BARRIERS TO THE ADOPTION OF BIOGAS TECHNOLOGY: A KENYAN CASE

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF MECHANICAL, PRODUCTION & ENERGY ENGINEERING, SCHOOL OF ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN SUSTAINABLE ENERGY AND ENERGY ACCESS

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DECLARATION

Declaration by the Candidate

I declare this thesis is my original work and has not been presented to any other institution for the award of any certificate. This thesis may not be reproduced in whole or part unless with the consent of my approval and that of Moi University.

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DEDICATION

I dedicate this thesis to my loving family, whose unwavering support and encouragement have been the cornerstone of my academic journey. To my parents, William Mutahi Gikandi and Shelmith Mweru Muturi, your endless sacrifices and belief in my abilities have fueled my determination to pursue excellence. To all my siblings, thank you for your understanding and patience during the countless hours spent studying. Your love and encouragement have been my source of strength throughout this endeavor.

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ABSTRACT

Generally, households in sub-Saharan Africa countries depend on biomass energy for cooking. In view of its negative impacts, biogas technology emerges as a promising solution. However, in spite of its potential to mitigate these hazards, its adoption faces numerous hurdles that hinder uptake at both individual and systemic levels. The main objective of this study was to investigate the barriers to the adoption of biogas technology in Kenya. Specifically, the study aimed to identify and assess the key criteria and sub-criteria that obstruct biogas adoption, prioritize these barriers using the Analytical Hierarchy Process (AHP) to determine their relative importance, and validate the model's results. A stratified random sampling technique was employed to select 32 biogas experts from the target groups within the renewable energy sector (N_1=200), biogas sector (N_2=200), and government & policy sector (N_3=100). Data collection was carried out using a structured questionnaire. Data analysis was conducted using the AHP, a Multi-Criteria Decision-Making (MCDM) tool, which processed the data through STATA to rank and identify the primary obstacles. The reliability of these assessments was ensured by maintaining an acceptable consistency ratio ($CR < 0.1$). Validation of results was done based on previous studies. The study categorized the barriers into five main groups: technical, economic, infrastructural, societal-cultural, and policy & regulatory factors. Among these, economic factors were ranked the highest, with a weight of 0.416 (CR=0.0650), followed by technical challenges at 0.354 (CR=0.0678). Societal factors came in third with a weight of 0.086 (CR=0.0647), while infrastructural impediments and policy & regulatory challenges were ranked fourth and fifth, with weights of 0.073 (CR=0.0495) and 0.070 (CR=0.0500), respectively. Within the sub-criteria, the lack of awareness and education about biogas benefits was identified as the most significant, with a weight of 0.496 (CR=0.0486). This was followed by poor infrastructure at 0.429 (CR=0.0268) and the unavailability of technicians at 0.428 (CR=0.0491). In conclusion, the study found that enhancing technical support, providing economic cushions, improving infrastructure, and increasing awareness and education about the benefits of biogas are essential to promoting its wider adoption and use. The study recommends the need for public awareness and educational training programs such as seminars and workshops to improve overall understanding, creation of targeted subsidies for low-income households, as well as flexible payment schemes, and concessional financing to relieve the financial burden towards installing and maintaining this technology as well as capacity-building initiatives aimed at improving technical expertise.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The escalating impact of climate change, driven by prolonged reliance on fossil fuels and complex global energy dynamics, has compelled nations like Kenya to explore domestic energy alternatives (Othoche, 2024). Recognizing the vulnerabilities of relying on fire wood, charcoal and imported energy, Kenya is prioritizing the development of renewable energy sources, including biogas technology, to enhance energy security and reduce environmental degradation (Detelinova et al., 2023). This aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7, which advocates for affordable and clean energy, and SDG 13, which addresses climate action (UN, 2023). However, despite the potential benefits, significant barriers continue to hinder the widespread uptake of biogas technology in Kenya.

In Europe, Germany leads the region in biogas production, with a well-established biogas industry comprising both small-scale digesters on farms and larger industrial facilities. The country's Renewable Energy Sources Act (EEG) provides favorable feed-in tariffs for biogas electricity, incentivizing investment and deployment (Hidalgo Sánchez et al., 2024). Other European countries, such as Austria, Denmark, and Sweden, also have robust biogas sectors, often integrated with their agricultural and waste management systems (Marcus et al., 2022). Biogas is increasingly recognized as a versatile renewable energy source utilized not only for electricity generation but also for heat production and biomethane production for injection into the natural gas grid or as a transportation fuel. Despite this progress, challenges remain within the continent, including ensuring sustainable feedstock supply, addressing environmental concerns, and optimizing biogas plant efficiency (Chemie, 2018).

In Asia, the biogas landscape varies widely across countries and regions, reflecting differences in economic development, technological readiness, and policy support (Surendra et al., 2014). China stands out as a leader in biogas production and utilization, with millions of household-scale digesters and large-scale plants managing agricultural waste and generating renewable energy (Tagne et al., 2021). India, with its vast agricultural sector and high livestock population, promotes biogas to address rural energy needs and waste management challenges, supported by government policies and initiatives (Gulnar et al., 2024). However, in spite of these efforts, most countries in the Asian continent exhibit variations in policies and regulations which may create uncertainty and inconsistency thus discouraging investment and hindering the development of a supportive regulatory environment for biogas adoption (Ali et al., 2022).

In the Americas, both North and South America show significant advancements in biogas production (Vidigal et al., 2025). In the United States, anaerobic digesters are increasingly used in agriculture and waste management, supported by federal and state incentives like tax credits and grants, alongside renewable energy standards driving demand for renewable natural gas (Rachel et al., 2021). Canada mirrors these trends, with rising biogas utilization and government backing for projects addressing organic waste and RNG production (Rogers, 2024). Meanwhile, in South America, Brazil leads in biogas production, mainly in agriculture, aided by policies such as feed-in tariffs (Vidigal et al., 2025). Argentina also shows growth in biogas applications, supported by government incentives aimed at diversifying the energy mix and reducing emissions (Zanatta, 2020). Nevertheless, regulatory and permitting processes in the region can be complex and time-consuming thus creating barriers to biogas project development (Sharath et al., 2024).

Africa possesses considerable potential for biogas production, driven by abundant organic waste sources from agriculture, livestock farming, and municipal waste (Ali et al., 2020). For instance, South Africa leads with a mature sector, supported by incentives and regulations (Shonhiwa et al., 2023) with Zambia and Zimbabwe showing promise, primarily in agriculture and municipal waste. In West Africa, there is notable potential for biogas production, particularly due to the region's large agricultural sector and livestock population (Mabatho et al., 2024). Nigeria, with its significant agricultural and livestock resources, presents opportunities for biogas development alongside Ghana and Senegal (Godfrey, 2024). Albeit all these efforts, biogas technology faces a myriad of obstacles such as technical, societal, economic amongst others that hinder its seamless adoption into the continent’s energy mix (Peter et al., 2019).

In Kenya, the total potential for biogas energy from various substrates is significant (Mudoga et al., 2022), with projections estimating a range from small-scale to medium-scale biodigesters across different sectors. For small-scale biodigesters, over 700,000 units could be installed, utilizing waste from dairy cows, pig farms, coffee wet mills, slaughterhouses, and more. For medium-scale biodigesters, 100,000 potential units could be sourced from commercial farms, flower farms, sisal, and wastewater treatment plants (Endev, 2024). However, in spite of this potential, biogas uptake within the country remains limited with the demand for petroleum products such as petrol, diesel, and ethanol projected to grow significantly by 2030 (Korir & Musembi, 2025). Specifically, the total demand for petroleum products is expected to rise to around 12.8 million cubic meters by 2030 (Miftah & Mutta, 2024).

Biogas systems in Kenya predominantly consist of fixed-dome and floating-drum digesters, designed for small- to medium-scale rural and peri-urban use (Endev, 2024). Fixed-dome digesters, constructed underground with high-quality materials, can last up to 20 years and provide steady gas supply, whereas floating-drum models offer adjustable capacity at the cost of higher maintenance (Isha et al., 2021). The primary substrate for these systems is livestock manure (cow and pig dung), valued for its availability and methane potential. Many systems also employ co-digestion, integrating kitchen scraps, poultry manure, and crop residues (e.g., maize husks, banana peels) to improve digestion balance and biogas yield (Adnane et al., 2024). Depending on household size and waste volume, typical digesters process 2–15 m^3 of feedstock daily, providing enough gas for cooking and heating needs (Sawyerr et al., 2020). The digestate is routinely used as an organic fertilizer, enhancing soil fertility and supporting sustainable agriculture (Erraji et al., 2023). Although these systems demonstrate environmental and economic benefits such as reduced deforestation, improved waste management, and lower indoor air pollution, their adoption remains constrained by a web of barriers.

Therefore, to narrow down and understand this web of barriers, the study chose STATA as its primary modeling tool. Leveraging STATA's versatility and robust statistical features (Tajul et al., 2022), the research explored diverse datasets encompassing economic, social, infrastructural, technical and policy regulatory variables, providing a holistic understanding of factors influencing biogas uptake. Data was analyzed using the Analytical Hierarchy Process (AHP) in STATA, quantitatively revealing the relative level of perceived impact of different barriers based on expert judgments. This approach addressed one of the gaps observed from previous studies, which was the lack of a systematic method for comprehensively evaluating and prioritizing the barriers to biogas adoption in the Kenyan scope. Utilizing AHP to rate or rank was found fit as AHP provides a structured framework for evaluating and prioritizing the various factors hindering biogas uptake. Integrating AHP into this study not only enhanced the rigor and reliability of the research findings but also facilitated the development of practical solutions to promote sustainable energy initiatives in the country.

1.2 Statement of the Problem

Biogas holds immense promise as a clean, renewable energy source capable of advancing Kenya's sustainable energy agenda, with an estimated potential of over 800,000 small- and medium-scale biodigester units (Endev, 2024) based on available substrates such as livestock waste, municipal solid waste, coffee husks, sisal residues, slaughterhouse waste, and agricultural by-products like crop residues (Mudoga et al., 2022). This projection is derived from sectoral mapping of organic waste availability across farms, agro-industries, and urban settlements. However, by 2023, only approximately 20,000 units had been installed nationwide, representing less than 3% of the total potential (MOE, 2023).

Despite its well-documented social, economic, and environmental benefits including reduced deforestation, improved waste management, and enhanced rural livelihoods, biogas technology has not yet fully gained widespread traction in Kenya (Korir & Musembi, 2025). Its progress is hampered by a complex set of obstacles preventing its seamless integration into the country's energy landscape (Hamid & Blanchard, 2018). This study was therefore motivated by the need for a current, comprehensive, and structured analysis that clearly prioritizes these barriers. Through the application of AHP, the research systematically identified, evaluated, and ranked the relative significance of each barrier, drawing on expert insights from the renewable energy, biogas, and policy sectors. The resulting findings were intended to guide targeted interventions and inform strategic policymaking efforts to accelerate biogas adoption and fully harness its potential in supporting Kenya’s clean energy transition.

1.3 Objectives

1.3.1 Main objective

The general objective of the study was to investigate the barriers to the adoption of biogas technology in Kenya.

1.3.2 Specific objectives

The specific objectives were as follows;

i. To identify and analyze the main criteria and sub-criteria that act as barriers to the adoption of biogas technology.
ii. To prioritize the impediments using the Multi criteria decision making (MCDM) approach to determine their relative significance.
iii. To validate the model results.

1.4 Research Questions

The following are the key research questions that the study attempted to answer;

i. What are the key criteria and sub-criteria that obstruct biogas adoption?
ii. Which barriers to biogas adoption are most significant according to the AHP approach?
iii. Can the model's results be validated to ensure their accuracy and reliability?

1.5 Justification of the Study

Despite Kenya's significant biogas estimated potential (Endev, 2024), the actual uptake remains alarmingly low, with fewer than 20,000 units installed nationwide as of 2023 (MOE, 2023). This disparity between potential and implementation indicates the presence of critical and persistent barriers to the development and adoption of biogas technology (Korir & Musembi, 2025). While earlier studies on biogas in Kenya provide valuable insights, they reflect conditions that have since evolved as many are over seven years old from the time of publication to date therefore limiting their relevance to the current landscape in biogas development. This study sought to fill that gap by providing a current scope of the barriers and status of biogas uptake and development in Kenya.

In addition, earlier research was identified to often lack a comprehensive and targeted analysis of the barriers hindering biogas adoption, resulting in a fragmented understanding of the challenges. Many of these studies examined socio-cultural, economic, or technical issues independently. This study, however, adopted a more integrated approach by thoroughly identifying and analyzing the full range of barriers in a unified framework. By presenting these findings in a single, consolidated report, it enables policymakers and project developers to clearly recognize key gaps and strategically prioritize their interventions. This method not only enhances the effectiveness of decision-making but also conserves time, financial resources, and effort by directing attention to the most pressing obstacles to biogas development in Kenya.

