption of biogas in the community?

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C3. From a technical standpoint, what factors contribute to the successful implementation and maintenance of biogas systems in rural settings like Domboshava?

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SECTION D. Livelihood Impact Assessment

D1. In your experience, how has the adoption of biogas technology impacted the livelihoods of individuals in Domboshava, particularly in terms of income generation, health, and time savings?

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D2. Are there any gender-specific considerations or differences in the way biogas adoption influences the livelihoods of men and women in Domboshava?

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D3. Beyond household energy needs, have you observed any emerging economic opportunities or income-generating activities directly linked to the use of biogas in the community?

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D4. Have you observed any correlations between biogas adoption and changes in agricultural productivity, either through improved soil fertility or changes in farming practices?

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SECTION E. Policy and Institutional Support

E1. How would you evaluate the existing policies and regulations in Zimbabwe regarding renewable energy, specifically biogas, and their relevance to local adoption in places like Domboshava?

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E2. What role do local institutions, NGOs, or government agencies play in facilitating or hindering the adoption of biogas technology in Domboshava?

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E3. What types of support services, such as technical assistance, training, or financial support,

are provided by local institutions or government agencies to facilitate the adoption and sustainability of biogas projects in Domboshava?

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SECTION F. Future Outlook and Recommendations

F1. In your opinion, what changes or interventions could enhance the prospects of biogas adoption in Domboshava, considering both community and policy-level aspects?

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F2. Based on your experiences, what are some best practices or lessons learned from other similar contexts that could be applied to promote biogas adoption in Domboshava?

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F3. How can decision-making processes related to biogas projects become more inclusive, ensuring the active participation of diverse community members and stakeholders, including women and marginalized groups?

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SECTION G. Closing Remarks

G1. Is there anything else you would like to share or emphasize regarding the determinants of biogas adoption and its impact on livelihoods in Domboshava, Zimbabwe?

3. FOCUS GROUP GUIDE

Stakeholder Group :(Chief, 6 village heads, representatives of Domboshava rural district and Ministry of Energy and Power Development representatives)

Date:

Number of focus group participants:

Provide description of make-up for the focus group:

Facilitator(s):

Note Taker(s):

Purpose statement:

Introduction and Engagement:

How familiar are you with the concept of biogas adoption in the context of Domboshava, Zimbabwe?

Have you or anyone you know been involved in or affected by biogas adoption initiatives in the area?

Awareness and Perceptions:

What is your understanding of the term "biogas adoption" based on your experiences or knowledge?

How do you perceive the role of biogas adoption in improving livelihoods within the community?

Determinants of Biogas Adoption:

In your opinion, what factors influence or hinder the adoption of biogas technologies in Domboshava?

Are there specific challenges or benefits associated with biogas adoption that you think are

particularly relevant to this community?

Impact on Livelihoods:

How do you think the adoption of biogas has affected the economic aspects of livelihoods in Domboshava?

Can you share any specific examples or anecdotes regarding changes in livelihoods resulting from biogas adoption?

Community Dynamics and Support:

How has the community responded to biogas initiatives? Are there instances of collaboration or resistance?

What role do you think community support plays in the success or failure of biogas adoption projects?

Access and Affordability:

Are there any accessibility issues related to the adoption of biogas technologies in Domboshava?

How affordable do you perceive biogas adoption to be for different segments of the community?

Sustainability and Maintenance:

From your perspective, how sustainable are the biogas systems implemented in the community?

What challenges or successes have been observed in the maintenance of biogas facilities?

Policy and Institutional Factors:

Do you think there are any policies or institutional factors that either facilitate or impede the widespread adoption of biogas in the area?

How can government or other institutions better support biogas initiatives in Domboshava?

Future Prospects and Recommendations:

What changes or improvements would you suggest to enhance the impact of biogas adoption on livelihoods?

In your opinion, what are the future prospects for biogas adoption in Domboshava?

Notes:

Question	Notes	Note Taker/Facilitator Comments
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Additional Comments

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