Moreover, previous studies revealed the lack of a structured and hierarchical approach to accurately identify and assess the significance of the key challenges hindering biogas adoption in Kenya. This study sought to address that gap by employing the AHP, a multi-criteria decision-making technique, to systematically identify, categorize, and prioritize the barriers based on expert input from stakeholders in the biogas, renewable energy, and policy sectors. Through this approach, the study provides a current and structured analysis that is useful for policy formulation, resource allocation, and program implementation, thereby justifying its necessity in both academic and practical terms.

1.6 Significance of the Study

The findings of this research carry significant implications for policy, practice, academia, and the broader societal effort to transition toward sustainable energy solutions in Kenya. At the policy level, the study provides a data-driven basis for government agencies and regulatory bodies to design targeted interventions that directly address the most pressing barriers to biogas adoption. This is particularly relevant given the national commitment to achieving universal access to clean cooking fuels, as well as Kenya's alignment with SDG 7, Affordable and Clean Energy and Goal 13, Climate Action (UN, 2023).

From a practical standpoint, the study's outputs offer clear prioritization of obstacles, empowering stakeholders in the biogas sector such as private companies, NGOs, and development partners, to channel resources efficiently and design programs that are both context-specific and impact-driven. The identification and ranking of barriers, including financial constraints, technical shortcomings, policy gaps, and socio-cultural challenges, provide a roadmap for scaling biogas technology across diverse regions of the country.

Academically, the application of the AHP technique within this study contributes to the growing body of literature on multi-criteria decision-making in energy access. It sets a methodological precedent for analyzing similarly complex issues in developing countries, offering a replicable model for future research. Socially and environmentally, the study underscores the role of biogas in improving public health, reducing deforestation, enhancing waste management, and strengthening rural livelihoods through sustainable energy solutions. As such, the significance of this study extends beyond academic inquiry, contributing to both national development objectives and global sustainability agendas.

1.7 Scope and Limitations

In spite of the cutting-edge research that this study provides, some sets of limitations could hamper the delivery of a completely competent piece of research work. These include;

1. Resource limitations such as the lack of prior in-depth research experience that cost valuable progressive time. This was the case where I had to take a lot of time to learn how to use codes on the Stata program as well as learn how to work with AHP.
2. Temporal Relevance: The barriers identified and ranked in this study are based on current conditions and data. As the energy landscape in Kenya evolves, new barriers may emerge, or the impact of existing barriers may change, potentially affecting the relevance of the study's findings over time.
3. Limited Stakeholder Engagement: Although the study includes expert insights, it may not fully capture the perspectives of all relevant stakeholders, such as local communities, biogas users, and small-scale entrepreneurs. This could result in an incomplete understanding of the barriers from the ground level.

1.8 Structure of the thesis

In chapter one, the context of the study has been introduced. The research objectives and questions have been identified, and the value of such research has been justified. The limitations of the study have also been discussed. In chapter two, the existing literature will be reviewed to demystify what is already known and what has already been done by running a background check on the brief history that pertains to the topic of biogas adoption barriers in the country as well as current developments in the study area. In chapter three, the research methodology will be laid bare as the qualitative and quantitative methodologies used throughout this study will be in-depthly discussed. In chapter four, the research findings will be tabulated as well as hold the review and analysis of the data collected. Finally, the fifth chapter will deliver the conclusions and suitable recommendations identified for the research study area at hand.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Biogas, a renewable energy source produced through the anaerobic digestion of organic matter, has emerged as a promising solution to address energy security, environmental sustainability, and rural development challenges globally (Arslan et al., 2024). In the context of both developing and developed countries, biogas technology offers significant potential to improve energy access, reduce greenhouse gas emissions, and promote sustainable development (Moses et al., 2022). This technology aligns with the need of ensuring abundant, cost-effective, and environmentally friendly energy services, crucial for the holistic development of nations (Alayi et al., 2017). However, significant barriers prevent the widespread adoption of this resource (Nevzorova & Kutcherov, 2019). This study sought to investigate these complexities hindering biogas uptake in Kenya. By doing so, it aimed to provide critical insights to inform targeted policy initiatives and interventions that will support the transition toward sustainable energy systems. The study acknowledges the urgency of addressing these barriers, as doing so is key to promoting sustainable development. The study's findings are intended to drive both practical and policy-based solutions aimed at facilitating a smoother transition to sustainable energy systems, which is crucial in both local and global efforts to mitigate climate change and promote renewable energy use.

2.2 Biogas Technology Landscape

2.2.1 Overview of the biogas Landscape in Africa

Numerous studies have been undertaken to assess the viability of biogas across the continent to understand its potential as a sustainable energy source Ashira et al. (2020). For instance, in Zambia, a study by Shane & Gheewala, (2017) revealed that crop residues and livestock waste have the potential to produce a total of 76 petajoules of biogas energy every year, whereby 1.473×10^9 m^3 of biogas was harnessed from cow dung and 1.473×10^9 m^3 from crop residue.

Further on, a study examining biogas production potential from agricultural waste and agro-processing sectors in South Africa discovered that the liquor industry, including clear beer and wineries, demonstrated the highest potential with approximately 35×10^6 m^3 per year, while pig farming exhibited the lowest potential at about 0.02 million cubic meters per year (Mugodo et al., 2017). Overall, these sectors could generate an average of 86 $\times10^6$ m^3 of biogas annually. This quantity equates to 148 gigawatt-hours (GWh) of electrical energy, doubling the country's biogas target for 2030, which is set at 75 GWh. A study conducted in Northern Cameroon revealed promising opportunities for the utilization of biogas as a fuel source for rural electrification initiatives. Particularly noteworthy were the findings suggesting the viability of a hybrid energy configuration, integrating biogas with other renewable energy sources such as photovoltaic, wind, and pumped hydro systems (Nasseret al., 2018).

In recent years, African nations have taken significant strides towards advancing renewable energy development through the implementation of diverse support policies. These policies represent a comprehensive approach aimed at catalyzing the transition towards sustainable energy systems across the continent (Sibanda & Uzabakiriho, 2024). One key aspect of these policies is the establishment of renewable energy targets, which serve as benchmarks for guiding national energy strategies and promoting the deployment of renewable energy technologies. In accordance with the Global Renewable Energy Status Report 2024, a majority of African nations have established renewable energy targets, focusing either on overall energy production or electricity generation (REN, 2024).

Additionally, the implementation of feed-in tariffs (FiTs) has played a crucial role in incentivizing renewable energy generation by guaranteeing favorable prices for electricity fed into the grid from renewable sources (Morse, 2021). For instance, in South Africa, the country's Renewable Energy Independent Power Producer Procurement (REIPPP) Program includes biogas as one of the eligible technologies for procurement. Under the REIPPP Program, biogas projects can participate in competitive bidding processes to secure long-term power purchase agreements (PPAs) with the government or utility . While this is not a traditional feed-in tariff (FiT) mechanism, it serves a similar purpose by providing a guaranteed price for electricity generated from biogas sources, thereby incentivizing investment in biogas energy projects. However, despite the realization of the biogas potential across the continent and the implementation of policies standing in favor of the adoption of renewable energy, numerous challenges have been encountered. Several studies have been conducted to comprehend the ground realities that hinder the adoption process of this technology amongst several African Countries.

A study on understanding biogas plant failure and abandonment in Northern Tanzania by Hewitt (2022) yielded that challenges faced during the implementation of biogas projects in the region were exacerbated by issues such as inadequate construction and installation, suboptimal husbandry practices, operational and maintenance challenges, as well as inadequate training leading to erosion of knowledge. Elsewhere, a Nigerian biogas mini-grid project aimed to provide sustainable and reliable electricity to residents using biogas technology. However, the project faced numerous challenges, leading to its failure. Despite initial enthusiasm and investment, the project encountered technical difficulties, including frequent breakdowns and maintenance issues with the biogas plant. Additionally, there were financial constraints and a lack of sustained funding, hindering the project's operational viability. Furthermore, limited community engagement and awareness about biogas technology contributed to low demand and usage among residents. Regulatory hurdles and bureaucratic delays further impeded the project's progress. Ultimately, these factors culminated in the failure of this mini-grid project, highlighting the complexities and challenges associated with implementing renewable energy solutions in rural communities. (Kenneth, 2023).

In a study aimed at understanding the opportunities and challenges of biogas adoption in South Africa, it was found that despite its considerable potential, the uptake of biogas technology had been sluggish. This slow adoption was attributed to several factors, including market development challenges, limited technical expertise, and a lack of strategic planning. To address these barriers and learn from successful biogas markets, a group of biogas stakeholders from South Africa, including representatives from the Southern Africa Biogas Association (SABIA), South African cane growers, project developers, policymakers, biogas technology consultants, environmental consultants, and beef entrepreneurs, conducted a study tour to Denmark. Denmark was chosen for its advanced biogas market, providing valuable insights and lessons that could be applied to the South African context. This initiative demonstrated a proactive approach by South African stakeholders to try overcome challenges and accelerate the adoption of biogas technology in the country (AFAP, 2023).

In addition to that, a study conducted in the Birim North District of Ghana provided insights into households' willingness to adopt biogas energy, offering valuable information for local governments and stakeholders (Charles et al., 2023). The research findings demonstrated the significant effects of socio-economic variables on biogas adoption, highlighting the importance of targeted educational and marketing strategies. This study underscored the necessity for comprehensive research to identify barriers and opportunities in promoting clean energy solutions, enabling policymakers and stakeholders to develop effective interventions and policies (Charles et al., 2023).

The study "Challenges and Solutions in Biogas Technology Adoption in Ethiopia: A Review" highlighted the critical need for research in understanding the obstacles and opportunities associated with the expansion of biogas technology in Ethiopia (Abebe et al., 2022). The review identified numerous barriers to biogas adoption, including high initial investment costs, a lack of biogas substrates, limited research, failed pilot projects, inadequate public awareness campaigns, and insufficient expertise in construction and maintenance. Additionally, challenges such as low biogas technology efficiency and inadequate bio-slurry management further hindered the widespread adoption of biogas technology in the country. To address these challenges, the study emphasized the importance of appropriately sizing biogas plants to match available substrates, as well as increasing the calorific value of biogas to enable its use in powering generator sets and internal combustion engines. By shedding a light on these adoption challenges, the study provided valuable insights for policymakers and stakeholders, enabling informed decision-making to overcome barriers and promote the successful implementation of biogas technology in Ethiopia (Abebe et al., 2022).

Despite the challenges, several African countries have endeavored to adopt biogas technology, anticipating that these obstacles will become less formidable in the future. Table 2.1 presents the current and future potential installations of biogas plants in various African nations. The data highlights the existing infrastructure and growth prospects, offering valuable insights into the expansion of biogas technology across the continent. This information underscores the efforts being made and the promising potential for widespread adoption, which can contribute significantly to sustainable energy solutions in Africa.

Table 2.1: Current & future potential Installations of biogas plants in some African Countries

Country	Current Installations	Future Potential Installations
Kenya	Approximately 20,000 biogas digesters Installed (Lumadede et al., 2021).	Over 800,000 potential small and medium scale units (Endev, 2024)
Uganda	11,000 biogas digesters (Bruyn, 2022).	Additional 8,000 by 2025 under ABC Project (SNV, 2023).
Ethiopia	10,000 biogas digesters installed (Bruyn, 2022).	Biogas potential from husk, pulp, and mucilage stands at 68 × 10^6 m^3 methane per year i.e. 238 GWh of electricity (Chala et al., 2018).
Tanzania	12,000 biogas plants installed with 4,633 verified (SNV, 2024).	Potential for up to 700,000 biogas digesters (FurtherAfrica, 2018).
Burkina Faso	16,140 biogas plants installed (Martina et al., 2020).	Moderate to high potential, ongoing expansion including large-scale projects.
South Africa	350 biogas digesters Installed (Bruyn, 2022).	Potential of up to 21,000 initial units, with a yearly demand of up to 50,400 units (Bruyn, 2022).

Investigating and examining the uptake of biogas in Africa holds great importance because of its wide-ranging advantages within the African setting. By comprehending the intricacies surrounding biogas adoption, policymakers and stakeholders gain the ability to capitalize on its potential to enhance energy accessibility, propel economic advancement, and alleviate the effects of climate change throughout the continent. Consequently, allocating resources to research on biogas adoption becomes imperative for crafting impactful strategies and policies that cater specifically to Africa's unique circumstances, thereby nurturing socio-economic progress and advancing environmental sustainability.

2.2.2 Overview of Energy Situation in EAC

In the East African Community (EAC), forest-based biomass energy resources, such as firewood and charcoal, hold a dominant position as the primary cooking energy sources for the majority of households (Sola et al., 2017). This prevalent reliance on forest-based biomass is influenced by several factors such as accessibility which plays a crucial role, particularly in rural areas where households often have limited access to alternative energy sources (Carvalho et al., 2019). Moreover, cultural preferences and traditional cooking methods contribute to the widespread use of forest-based biomass. Cooking with firewood or charcoal is deeply rooted in the cultural practices of communities across the EAC, further solidifying its dominance in household energy use (Adamu et al., 2018). This reliance underscores the urgent need for sustainable forestry management practices as well as the widespread adoption of cleaner cooking technologies to address environmental degradation, indoor air pollution, and associated health risks in households throughout the region (Julia et al., 2019).

Introducing biogas as an alternative energy resource holds significant potential for replacing forest-based biomass and imported LPG in household cooking within the EAC (Kimutai et al., 2025). Biogas, derived from organic waste through anaerobic digestion, offers a sustainable and renewable energy source that can mitigate deforestation, reduce reliance on imported fuels, and alleviate indoor air pollution (Singh et al., 2023). Moreover, this not only reduces the demand for forest-based biomass but also contributes to the energy independence and security within the region (IRENA, 2022). Furthermore, the utilization of biogas promotes environmental sustainability by mitigating greenhouse gas emissions and reducing organic waste disposal in landfills (Singh et al., 2023). To fully realize the potential of biogas adoption, comprehensive policies, financial incentives, and awareness campaigns are essential to encourage its widespread adoption and overcome barriers to implementation (Tatiana et al., 2019).

Exemplary efforts have been made to identify the biogas potential of the East African region. In Rwanda, estimates suggest significant biogas potential, with studies indicating a capacity to generate 100 to 200 MW of electricity from organic waste sources, including agricultural residues, livestock waste, and organic municipal waste (Ezgad et al., 2023). Similarly, Tanzania exhibits substantial biogas potential, with projections indicating the ability to produce up to 260 MW of electricity from agricultural, livestock, and municipal organic waste (Zahida et al., 2021). Additionally, Ethiopia also shows a significant promise, with estimates suggesting the potential to generate up to 500 MW of electricity from biogas sources, primarily derived from agricultural and livestock waste (Tolessa, 2023).

However, despite the efforts of moving into a positive trajectory in the technology, obstacles to its adoption in EAC countries, including Rwanda, Tanzania, Ethiopia, and Uganda remain. These challenges encompass several distinctive categories surrounding economic, technical, societal, environmental amongst others (Ketuama et al., 2022). Efforts have been made to address these challenges through the implementation of several key strategies such as the EAC Renewable Energy and Energy Efficiency Strategy (2012-2032). Crafted by the EAC, this strategy advocates for the sustainable utilization of renewable energy sources, including biogas, with the goal of advancing access to modern energy services, bolstering energy security, and mitigating climate change impacts across the region.

Understanding and addressing barriers to biogas adoption in the EAC is imperative to unlock the technology's full potential for sustainable development. By overcoming these adoption obstacles, the EAC can expand energy access, foster rural development, and promote environmental sustainability (Clemens et al., 2018). Biogas adoption not only enhances energy security by diversifying the energy mix but also stimulates economic growth, mitigates climate change impacts, and improves waste management practices (Jameel et al., 2024). Ultimately, addressing these barriers is essential for realizing the socio-economic, environmental, and energy-related benefits of biogas technology in the EAC region.

2.2.3 Biogas Terrain in Kenya

Biogas technology has been part of Kenya's energy landscape for over five decades, dating back to the construction of the country's inaugural digester on a rural coffee farm in 1957 owned by Mr. Tim Hutchison. Years on, the interest in alternative energy sources spiked during the 1970s, driven by escalating fossil fuel prices, which prompted extensive research into biogas utilization across rural areas (Wanjohi et al., 2022). Notably, this period saw the sale of over 100 biogas plants in Kenya, primarily targeting large-scale farmers through private entrepreneurs (Ignatius, 2019). Over time, biogas technology gained momentum with the backing of both national and international organizations, governmental and non-governmental alike. Working in collaboration with skilled Kenyan technicians, these entities facilitated the installation of numerous biogas digesters across the country (Lumadede et al., 2021).

The initial effort to draft an energy policy document occurred in 1987, aiming to address various objectives, including alleviating the negative impacts of oil imports on the domestic economy and balance of payments (Byrne et al., 2014). The emergence of fresh challenges during the 1990s due to the liberalization of the economy, coupled with issues such as deforestation and the growing impact of climate change, necessitated the formulation of a novel energy sector development strategy (Detelinova et al., 2023). This strategy aimed to adopt prudent integrated policies aligned with broader governmental strategies concerning socio-economic development. (Matoke, 2021). Therefore, in accordance with the Government's Economic Recovery Strategy for Employment and Wealth Creation, Session Paper No. 4 of 2004 on Energy was developed. Furthermore, the Energy Act of 2006 which included provisions aimed at promoting renewable energy sources, including biogas was also drafted. Additionally, over the years, the Kenya Climate Smart Agriculture Strategy (KCSAS) for the period of 2017 to 2026 recognized the significance of adopting appropriate technologies such as biogas to mitigate greenhouse gas emissions.

Currently, approximately 20,000 domestic biogas units have been deployed in Kenya, propelled by initiatives like the Kenya Biogas Partnership Program, which has overseen the installation of 17,000 units in 36 counties (MOE, 2023). Private household biogas enterprises such as Takamoto, Sustainable Energy Strategies, Taita Biogas Ltd., Afrisol, and others, have collectively installed approximately 2,000 digesters whilst energy centers established by the Ministry of Energy and Petroleum (MOE) have also contributed to this milestone with the construction of about 1,000 domestic biogas digesters (Lumadede et al., 2021). To facilitate biogas technology training in higher education institutions, the MOE has undertaken the construction of large digesters in several institutions, as detailed below in Table 2.2:

Table 2.2: Installed institutional biogas digesters for training in Kenya

Institution	County	Digester Capacity (m^3)
Jomo Kenyatta University of Science and Technology	Kiambu	385
Kaimosi Teacher’s College	Vihiga	200
College of Agriculture and Veterinary Sciences	Kiambu	120
Siana Boarding Primary School	Narok	120

Source, (MOE, 2023).

In spite of this progress, Kenya's goal of achieving widespread access to clean cooking by 2028 through the promotion of biogas, bio-ethanol, and other eco-friendly fuels faces challenges (MOE, 2020). The exploration efforts into biogas energy projects encounter numerous adoption barriers, underscoring the need for comprehensive strategies to overcome these hurdles and realize the full potential of biogas technology in Kenya (Kehbila, 2023).

Kenya's heavy reliance on wood fuel for daily cooking needs, underscores a critical energy challenge facing the country, particularly in rural areas where approximately 90% of the population resides (Anna et., 2021). Despite Kenya’s significant biogas potential, the majority of households, especially in rural areas, continue to rely on traditional biomass as their primary cooking fuel. In rural communities, up to 92 % of households depend on traditional biomass , with this trend compounded by fuel stacking where LPG users still consume substantial amounts of charcoal, citing approximately 42 % of charcoal usage compared to primary charcoal users (Ogalo & Rop. PhD, 2024)

This dependence on biomass energy carries significant implications that extend beyond mere energy provision (Shakti et al., 2023). Economically, it perpetuates a cycle of poverty by exacerbating the financial burden on households, as wood fuel collection often entails significant time and labor costs, hindering productivity and income generation opportunities (Kirstie et al., 2020). Socially, the reliance on wood fuel affects the health and well-being of communities, exposing them to indoor air pollution, respiratory illnesses, and other health hazards associated with inefficient cooking practices (Ali et al., 2021). Additionally, the environmental ramifications are profound, contributing to deforestation, land degradation, and loss of biodiversity as forests are depleted to meet the escalating demand for wood fuel (Mark et al., 2019).

In spite of all this, there still are sufficient substrates for biogas such as cattle manure and crop residues like maize husks, sugarcane, and coffee waste, which are largely unutilized (Eipa et al., 2019). A recent study in rural Sub-Saharan Africa confirmed that animal manure remains abundant and suitable for biogas production in the region

(Sibanda & Uzabakiriho, 2024).Additionally, techno-economic research in Kenya identified manure as the predominant feedstock, with crop residues also showing strong potential in biogas systems (Hamid & Blanchard, 2018). Consequently, non-users of biogas persist with environmentally harmful and health-damaging fuels, even when viable alternatives are accessible. Rechanneling livestock waste and agricultural residues into biodigesters could reduce deforestation, improve indoor air quality, and expand energy access.

In response to these challenges, Stichting Nederlandse Vrijwilligers (SNV), a Dutch non-profit organization with a longstanding commitment to promoting sustainable energy solutions globally, initiated biogas technology promotion efforts in Kenya in 1967 (SNV, 2023). Collaborating closely with Non- Governmental Organizations (NGOs) such as Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Humanistisch Instituut voor Ontwikkelingssamenwerking (HIVOS), Practical Action and government bodies such as the Kenya Biogas Program (KBP), SNV implemented various initiatives aimed at raising awareness about biogas, providing technical assistance, and facilitating financing for biogas projects, particularly in rural areas where access to clean energy was limited. Over time, the combined efforts of SNV and its partners have contributed to a gradual uptake of biogas across Kenya, with more households and institutions embracing this eco-friendly energy source which has a variety of substrates as shown in Table 2.3;

Table 2.3: Latent biogas substrates and their corresponding energy potential (GWh)

Substrate Source	Energy Potential in GWh
Municipal Waste	80.6-512.6
Sisal	65.4 - 284.3
Sugar	18.6 - 42.8
Coffee	12.6 -147.6
Chicken	5.8 - 24.7
Pineapple	9.6 - 26.6
Tea	2.7- 7.8
Cut Flowers	2.4 - 7.6
Milk	1.4 - 7.2
Distillery	1.8 - 14.9
Pig	1.6 - 3.8
Meat	0.09 - 0.6
Vegetable	0.02 - 0.2

Source, (Mudoga et al., 2022).

The implementation of strategies aimed at maximizing the potential of biogas systems to tackle energy access issues, promote sustainable development, and mitigate environmental degradation, have faced several challenges that have impeded the comprehensive adoption of this technology (Korir & Musembi, 2025).Various studies have been conducted to understand the practical situations impeding the adoption process of this technology within the country. For instance, a study conducted to analyze the socio-economic factors influencing the adoption of biogas technology among farm households in the North Rift Region of Kenya by Charles (2019), shed a light on crucial aspects that affect biogas adoption. It revealed the significance of socio-economic factors as determinants of biogas technology adoption in the region. The findings highlighted the need for policymakers and stakeholders to design and implement policies that encourage the use of sustainable energy sources like biogas.

In another study conducted by Ignatius (2020) titled "Assessing the uptake of biogas as a source of clean energy for cooking by low-income households in Kibera slum, Kenya," challenges hindering biogas adoption in urban settings were revealed. Findings indicated a low uptake of biogas in Kibera, with many bio-centres falling into disuse. Socio-economic factors such as household income, education level, cultural affiliations, household size, and distance from biogas centres significantly influenced biogas uptake. The study highlighted misconceptions about biogas stemming from its source, human excreta, contributing to low acceptance. Government initiatives primarily focused on animal and agricultural waste, neglecting urban biogas potential. To address these challenges, continuous sensitization, education, and awareness campaigns were recommended to bridge the gap between the source and end product of biogas.

Moreover, the study review on Biogas Technology in Kenya by Lumadede et al., (2021) was conducted to examine the energy potential of biogas production from crop residues and its implications for Kenya's energy mix. It aimed to promote the integration of biogas into the country's energy sector by providing insights into approaches, achievements, and lessons learned from domestic biogas programs. it highlighted the role of development partners in supporting the implementation of market-based domestic biogas programs, with the goal of establishing a commercially viable biogas sector. Overall, the study offered valuable knowledge and guidance in enhancing biogas utilization and addressing energy challenges in Kenya.

The study on the Adoption and Deployment of Household Renewable Energy Technologies in the Global South: The Case of Biogas in Rural Kenya investigated various aspects of biogas adoption and deployment. Its objectives included identifying the dynamics of biogas development, analyzing discourses that stabilized or destabilized actor-networks, establishing the role of socio-cultural factors in biogas uptake, and evaluating the gendering of biogas use. The study concluded that the linear transfer of biogas technology from experts in the Global North to users in the Global South, without considering socio-cultural contexts, was no longer effective. Instead, it recommended a collaborative approach, where biogas promoters worked closely with rural Kenyan communities to integrate biogas technology into local contexts, economies, and ways of life. This approach aimed to ensure the sustainable adoption and utilization of biogas technology in rural Kenya (Munga, 2020).

In spite of the existing studies attempting to shed a light on biogas adoption and its development, several shortcomings are exhibited that hinder a comprehensive understanding of the challenges and opportunities in this field. Firstly, while earlier studies on biogas in Kenya provide valuable insights, they reflect conditions that have since evolved as many are over seven years old from the time of publication to date therefore limiting their relevance to the current landscape in biogas development., such as those by J. W. Mwirigi et al. (2009) ; Nyonje et al. (2013) ; Ndungu (2014) ; Wachera (2014); Hamlin (2012); Muriuki (2015); J. Mwirigi et al. (2014); Jonušauskaitė et al. (2010); Kamau et al. (2015); Nzila et al. (2010) amongst others. This study fills that gap by providing the current scope of the barriers and status of biogas uptake and development in Kenya.

Moreover, previous studies suffer from a lack of focused examination on barriers to biogas uptake, leading to a scattered understanding of the challenges as many studies explore socio, economic or technical factors independently. Reports such as the exploration of the socio-economic determinants impacting the adoption of biogas technology within households in Kilifi County, Kenya by Hilda et al. (2019) or another by R.G Hamid and co-author R.E Blanchard (2021) in their work; An assessment of Biogas as a domestic energy source in Rural Kenya amongst others like those by; Jung & Huxham, (2019); Kyalo et al. (2018); Momanyi et al. (2016); Ochieng et al. (2020); Ong'ayo (2016); Ongiyo (2019) provide a multiplicity of separate conclusions and recommendations on barriers to biogas adoption. In contrast, this focused examination of barriers that the research provides, offers clarity and direction. By systematically consolidating the identified and analyzed barriers into one report, policymakers and project developers can pinpoint major loopholes and prioritize interventions effectively. This approach saves time, finances, and labor by streamlining decision-making processes and ensuring that resources are allocated efficiently to address the most critical barriers to biogas development in Kenya

Additionally, previous studies reveal the lack of a structured and hierarchical approach to accurately identify and assess the significance of the key challenges hindering biogas adoption in Kenya. This study fills the gap by using AHP to systematically prioritize and rank these barriers, providing a comprehensive analysis of the primary obstacles impeding the development of biogas technology in the country. This study builds on a growing body of research that employs Multi-Criteria Decision-Making (MCDM) approaches to evaluate barriers to biogas adoption in developing countries such as the work done by Mukeshimana et al. (2021) in Rwanda. While both studies share the same decision-making framework, the present research departs significantly from Mukeshimana's in terms of methodology, stakeholder engagement, and analytical rigor. First, in identifying barriers, Mukeshimana et al. (2021) used a pre-developed list presented to a mixed group of biogas users, technicians, scholars, and professionals, who then selected what they considered the most relevant impediments. While participatory, this approach risks bias as it relies heavily on personal familiarity rather than empirical grounding. In contrast, the current study employed a systematic and evidence-based process to identify barriers, drawing from a comprehensive review of peer-reviewed literature and technical reports which were then thematically categorized thus ensuring a conceptually coherent and empirically sound framework prior to expert evaluation.

Secondly, in terms of stakeholder representation, the Rwandan study involved participants chosen primarily based on general familiarity with biogas programs, without clear sectoral stratification. The present study, however, implemented stratified random sampling to engage domain experts from three clearly defined sectors: the biogas industry, the broader renewable energy sector, and government and policy institutions. This ensured that the data captured reflected a balanced and institutionally relevant cross-section of Kenya's energy landscape. Thirdly, regarding analytical rigor, while both studies utilized AHP, the current research applied the method within STATA, a robust statistical environment that allowed for automated consistency ratio checks, matrix validation, and enhanced result reproducibility. This increased the mathematical transparency and precision of the findings. Finally, the inclusion of a cross-validation step marks a significant methodological advancement. After computing the barrier rankings through AHP, the results were validated against recent empirical studies, policy documents, and expert opinions—an approach that reinforced both internal coherence and external validity. In contrast, Mukeshimana et al. (2021) did not report any form of result validation. These distinctions collectively underscore the enhanced methodological robustness and credibility of the present study within the context of MCDM applications in sustainable energy research. In summary, the research on impediments to the development and adoption of biogas technology in Kenya is justified by its potential to address energy requirements, advance environmental sustainability, contribute to rural development, create economic opportunities, guide policymaking, and promote knowledge transfer for a more resilient and sustainable future.

2.3 Barriers to biogas adoption- A thematic review

2.3.1 Economic Barriers

In a study by Shallo et al., (2020) identified that, in Ethiopia, the substantial upfront capital required for biogas digesters deterred many potential users, particularly in rural areas with low-income levels. This initial investment was often beyond the financial reach of many households, making it difficult for them to consider biogas as a viable energy solution. This sentiment was echoed in Ethiopia, where Benti & Asfaw (2022) noted that limited financial assistance hampered the expansion of biogas technology. The lack of financial support systems, such as governmental or non-governmental funding, created a significant economic barrier that prevented many potential users from adopting biogas solutions.

In Kenya, it was identified that the initial cost of installing a digester was prohibitively expensive for the majority of rural households, who typically operate under constrained financial conditions Ogalo & Rop. PhD, (2024). Moreover, in a study by Rotich et al. (2024) on the renewable energy status and uptake in Kenya, noted that the absence of tailored financial instruments such as affordable credit facilities or subsidized loan schemes, limited access to biogas technology, even in areas where feedstock like livestock manure was readily available. Existing financing options often carried high interest rates, sometimes exceeding 20%, rendering them inaccessible to most smallholder farmers. Further, in a report by Eastleigh Voice newsletter, (Onyango, 2025), revealed that the lack of sustained government-backed incentives or subsidies discouraged widespread adoption, especially in regions where households were willing but financially incapable of investing in such infrastructure. These financial hurdles were compounded by ongoing costs related to system maintenance, user training, and periodic repairs, which many households cannot afford without external support. The compounded effect of high initial costs and inadequate financial support mechanisms underscores the need for comprehensive financial strategies to promote the adoption of biogas technology, ensuring it becomes a feasible option for a larger segment of the population.

2.3.2 Technical & Infrastructural Barriers

In Kenya, key technical and infrastructural challenges continue to limit the effective adoption of biogas technology. For instance, insufficient technical capacity among users has been found to undermine digester performance. The Power for All consortium (2020) reported that households lacked operational skills, resulting in under-performing systems and poor gas yields. Furthermore, the scarcity of qualified technicians in rural areas creates persistent service gaps. Despite the presence of over 147 Biogas Construction Entrepreneurs (BCEs), many parts of Kenya remain underserved, making routine maintenance and repairs unreliable or delayed (Lee et al., 2021).

Additionally, concerns around poor build quality and non-durable materials persist. A review by Stepping on the Gas by Robinson et al., (2025) highlighted that substandard sealing, incorrect pipe fittings, and weak structural joints contributed to gas leaks and frequent breakdowns. These technical and infrastructural weaknesses ranging from user inexperience to inadequate installation standards, culminate in system inefficiencies and early project failure. To ensure the long-term success of biogas systems, the country ought to scale up comprehensive training for users, certified technician programs, and rigorous construction quality controls underpinned by national standards. Addressing these technical challenges is essential for ensuring the long-term sustainability and reliability of biogas systems, thereby promoting their wider adoption.

2.3.3 Socio- cultural Barriers

In Kenya, the widespread adoption of biogas technology also encounters significant social and cultural barriers. One of the challenges remain to be low awareness and insufficient understanding of biogas technology among the local population, which often hinders its acceptance. Many individuals in rural areas are unfamiliar with the technology's potential benefits, leading to reluctance in adopting it (Mbali, 2018). This finding is supported by observations emphasizing the crucial role of awareness campaigns in improving the adoption rates of biogas technology by educating the public on its environmental and economic advantages, thereby fostering a more favorable perception and greater acceptance (Onyango, 2025).

Cultural practices and established preferences also play a crucial role in the adoption of biogas technology in Kenya. Traditional cooking methods and ingrained preferences for using firewood, for instance, pose significant challenges to biogas adoption. Many households are accustomed to using firewood, and shifting to biogas stoves requires a notable change in cooking habits and cultural practices (Ogalo & Rop. PhD, 2024). This resistance to change often reflects deeply ingrained norms and practices, which can overshadow the practical benefits of biogas technology, making it difficult to convince households to switch to biogas stoves despite their advantages (Onyango, 2025).

Overall, the combined impact of low awareness and strong cultural preferences creates a substantial barrier to the adoption and development of biogas technology in Kenya. Efforts to promote biogas adoption, therefore, need to address both the informational and cultural dimensions, emphasizing education and awareness campaigns tailored to local contexts and directly addressing specific cultural preferences. By understanding and mitigating these socio-cultural barriers, stakeholders can develop more effective strategies to increase the acceptance and adoption of biogas technology in diverse communities across Kenya.

2.3.4 Policy & Regulatory Barriers

In a study by Tembo et al. (2023), weak local government policies and a lack of regulatory support were pointed out as core barriers that stymied the development and adoption of biogas technology in Zambia. This lack of support from local governments created an environment where potential biogas users and investors were hesitant to engage in biogas projects due to the absence of clear guidelines and incentives. Similarly, inconsistencies and lack of clarity in regulations further hinder the adoption of biogas technology. In Ethiopia, Benti and Asfaw (2022) noted that unclear regulations and bureaucratic hurdles complicated the process of establishing and operating biogas plants. These regulatory ambiguities created significant obstacles for potential adopters, who faced lengthy and confusing bureaucratic processes to get their biogas projects approved and operational.

The widespread adoption of biogas technology in Kenya faces significant challenges stemming from current policy and regulatory environments. A notable impediment is inconsistent government support and the absence of a coordinated national subsidy or incentive program. Despite the existence of a robust policy and regulatory framework, including the Energy Act of 2019 and the National Energy Policy of 2018, there remains a lack of emphasis on directly promoting biogas for emissions reduction (Robinson et al., 2025). This inconsistency and the absence of a coordinated national subsidy or incentive programme limit the sector's growth, creating an environment where potential biogas users and investors hesitate to engage in biogas projects due to the perceived lack of clear incentives (Onyango, 2025). While some tax exemptions exist for biogas equipment, the overall financial incentive landscape is considered insufficient to drive widespread adoption (KIPRRA, 2018).

Additionally, the lack of clear regulatory frameworks and complex permitting procedures further impede the adoption of biogas technology. Bureaucratic hurdles and lengthy permitting processes for establishing and operating biogas plants complicate project implementation. These regulatory ambiguities can result in securing permits taking several years, requiring compliance with a range of local and national regulations, including environmental review processes that vary by location (Onyango, 2025). The compounded effect of the lack of supportive policies and regulatory frameworks, along with inconsistencies and unclear regulations, underscore the critical need for comprehensive and coherent policy strategies to promote the adoption of biogas technology.

2.4 An Overview of the Modelling Tool and Analytical Technique

In the study by Susan et al. (2019) investigating livestock farmers' perceptions on the generation of cattle waste-based biogas methane in Embu West District, Kenya, Statistical Package for Social Sciences (SPSS) was employed as the modeling tool. While SPSS offers powerful statistical analysis capabilities, its application in studying barriers to biogas adoption may not adequately capture the inherent complexities. The disadvantageous nature of using SPSS in this context may stem from its limitation in handling qualitative data, which is often integral to understanding the multifaceted barriers hindering biogas adoption. Moreover, despite R's widespread use in statistical analysis, employing it to examine barriers to biogas adoption could have been problematic. Although it is proficient in statistical modeling and data analysis, its suitability for studying barriers to biogas adoption may have been limited by the complexity of the analysis required to understand the various obstacles hindering biogas adoption.

This research study however utilized Stata as the preferred modeling tool for comprehensive data management, analysis, and representation of the results throughout the entirety of the analytical procedure of the project. AHP was used as the data analysis technique throughout the study. Using AHP structured technique in Stata for decision-making was a prudent choice for analyzing the barriers towards biogas adoption due to its ability to accommodate multiple criteria decision-making. In a study by (Mukeshimana et al., 2020) on the analysis on barriers to biogas dissemination in Rwanda, the AHP approach was utilized to effectively rank the barriers towards biogas dissemination in Rwanda. The findings from the AHP analysis revealed that barriers related to finance significantly impact the adoption of biogas, with high capital costs and inadequate financial mechanisms ranking prominently among all obstacles.

Moreover, in a study to assess and prioritize biogas barriers to alleviate energy poverty in Pakistan, AHP technique was incorporated. The research findings revealed that the "financial barrier" ranked as the top barrier among the main categories, followed by technical, socio-cultural, institutional and administrative, and environmental barriers (Kiran et al., 2023). Based on the findings, some policy recommendations were suggested for biogas uptake in Pakistan further suggesting the successful implementation of the AHP technique in the analysis of barriers to biogas adoption and uptake. Therefore, AHP provided a systematic framework for evaluating and prioritizing the various factors or criteria influencing the decision at hand, ranking the barriers in order of perceived importance, making it particularly suitable for assessing the complex and multifaceted nature of barriers to biogas adoption.

By employing AHP in Stata, the study was able to quantitatively analyze the relative importance of different barriers based on expert feedback. This facilitated a comprehensive understanding of the challenges hindering biogas adoption, creating an enabling environment for the prioritization of interventions and effective allocation of resources. The structured nature of AHP, coupled with Stata's analytical capabilities, enhanced the rigor and reliability of the decision-making process, ultimately contributing to a more informed and evidence-based strategy for promoting biogas technology adoption.

2.5 Conceptual Framework & Research Gap

This visual representation of the conceptual framework presented in Figure 2.1 below forms the theoretical underpinning of this study, offering a structured approach in understanding the main criteria and sub-criteria that act as barriers to the adoption of biogas technology in Kenya. The dependent variable of this study was: "Biogas Technology Development and Adoption." This represented the overarching phenomenon under investigation, encompassing the intricate processes, challenges, and dynamics involved in the integration of biogas technology in the Kenyan context. The independent variables were the criterias and sub-criterias affecting biogas uptake.

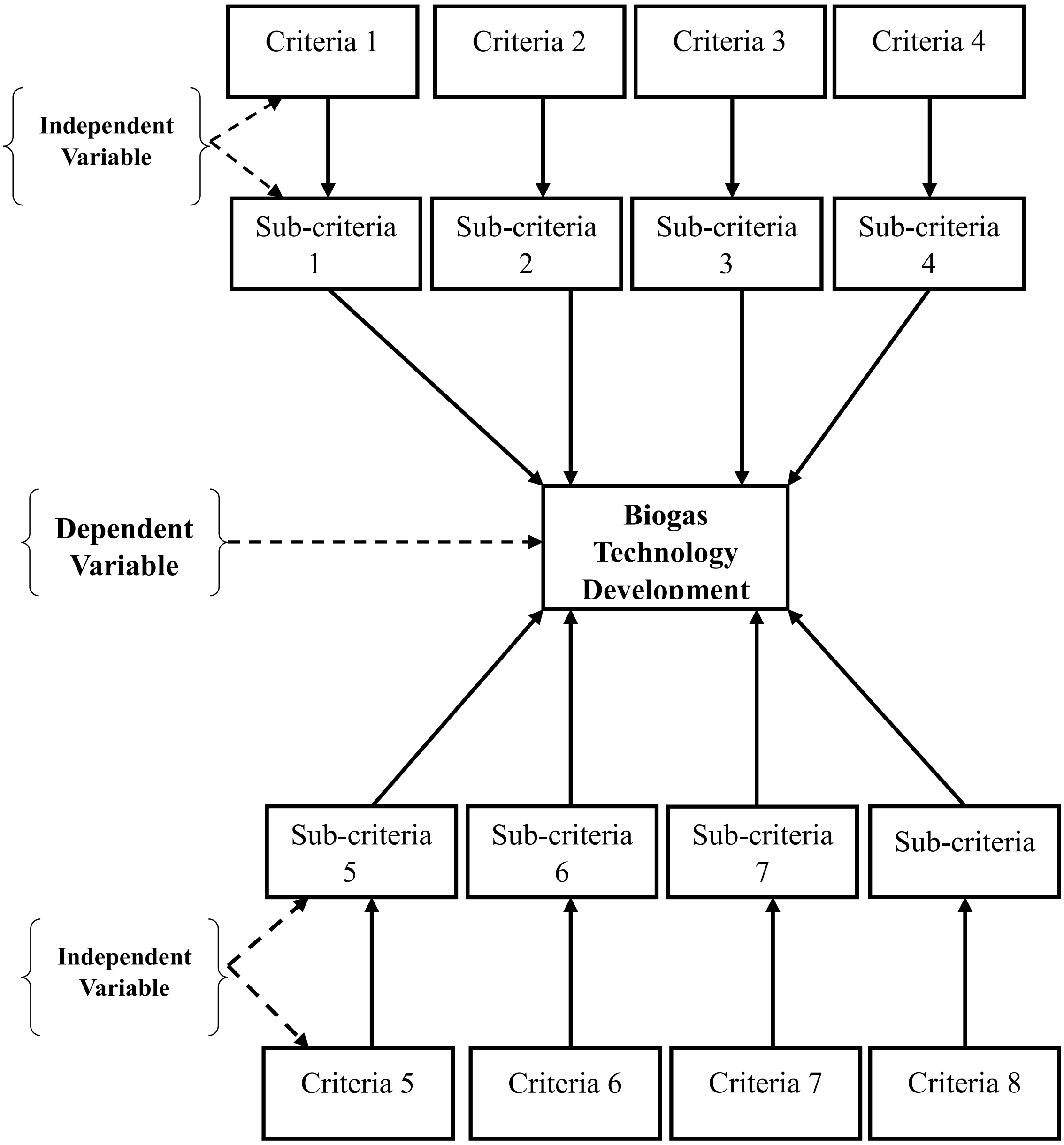

Figure 2.1: A visual representation of the conceptual framework of the study

To ground this study within existing scholarly and practical discourse, a review of recent literature on biogas adoption in Kenya, the broader East African region, and internationally was conducted. The table 2.4 below summarizes key studies, highlighting their focus variables, methodologies, findings, and identified research gaps. This synthesis provides a contextual foundation for the present study and demonstrates how it addresses critical limitations in past research through a more comprehensive, Kenya-specific, and analytically rigorous approach

Table 2.4: Summary literature review table with identified research gaps

Study Title	Country	Variables	Analysis Technique	Key Findings / Conclusions	Research Gaps Identified
Biogas Technology in Kenya: A Review	Kenya	Feedstock availability, maintenance, cost	Mixed Methods	Biogas viability undermined by poor maintenance practices	No structured approach to assess and prioritize barriers
Determinants of biogas technology adoption in southern Ethiopia	Ethiopia	Installation costs, household income, adoption rate	Descriptive Statistics	High costs reduce adoption in rural areas	No comparative insight into urban vs rural or institutional dynamics
Technological, Economic, Social and Environmental Barriers to Adoption of Small-Scale Biogas Plants: Case of Indonesia	Indonesia	Awareness, cultural beliefs, energy pricing	SEM	Cultural and informational barriers slow uptake	Lacks specific strategies to overcome socio-cultural resistance
Adoption of biogas technology as an alternative energy source in Gakawa Location, Nyeri County, Kenya	Kenya	Technician training, user attitudes, institutional barriers	Case Study	Poor implementation due to skills gap and weak policy	No structured prioritization of barriers
The current status, challenges and prospects of using biomass energy in Ethiopia	Ethiopia	Cost, awareness, fuel alternatives	Literature Review	Lack of awareness and high costs major barriers	Does not quantify impact of each barrier or propose priority areas
Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya	Kenya	Income, awareness, policy support	Descriptive Survey	Income and information access influence adoption	Over 7years old from time of publication therefore limiting its relevance and no policy linkages with devolved structures
Analysis on barriers to biogas dissemination in Rwanda: AHP approach	Rwanda	Technical knowledge, infrastructure, user perception	AHP	Poor skills and inadequate infrastructure reduce efficiency	No cross-validation to establish coherence with similar studies in the region.
Social-Economic Factors Influencing Biogas Technology Adoption among Households in Kilifi County- Kenya	Kenya	Household fuel use, income, technology exposure	Household Survey	Income and education shape biogas uptake	Excludes institutional and policy variables

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Research Design

A research design is a methodical strategy or layout detailing the organized steps involved in conducting a research investigation. It provides a structured framework for gathering, analyzing, and making sense of data, guaranteeing that the study is orderly, logical, and equipped to tackle the research inquiries or goals effectively. The research design steers choices regarding the research methodology, approaches to data collection, and methods of data analysis (Jilcha Sileyew, 2020). This study employed a mixed-methods research design, combining qualitative identification of barriers with quantitative prioritization using AHP. The design aimed to ensure a structured, transparent, and replicable approach to understanding and ranking the barriers to biogas technology adoption in Kenya. The process began with a targeted review of recent literature to identify relevant criteria and sub-criteria affecting biogas adoption. These barriers were organized into a hierarchical framework suitable for AHP analysis.

Data was then collected through structured questionnaires administered to a stratified random sample of experts drawn from the biogas, renewable energy, and policy sectors. Respondents provided pairwise comparisons of the identified barriers using Saaty's 1–9 scale. The data was then analyzed using STATA, where the pairwise matrices were processed to generate priority weights. This involved computing the average of normalized values, normalizing the priority vector to ensure comparability, and assessing the consistency of responses using the Consistency Ratio. The mixed-methods approach was selected for its ability to integrate qualitative insights with quantitative evaluation, allowing for a comprehensive understanding of the barriers. The qualitative phase provided context and depth, offering detailed insights into the challenges, while the quantitative phase ensured an objective ranking of the barriers, making the findings both robust and actionable.

3.2 The Study Area

Fig 3.1 shows Kenya situated in Eastern Africa. It is strategically located between latitudes 5°N and 5°S and longitudes 34°E and 42°E (Timar et al., 2023). This geographic positioning places the country in a unique climatic and environmental setting that spans from the tropical conditions of the coastal regions along the Indian Ocean to the temperate climates of the central highlands and the arid landscapes in the northern areas.

Figure 3.1: Map showing the study area

As of 2022, Kenya's population stood at approximately 54,027,487, according to the World Bank data. This was coupled by a population growth rate of 2% per year which reflected the growth of a rich tapestry of ethnicities and cultures. The population distribution exhibits variations, with urban centers like Nairobi displaying higher population density, while rural areas feature more scattered settlements. The economic landscape is varied, with agriculture, manufacturing and services making significant contributions. The country is also witnessing remarkable growth in the technology sector, notably in Nairobi's "Silicon Savannah," positioning Kenya as a technological hub in the region. The decision to adopt a national-level approach in the study of biogas adoption in Kenya was driven by the research's overarching goal: to provide a holistic understanding of the complexities surrounding the uptake of biogas technology.

3.3 Sampling Technique

In this study, stratified random sampling (Bhardwaj, 2019) was chosen as the most suitable method due to its ability to effectively capture variability across different strata within the population. The randomly selected sample was allocated proportionately across three strata namely the renewable energy sector, the biogas sector, and the government and policy sector. The proportionate allocation formula used was as shown in equation 3.1:

$$\boldsymbol{n_i = \left(\frac{N_i}{N}\right) \times n} \qquad \textbf{3.1}$$

Where:

- n_i is the sample size for each stratum,
- Ni is the population size of each stratum,
- N is the total population size, and
- n is the desired total sample size.

3.4 Target Population

The population consisted of industrial experts, divided into three distinct strata: the renewable energy sector (N1 = 200), the biogas sector (N2 = 200), and the government and policy sector (N3 = 100). To determine the target population across the three defined strata the study drew upon a total pool of 500 professionals actively engaged in Kenya's energy landscape. This initial population was selected using simple random sampling to ensure an unbiased and representative group of participants. Following this, the allocation of professionals into the three strata was also performed randomly through stratified random sampling while being guided by the study's thematic focus and sectoral relevance.

The proportional distribution into N_1, N_2, and N_3 was based on the recognition that the renewable energy and biogas sectors encompass a larger and more diverse set of stakeholders compared to the relatively smaller but strategically significant government and policy sector. The renewable energy sector ($N_1 = 200$) included professionals from the solar, wind, hydro, and geothermal domains, reflecting Kenya's diversified investment in clean energy infrastructure. The biogas sector ($N_2 = 200$) comprised individuals directly involved in the design, deployment, and oversight of biogas technologies, while the government and policy sector ($N_3 = 100$) consisted of energy policymakers, regulatory officials, and advisors involved in shaping Kenya's renewable energy framework. This stratification ensured that each group relevant to the research problem was appropriately captured and represented.

To maintain representativeness, the desired sample size of 32 respondents that was to be selected was proportionally allocated across these strata. As a result, 13 respondents were selected from both the renewable energy and biogas sectors, while 6 respondents were drawn from the government and policy sector as show in Table 3.1 below.

Table 3.1: Proportional allocation of the desired sample size across the strata

Strata	Population Size (Ni)	Proportion (N_i/N)	Sample Size (n_i)
Renewable Energy Sector	200	200/500 = 0.40	0.4× 32 = 12.80 ≈ 13
Biogas Sector	200	200/500= 0.40	0.4 × 32 = 12.80 ≈ 13
Government and policy sector	100	100/500 = 0.20	0.2 × 32 = 6.4 ≈ 6
Total	500	**1.00**	**32**

Out of the 32 randomly selected respondents, 62.5% (n = 20) fully participated in the survey. The incomplete or partial responses on the questionnaires from the remaining 37.5% (n = 12) of the respondents was considered obsolete and therefore excluded from the final analysis. This resulted in a final sample size of 20 respondents, which was used for subsequent analyses in this study. Demographically, the sample reflected a diverse representation: of the total experts, 50% were found to be directly engaged in the biogas sector such as founders, technical officers, quality managers, engineers and quality service providers who represented individuals actively involved in the day-to-day operations of biogas-related activities.

Another 40% of the experts were affiliated with organizations in the renewable energy sector, such as renewable energy officers, energy efficiency officers, research scientists as well as research associates who underscored a substantial portion of the sample contributing to broader sustainability and energy initiatives. Moreover, 10% of the participants were associated with government entities such as county coordinators as well as participants in the policy sector such as energy analysts in refugee councils & business development directors. This signified a noteworthy presence of experts contributing to crucial aspects in the biogas domain. The selection focused on individuals with more than three years of experience, with most having over five years of working experience. These were deemed highly suitable to participate as experts in the field.

This composition underscored the relevance of the target group to the research topic, as these professionals were directly affected by the issues of biogas utilization, policy frameworks, and sustainability initiatives. Accessibility for data collection purposes was facilitated by the willingness of these experts to participate in interviews and surveys, given their vested interest in advancing the biogas sector. Limitations of the target group selection included potential biases towards individuals with higher levels of experience and expertise, which may have affected the generalizability of findings. However, this focus aligned with the research methods employed, allowing for in-depth exploration through qualitative interviews. Insights gained from studying this target group enriched the findings and conclusions of the thesis by providing necessary perspectives from key stakeholders, thereby contributing to a more holistic understanding of biogas development and policy implementation.

3.5 Data Collection Instrument

The study employed a structured questionnaire as the principal instrument for data collection. This instrument was designed to capture expert judgments on the relative significance of various barriers to the adoption of biogas technology in Kenya. The structured format facilitated systematic data collection across respondents and enabled the application of AHP, which requires consistent pairwise comparison data for deriving priority weights.

Unlike traditional Likert-type questionnaires, the instrument in this study incorporated a specialized pairwise comparison matrix based on the Saaty scale (1–9), as prescribed in the AHP methodology. Respondents were asked to compare pairs of barrier criteria and sub-criteria in terms of their relative importance in hindering biogas adoption. Each comparison was rated on a scale from 1 (equal importance) to 9 (extreme importance of one over the other), with reciprocal values (e.g., 1/3, 1/5) applied as necessary. This design allowed for the quantitative derivation of weights reflecting expert consensus on the most critical obstacles.

To complement the AHP matrices, the questionnaire also included brief preliminary items capturing respondent background information, such as organizational affiliation, role, and years of experience in the renewable energy or biogas sector. This helped to contextualize the responses and ensure that expert opinions were drawn from a diverse yet relevant pool of stakeholders. The questionnaire was administered electronically to enhance accessibility and convenience for busy professionals. Specifically, it was distributed through two main channels: email invitations and LinkedIn direct messages. Participation was voluntary, and respondents were given adequate time to complete the instrument at their convenience.

To ensure alignment with the study's specific objectives, the questionnaire items were logically structured to correspond to each major barrier category. The technical section included comparisons related to issues such as availability of technicians, suitable feedstock, and production technologies. Economic comparisons focused on cost barriers, access to capital, and return on investment. Policy-related matrices examined the strength of regulatory frameworks, government incentives, and implementation challenges, while the socio-cultural dimension explored awareness, acceptance, and behavioral resistance within communities. The questionnaires also included some open-ended questions to collect a diversity of required data as shown in Appendix i. The open-ended questions allowed participants to respond in detail in their own words.

The table 3.2 below provides a summary linking the key sections of the questionnaire with their relevance to the objectives of the study;

Table 3.2: Summary mapping of the questionnaire sections

Questionnaire Focus Area	**Sample Comparative Items (Pairwise)**	**Relevance to the Objective of the Study**
Respondent Background	Organization type, years of experience, involvement in biogas sector	Provided contextual understanding of the expertise and distribution of respondents across sectors, which supported the validity and representativeness of the AHP analysis.
Technical Barriers	Availability of technicians vs. feedstock availability; biogas quality control vs. production technologies	Identified the extent to which limitations in technical knowledge, design, and operational factors constrain technology uptake and system sustainability.
Economic Barriers	Startup cost vs. maintenance cost vs. financial returns vs. subsidies	Clarified the perceived weight of affordability, financing availability, and economic feasibility in decision-making among potential adopters.
Policy and Regulatory Barriers	Strength of policy vs. implementation; subsidies vs. enforcement mechanisms	Assessed the extent at which gaps in policy formulation, enforcement, or incentives significantly deter investment in or scaling up of biogas initiatives.
Social and Cultural Barriers	Awareness vs. cultural acceptance; trust in technology vs. community influence	Explored the rate at which societal perceptions, behavioral norms, and community influence in shaping user receptiveness and long-term commitment to biogas use.
Infrastructural Barriers	Biogas infrastructure vs. land needs, vs. water availability vs. availability of digestate treatment facilities	Examined how the infrastructural challenges rated against each other to influence feasibility and adoption rates.

3.6 Data Analysis

3.6.1 Analytical Hierarchy Process (AHP)

To execute the first stage, a thorough review of relevant literature was conducted. The review focused on scholarly articles, reports, and case studies published within the last seven years. The search aimed at identifying core sub-criteria in the adoption of biogas technology in developing countries, with special attention to those pertinent to the Kenyan context as shown in Figure 3.2. Several databases, including Google Scholar, ScienceDirect, Litmaps, and SpringerLink, were utilized to ensure a broad range of perspectives. The search strategy incorporated specific keywords such as "biogas adoption barriers," "Kenya," "developing countries," and "renewable energy challenges," which were refined using Boolean operators (AND, OR, NOT) to narrow the scope. Additionally, backward and forward citation tracking was employed to identify further relevant studies.

Inclusion criteria were established to focus on studies addressing barriers to biogas adoption in developing countries, with preference given to peer-reviewed articles or credible reports. Studies centered on developed countries or those published before 2018 were excluded unless they offered foundational insights essential for understanding current barriers. Data was extracted systematically to catalog the sub-criteria, prioritizing those that specifically mentioned Kenya or similar contexts. The identified barriers were analyzed using thematic analysis and grouped into coherent criteria based on recurring themes.

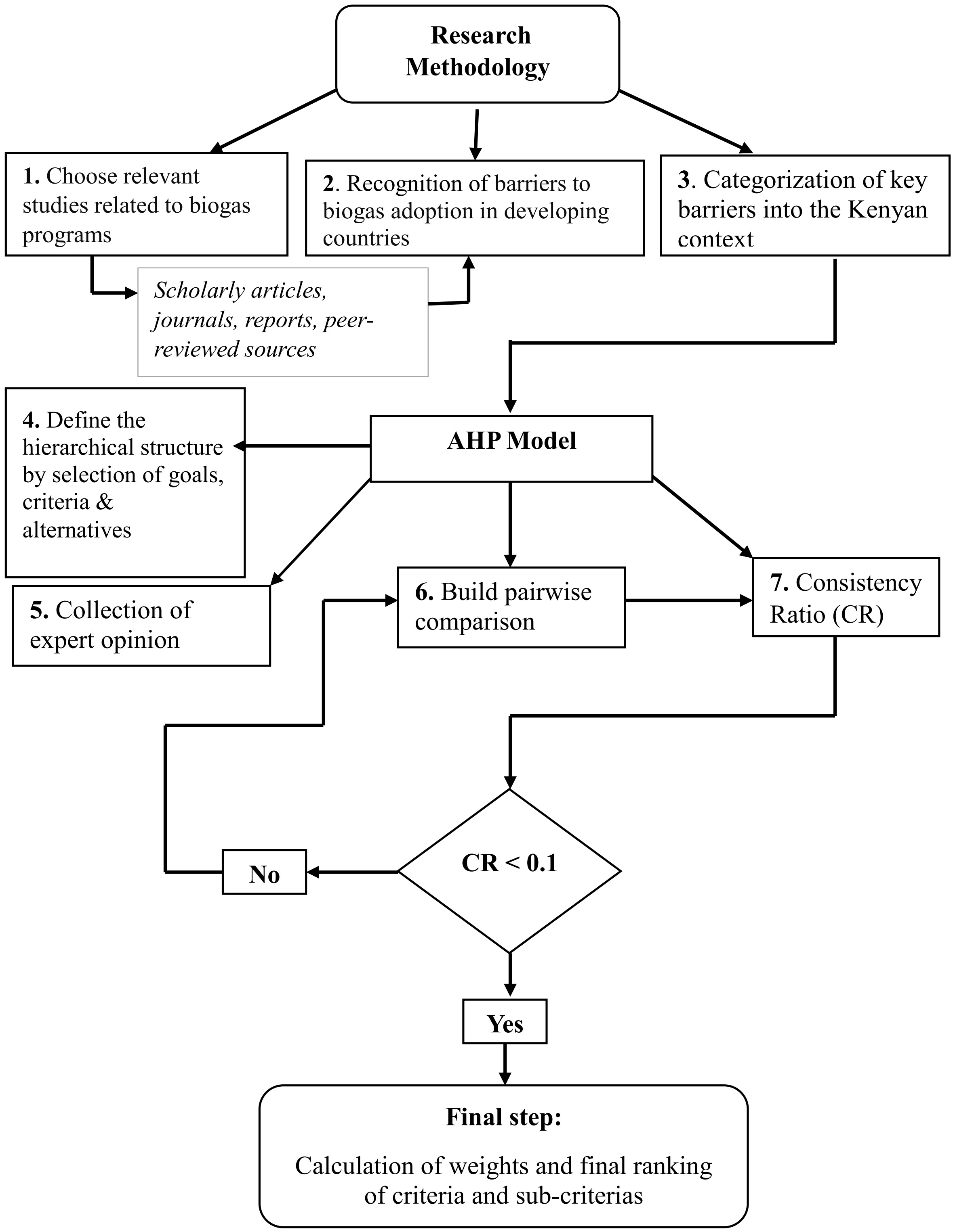

Figure 3.2: Flowchart of the research methodology process; *Adapted from* (Mukeshimana et al., 2020)

Each category then underwent meticulous examination through the AHP approach, which was executed using the Stata program in the second stage. This was done by first organizing the decision challenge into a hierarchical structure as shown in Figure 3.3;

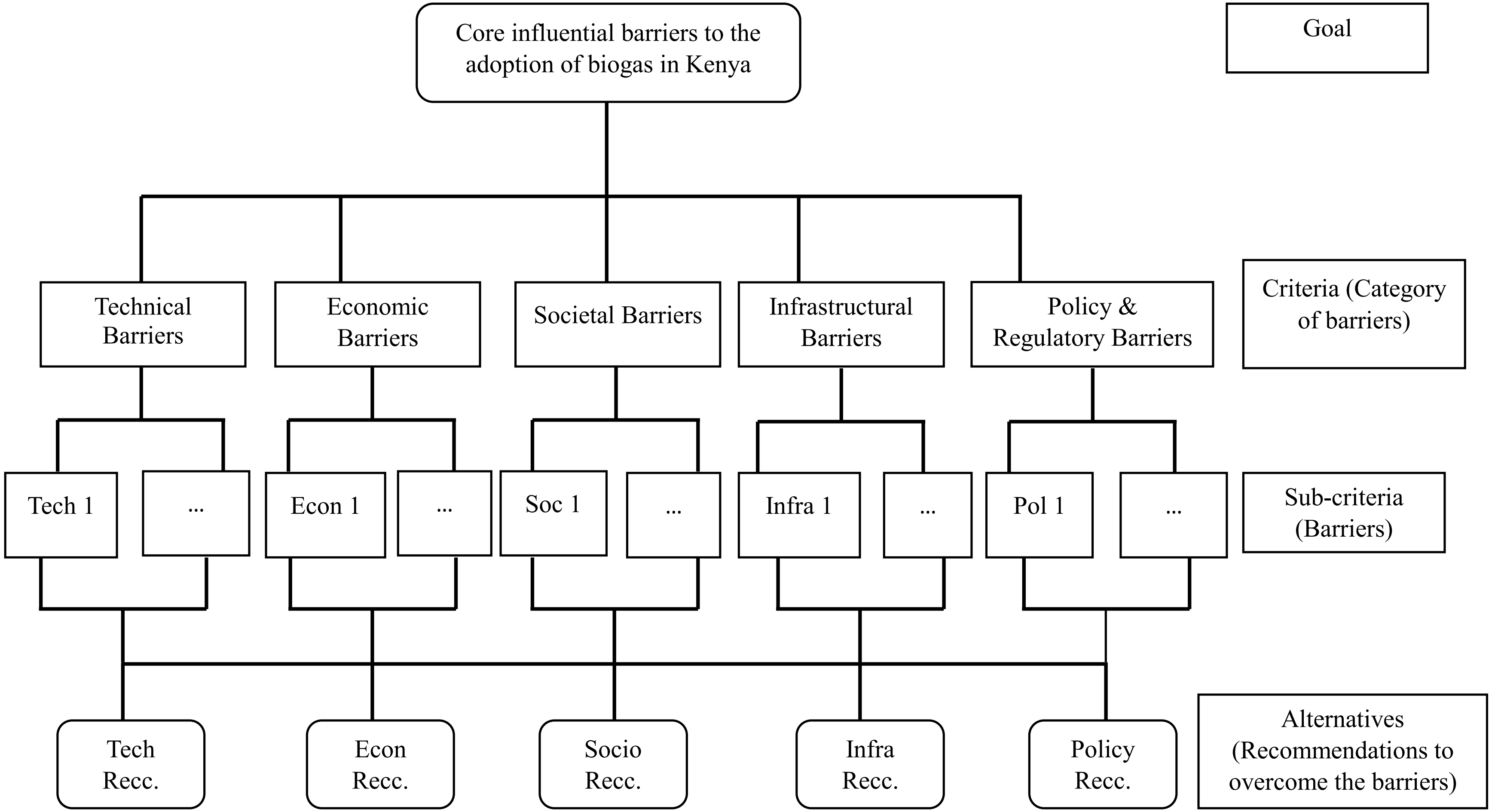

Figure 3.3: The hierarchical structure of the decision problem in the AHP approach, Adapted from (Mukeshimana et al., 2020)

Thereafter, data was collected from expert judgements through comparison matrices in the shared questionnaires. Participants were presented with pairs of criteria or factors related to biogas adoption and were asked to rate their relative importance or preference using a numerical Saaty scale (Saaty, 1980), typically ranging from 1 to 9. In this scale, a rating of 1 indicated that the two criteria were equally significant, while a rating of 9 indicated that one criterion was extremely more significant or preferable than the other. The intermediate values allowed for varying degrees of preference between these extremes. This structured approach allowed for the systematic assessment of participants' perceptions and preferences. The data collected through the questionnaires was then analyzed through Stata to gain insights on the ranking of the criteria and sub-criteria hindering biogas uptake.

Subsequently, pairwise comparison matrix *A,* with A_{ij} representing the preference or importance of factor *i* compared to factor *j* was built after averaging the results from expert insights as shown in Table 3.3. The weights of the main factors were denoted as $w_1, w_2 ... w_n$, where n showed the number of factors.

Table 3.3: Analytical Hierarchy Process (AHP)Pairwise comparison Matrix

Criteria	A_i	A_j	…	….	A_n
A_i	1	Aij	**…**	**…**	A_{in}
A_j	1/Aij	1	.	.	A_{jn}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_n	$1/A_{in}$	$1/A_{jn}$	.	.	1

The pairwise comparison matrix, constructed from expert judgments using Saaty's scale, was first normalized to ensure consistency and comparability across criteria. Normalization was done by dividing each element in a column of matrix A by the sum of that column. This process resulted in a normalized matrix, $N = n_{ij}$ where each element was given as shown in the equation 3.2:

$$n_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}} \tag{3.2}$$

Once the matrix was normalized, the next step was to compute the priority vector *w*, which represents the relative weight of each criterion. This was achieved by calculating the average of each row in the normalized matrix N. The mathematical expression for this calculation is shown in Equation 3.3:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} n_{ij} \tag{3.3}$$

Where:

- w_i is the derived weight for the i^{th} criterion,
- n is the total number of criteria, and
- n_{ij} is the normalized value of the i^{th} row and j^{th} column in matrix N.

Each w_i value quantifies the relative importance of a criterion based on expert evaluations. This priority vector was later normalized to ensure that the sum of all weights equals 1, enabling valid comparisons and rankings across criteria as shown in Equation 3.4:

$$w'_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{3.4}$$

The sequential implementation of AHP enabled the prioritization of barriers based on their perceived significance, thereby facilitating the prioritization of interventions for the barriers ranked highest in importance.

The validation of this study's model was conducted by benchmarking the results of AHP against findings from previous research on barriers to renewable energy adoption. The comparison focused on studies conducted within the last seven years that used AHP and related MCDM approaches. This comprehensive analysis ensured that the findings are both robust and generalizable, particularly in the context of biogas adoption in Kenya.

3.6.2 Validity & reliability of the Technique

To ensure the accuracy and reliability of the collected data and subsequent analysis, several measures were adopted. First, the Consistency Ratio (CR) and Consistency Index (CI) were calculated for each pairwise comparison matrix to evaluate the logical coherence of expert judgments. Only matrices with a CR value of less than 0.1, as recommended in AHP literature (Amenta et al., 2020), were accepted for analysis, signifying an acceptable level of consistency. The CI was calculated by first obtaining λ_{max}, the largest eigenvalue as shown in equation 3.5:

$$\lambda_{max} = \frac{\Sigma_{i=1}^{n}\Sigma_{j=1}^{n}A_{ij}\times W_j}{W'_i}$$

3.5

Where A_{ij} represented the elements of the pairwise comparison matrix, W_j was the sum of the columns, and n was the size of the matrix.

The CI was then calculated as shown in equation 3.6;

$$CI = \frac{\lambda_{max}-n}{n-1} \qquad 3.6$$

The average CI values reported in the results tables referred to the contribution of each sub-criterion to the overall matrix inconsistency. These were calculated by determining the deviation of each λ_i from n, applying the same CI formula to each row's contribution, and averaging the results across all sub-criteria. This approach allowed for a more granular understanding of how each judgment contributed to matrix inconsistency. All calculations were performed using AHP logic implemented in STATA, allowing for CR validation and transparency in replication.

The CR was computed as shown in equation 3.7:

$$CR = \frac{CI}{RI} \qquad 3.7$$

The Random Index (RI) value, was determined based on the size of the matrix according to a predefined table by (Saaty, 1980) as shown in Table 3.4 below:

Table 3.4: Saaty Fundamental Scale for criteria n >=10

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The use of Saaty's fundamental scale (1–9) in structured pairwise comparisons enhanced the precision of responses by providing a standardized framework for judgment. Once consistency was confirmed, priorities could be determined by normalizing the pairwise comparison matrix. This involved dividing each element by the sum of its respective column, resulting in a priority vector as in Equation 3.8:

$$Priority\,Vector, w = \left(\frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}}\right) \qquad 3.8$$

Additionally, expert participants were pre-screened based on their experience (minimum 3 years) and familiarity with biogas, renewable energy, or policy-related sectors. This helped ensure the data was sourced from informed and credible respondents. Finally, the outcomes of the AHP analysis—particularly the computed weights and rankings—were cross-validated through comparison with findings from previous relevant studies. This triangulation helped to confirm the stability and reliability of the results within a reasonable range of deviation. This systematic process ensured the reliability and validity of the judgments within the matrix, enabling informed decision-making based on concrete mathematical principles.

3.6.3 Weights Calculation

In AHP, the process of deriving priority weights for each criterion and sub-criterion involves two common methods: (i) the normalized row average method, and (ii) the principal eigenvector method. While both methods aim to quantify the relative importance of each element in the decision hierarchy, they may produce slightly different results depending on the consistency and structure of the judgment matrix. This study utilized Equations 3.2 and 3.3 to demonstrate the normalization process conceptually. However, the final weights reported for each criterion and sub-criterion were computed using the eigenvector method, which is the preferred and more accurate approach in AHP literature (Forman & Gass, 2001; Saaty, 1984).

3.6.4 Theoretical basis for weight calculation (Eigenvector method)

The normalized row average method as depicted in Equations 3.2 and 3.3 involves dividing each element of the pairwise comparison matrix by the total of its respective column and then averaging the rows to obtain approximate weights. This method is useful for simplifying AHP calculations and explaining the underlying logic. However, it assumes perfect consistency in expert judgments, which is rarely achievable in practice due to the subjective nature of human evaluations. In contrast, the eigenvector method which this study utilized, derived weights as the principal right eigenvector of the pairwise comparison matrix. It mathematically synthesized all pairwise judgments by solving the linear system as shown in equation 3.9:

$$A.w = \lambda_{max}.w \qquad 3.9$$

where:

- A is the pairwise comparison matrix,
- *w* is the priority vector (eigenvector),
- λ_{max} is the maximum eigenvalue of matrix A.

This method considered not just the direct relative preferences between criteria, but also their global coherence across the matrix. As such, it provided a more robust and reliable set of priority weights, especially in the case a degree of inconsistency was present.

3.6.5 Justification for the eigenvector approach

The choice to use the eigenvector method for final weight computation aligned with the standard practice in AHP applications, particularly where decision matrices were moderately inconsistent. This method ensured that the final weights reflected the true underlying structure of preferences and uphold the overall consistency of the matrix. Furthermore, the eigenvector method remained robust in aggregating inconsistent judgments while maintaining mathematical validity, making it especially suitable for multi-criteria decision problems involving complex trade-offs, such as barriers to biogas adoption. Accordingly, although the simplified formulas provided in Equations 3.2 and 3.3 helped to demonstrate the logic behind the AHP methodology, the final weights reported across all criteria in this study were derived from the eigenvector method to enhance precision and interpretive reliability.

3.7 Description of Explanatory Variables

The summary below encapsulates the identified primary criteria & sub-criteria hindering the adoption of biogas technology in Kenya. This was after drawing insights from an extensive literature review on barriers prevalent in developing countries that are closely related to the Kenyan scope. Following thematic analysis, the barriers were grouped into five coherent categories based on recurring themes as follows—Technical, Infrastructural, Economic, Societal, and Policy & Regulatory Impediments as shown in Table 3.5.

Table 3.5: Catalog of identified criteria and sub-criteria

Categories (Criteria)	**Description of barriers (Sub-criteria)**	**References**
Technical Barriers	Unavailability of technicians	Sime, (2020), Kalinda, (2019), Gul et al. (2022)
	Poor gas quality & Composition	Ignatius, (2020), World bank (2019)
	Lack of storage & Transport	Tatiana et al. (2019), Hassan et al. (2020)
	Inefficient Production Technologies	Hassan et al. (2020)
	Lack of suitable feedstock	Jana et al. (2022)
Infrastructural Barriers	Poor infrastructure for biogas distribution	Vladmir et al. (2019), Patinov et al. (2019)
	Insufficient land for installing biogas digesters	Tatiana et al. (2019)
	Integration issues with existing Infrastructure	Emetere et al. (2021)
	Water unavailability	Tatiana et al. (2019)
	Lack of facilities for digestate treatment	Hassan et al. (2020)
Economic Barriers	High initial startup costs	Ashira et al. (2020), Edson et al. (2021), Ignatius, (2020)
	High maintenance and operating costs	Hassan et al. (2020), Sime (2020)
	Limited subsidies on biogas technologies	Vladmir et al. (2019), Ali et al. (2022), Lumadede et al. (2021)
	Uncertain profitability (ROI) in biogas projects	Mark et al. (2020)
	Limited investment and funding opportunities	Patinov et al. (2019), Erick (2018)
Societal Barriers	Lack of awareness and education about biogas benefits	Ignatius, (2020), Marie et al. (2021), Patrik et al. (2020)
	Cultural perceptions regarding biogas projects	Eliana et al. (2022), Ignatius, (2020)
	Community resistance to biogas projects	Munga (2020), Ricardo et al. (2022)
	Limited participation of local communities	Vanessa et al. (2021), Ikonya, (2018)
Policy & Regulatory Impediments	Lack of clear regulatory frameworks	Shahid et al. (2022)
	Inconsistent Government Support	Patrik et al. (2020)
	Insufficient financial incentives	Patinov et al. (2019)
	Land Use Policies	Tatiana et al. (2019)
	Waste Management Regulations	Patrik et al. (2020)
	Tariff Structures	Chen et al. (2022)

3.8 Assumptions of the Study

This study was conducted under the following key assumptions, which were considered necessary to support the validity of the research process and outcomes:

1. **Validity of expert judgement**

It was assumed that the experts selected to participate in the study possessed adequate knowledge, experience, and familiarity with the biogas, renewable energy, and policy sectors. Their responses were presumed to be truthful, informed, and reflective of sector-specific realities.

2. **Consistency in pairwise comparisons**

The study assumed that all respondents correctly understood and applied the Saaty scale during the pairwise comparison process and that any inconsistencies in judgment were within acceptable limits ($CR < 0.1$), allowing for reliable computation of weights.

3. **Sectoral representation and homogeneity**

The three stakeholder categories; biogas, renewable energy, and policy/government, were assumed to be sufficiently represented within the sample. It was further assumed that individuals within each category shared relatively homogeneous perspectives, making aggregation of their judgments valid for the purpose of analysis.

4. **Relevance and stability of evaluation criteria**

The selected criteria and sub-criteria, derived from recent literature and validated by expert feedback, were assumed to be relevant, comprehensive, and stable over the period of the study, thereby providing a reliable basis for analysis and prioritization. These assumptions formed the foundation for the data analysis process and interpretation of results. Efforts were made throughout the study to minimize potential bias and ensure methodological rigor in light of these assumptions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characteristics of the Survey

4.1.1 Response rate

The gender distribution among the respondents (n=20) indicated that 85% were male, and 15% were female as shown in Table 4.1. The response rate was deemed satisfactory for drawing conclusions, and the distribution across gender and sector affiliations was representative of the diverse perspectives within the study.

Table 4.1: The table below shows the interviewee response rate

Characteristics	**Category**	**Frequency**	**Percentage (%)**
Sample Population n=32	Individuals who responded fully	20	62.5%
	Individuals who partially responded	12	37.5%
Total		**32**	**100%**
Gender of respondents n=32	Male	17	85%
	Female	3	15%
Total		**20**	**100%**

4.1.2 Sectoral Composition of Respondents

Table 4.2 reveals a breakdown of the diverse professional backgrounds of the 20 biogas experts who fully participated in the interviews in relation to their organizational affiliations.

Table 4.2: Relationship between gender and Affiliation to biogas sector

Gender	**Renewable Energy Sector**	**Working in the biogas sector**	**Working in the government & Policy**	**Total**
Male	6	9	2	17
Female	1	1	1	3
Total	7	10	3	20

4.1.3 Understanding, Involvement, and Experience

In the conducted interviews with the biogas experts, an admirable level of understanding of biogas technology was revealed as evidenced in Table 4.3. This was underscored by the participants' mean understanding score of 4.2 (M = 4.2, SD = 0.83) on a scale ranging from 1 to 5, signifying a robust grasp of the intricacies of biogas technology.

Furthermore, the experts exhibited substantial involvement in the biogas sector, as evidenced by their mean involvement score of 3.75 (M = 3.75, SD = 1.16) out of 5. This finding emphasizes their active engagement in various biogas-related activities. Additionally, the participants demonstrated diverse levels of experience in the biogas production industry, as indicated by a mean experience score of 1.65 (M = 1.65, SD = 0.81) on a scale ranging from 1 to 3.

Table 4.3: Correlation between Understanding, Involvement, and Experience

Variable	Observation	Mean	Std. Dev.	Min.	Max
Understanding	20	4.2	0.8335	2	5
Involvement	20	3.75	1.1642	2	5
Experience	20	1.65	0.8127	1	3

From the findings, it was evident that the range of experience among respondents was narrower than the range for understanding and involvement. This was due to the inclusion criteria for expert participation, which required a minimum of three years of experience in the biogas or related energy sectors. As a result, participants largely fell within a similar range of professional experience. However, their levels of understanding and involvement varied more widely due to the diverse nature of their roles ranging from policy formulation and academic research to technical fieldwork and project management, which influenced the depth and breadth of their engagement with biogas initiatives.

4.1.4 Expert Profiles by Biogas System Type and Substrate Used

Experts from the biogas sector reported the most direct engagement with system installation, operation, and maintenance as shown in table 4.4. These participants primarily worked with fixed-dome and, to a lesser extent, floating drum digesters. These systems were typically installed in rural and peri-urban household settings or in institutional applications such as schools and slaughterhouses. The scale of the digesters ranged from 2 to 15 cubic meters in daily feedstock capacity, indicating small- to medium-scale operations.

Respondents from the renewable energy sector also indicated involvement in biogas-related projects, particularly those that integrated prefabricated plastic digesters within broader clean cooking and rural energy programs. These experts emphasized the versatility and portability of such systems in off-grid environments, especially where financial and logistical constraints were present. The government and policy experts, while not directly involved in system design or installation, provided insight into national trends and policy-level interventions. They highlighted a strategic focus on livestock-based biodigesters and referenced pilot co-digestion programs aiming to scale up the use of crop residues and organic market waste as supplementary feedstocks.

Table 4.4: Biogas System types and Substrates known to the participants

Expert Sector (Stratum)	Number of Participants (n = 20)	Biogas System Type Involved	Scale of Systems	Primary Substrate Used	Additional/Co-Digested Substrates
Renewable Energy Sector	7	Fixed-dome & prefabricated plastic digesters	Small- to medium-scale (2–15 m^3/day)	Cow dung, pig manure	Poultry droppings, kitchen waste, maize stover
Biogas Sector	10	Fixed-dome, floating drum digesters	Household and institutional scale	Livestock manure (cow, pig)	Banana peels, market refuse, coffee pulp, food waste
Government & Policy Sector	3	Project oversight (non-installation role)	Planning and advisory level	Focus on livestock manure in policy	Pilot co-digestion programs with crop residues

These findings enriched the AHP model inputs by contextualizing the perspectives of the experts, ensuring that their judgments on barrier prioritization were grounded in practical, technology-specific, and substrate-informed experience.

4.2 AHP Matrix Analysis of Biogas Adoption Barriers

4.2.1 Technical Barriers

Table 4.5 reveals the AHP comparison matrix generated for the technical barriers.

Table 4.5: Technical Barriers AHP Comparison matrix

Sub-Criteria	TECH	LOSF	IET	QC	ST
TECH	1.000	4.700	4.850	6.098	4.950
LOSF	0.213	1.000	4.200	5.400	5.600
IET	0.206	0.238	1.000	5.100	0.197
QC	0.164	0.185	0.196	1.000	5.340
ST	0.202	0.179	5.065	0.187	1.000
CR= 0.0799					

The overall consistency ratio for this category was notably low at 0.0799, indicating a high level of consistency in the evaluations. Further on, the values of weights, average CI and CR of the sub-criteria were also calculated for the technical barriers' comparison matrix as shown in Table 4.6. The results showed that unavailability of technicians (TECH) emerged as a pivotal concern, bearing the highest weight of 0.4278. The accompanying low consistency ratio of 0.0491 for this category underscored a high level of agreement among experts in evaluating this barrier thus suggesting the reliability of their collective judgment.

Table 4.6: Sub-Criteria weights, Average consistency index & consistency ratio (Technical barriers)

Sub-Criteria	Sub-criteria Weights	Average CI	CR
TECH	0.4278	0.0550	0.0491
LOSF	0.3430	0.0850	0.0759
ST	0.0888	0.0900	0.0804
QC	0.0661	0.1070	0.0955
IET	0.0743	0.1103	0.0985

Following closely was the lack of suitable feedstock (LOSF) with a weight of 0.3430, signifying substantial importance but ranking lower than technician availability. The consistency ratio of 0.0759 suggested satisfactory agreement among experts on feedstock availability's impact. Biogas storage and transport (ST) was assigned a weight of 0.0888, indicating its perceived lower criticality as well as inefficient biogas production technologies (IET) which carried a weight of 0.0743. The CR of 0.0985 suggested a continued consistent level of agreement amongst the experts in evaluating production technology inefficiency. Poor biogas quality control (QC) held the lowest weight of 0.0661 positioning it as the least critical barrier. The consistency ratio of 0.0955 indicated a reasonable level of agreement among experts on this issue. The average consistency ratio was relatively low 0.0799, indicating a generally favorable condition. This suggested that the participants' judgments and comparisons of the barriers were consistent, thereby enhancing the reliability of the obtained results.

Upon analyzing the pairwise comparison matrix in Table 4.5, a notable inconsistency emerged among the sub-criteria IET, QC, and ST. According to the pairwise judgments, IET was rated as more influential than QC, QC as more influential than ST, and ST as more influential than IET. This created a circular pattern of judgments, reflecting a form of transitive inconsistency that often occurs in expert-based assessments using AHP. These inconsistencies typically resulted from the subjective nature of the expert comparisons, particularly when the factors being evaluated were closely related or difficult to distinguish in terms of influence. Nonetheless, the AHP method accounted for such inconsistencies by aggregating all judgments and computing normalized priority weights using eigenvalue-based calculations.

In this case, although the raw comparisons suggested ambiguity in the ranking of IET, QC, and ST, the final computed weights resolved the conflict. As indicated in Table 4.6, ST received a higher overall weight than QC, while IET ranked slightly lower than both. The CR for the matrix was 0.0799, which fell within the acceptable threshold of 0.10. This indicated that the overall level of consistency in the judgments was sufficient to validate the results.

Several reasons could have been attributed to the findings that highlighted the unavailability of technicians as the most critical barrier. These included the possibility of insufficient technical education and vocational training programs in the country focused on biogas technology and sustainable energy solutions. This educational gap could lead to a lack of qualified personnel capable of supporting biogas projects. Additionally, the inadequacy of infrastructure and support systems for training technicians in rural and remote areas, where biogas adoption is crucial could be another core reason for the perceived outcome. Without proper facilities and resources, it may be challenging to build and sustain the necessary technical expertise.

In a study conducted by Hafiz et al., (2020) on the challenges and potential for adopting biogas technology in Faisalabad, Pakistan, the study revealed that one of the primary issues hindering the effective operation and maintenance of biogas plants was the lack of adequately trained personnel. Many biogas plant owners were either untrained or only partially trained, which significantly impacted their ability to manage and maintain the systems efficiently. Additionally, there was a notable scarcity of technicians and skilled operators available to provide necessary support and technical expertise. This deficiency in human resources posed a significant barrier to the sustainable adoption and functionality of biogas technology in the region.

The study findings of this research work underscored the theoretical importance of human capital in the adoption of biogas technology. This highlighted the need for more research on workforce development and capacity building in the context of sustainable energy technologies. Practically, the results emphasized the urgent need for policies aimed at increasing the availability of trained technicians.

4.2.2 Infrastructural Barriers

Table 4.7 presents the AHP comparison matrix generated for the infrastructural barriers. The overall consistency ratio for this category was relatively low at 0.0683 thus confirming the consistency in the judgements**.** Subsequently, the weights and CR values of the sub-criteria were also computed for the matrix comparing infrastructural barriers as shown in Table 47.

Table 4.7: Infrastructural Barriers AHP Comparison matrix

Sub-Criteria	PIBD	INL	WIN	INTIS	LOF
PIBD	1.000	5.000	5.263	5.100	5.600
INL	0.200	1.000	5.200	5.100	5.600
WIN	0.190	0.192	1.000	5.250	0.200
INTIS	0.196	0.196	0.191	1.000	5.750
LOF	0.179	0.179	5.000	0.174	1.000
CR= 0.0683					

The findings revealed that, poor infrastructure for biogas distribution (PIBD) emerged as the most critical, carrying the highest weight of 0.4286, emphasizing its perceived importance. Insufficient land for installing biogas digesters (INL) closely followed with a weight of 0.3431, denoting significant importance but ranking lower than PIBD. Water unavailability (WIN) held a weight of 0.0832, integration issues with existing infrastructure (INTIS) with 0.0781, and lack of facilities for digestate treatment (LOF) with the lowest weight of 0.0670.

Table 4.8: Sub-Criteria weights, Average consistency index & consistency ratio (Infrastructural barriers)

Sub-Criteria	Sub-criteria Weights	Average CI	CR
PIBD	0.4286	0.0300	0.0268
INL	0.3431	0.0600	0.0536
WIN	0.0832	0.0725	0.0647
INTIS	0.0781	0.1100	0.0982
LOF	0.0670	0.1100	0.0982

From Table 4.7, a circular pattern of influence was observed among the sub-criteria; WIN, INTIS and LOF. WIN was more influential than INTIS, INTIS more influential than LOF, while LOF was more influential than WIN. This type of transitive inconsistency is not uncommon in expert-based comparisons within the AHP framework, especially when the sub-criteria under evaluation are closely related in practical impact. The Analytic Hierarchy Process resolved this loop by synthesizing all pairwise comparisons to produce a coherent set of priority weights through eigenvector calculations. While Equations 3.2 and 3.3 illustrated the simplified normalization approach where matrix values are column-normalized and row-averaged to approximate weights, the final weights in Table 4.8 were computed using the principal eigenvector method, as recommended in AHP. This method considered the full structure of the pairwise comparison matrix and accounted for minor inconsistencies in expert judgments, resulting in a more accurate and mathematically robust set of priority weights. The weights reflected the aggregated judgments rather than isolated comparisons, allowing for a balanced representation of each sub-criterion's influence. The presence of such a loop underscored the complexity of infrastructural barriers, where multiple factors interact and contribute almost equally to the overall challenge.

The findings indicating PIBD as the most critical barrier with a weight of 0.4286, suggested several potential reasons. Kenya's existing infrastructure may have been perceived to lack the necessary networks to efficiently distribute biogas from production sites to end-users, reflecting underdeveloped distribution networks. This deficiency could impede the widespread adoption of biogas technology. Additionally, limited public awareness or acceptance of biogas technology could reduce the urgency or priority placed on developing distribution infrastructure. Without strong public support, infrastructure projects could easily face resistance or skepticism.

In a study by Kemausuor et al. (2018), it was found that, for commercial biogas installations across sub-Saharan Africa, the absence of dedicated transport routes, local cylinder-filling depots, and mini-pipeline networks forced producers to flare or under-utilize significant volumes of gas, undermining both economic viability and investor confidence. Similarly, Black et al. (2021) in their study revealed that without regional bottling facilities and distribution hubs, peri-urban and institutional users could not access biogas in bulk, which raised both unit costs and disrupted supply continuity. In contexts like Kenya, where most digesters are installed in dispersed rural settings, the lack of centralized storage and delivery infrastructure could prevent biogas from reaching peri-urban or institutional users who could benefit from bulk supply. Moreover, inadequate road networks and logistical support could further constrain the ability to transport compressed biogas cylinders efficiently. This finding suggested that despite the potential benefits of biogas technology, such as energy security and waste management, the lack of proper distribution channels limits its accessibility and usability within communities.

From this study's findings, the theoretical implication underscored the need to view biogas adoption through a holistic lens by adopting a system thinking approach which considers the interconnectedness of various elements within the biogas supply chain and their impact on overall adoption dynamics thus recognizing the role of infrastructure in shaping technology uptake. From a practical standpoint, policymakers and stakeholders could prioritize investment in infrastructure development to address poor infrastructure for biogas distribution effectively. This could involve expanding distribution networks, improving transportation systems, and enhancing storage facilities to facilitate the efficient distribution of biogas.

4.2.3 Economic Barriers

Table 4.9 shows the AHP comparison matrix built for the economic barriers. The overall consistency ratio for this category was found to be 0.0814. Following that, the matrix depicting economic barriers was subjected to the computation of weights, average CI, and CR values of the sub-criteria, as illustrated in Table 4.10

Table 4.9: Economic Barriers AHP Comparison matrix

Sub-Criteria	HISC	HOMC	LS	ROI	LIF
HISC	1.000	4.100	5.340	5.887	5.120
HOMC	0.244	1.000	4.240	5.450	5.760
LS	0.187	0.236	1.000	5.440	0.194
ROI	0.170	0.184	0.184	1.000	5.089
LIF	0.195	0.174	5.150	0.197	1.000
CR= 0.0814					

Table 4.10: Sub-criteria weights, Average consistency index & consistency ratio (Economic Barriers)

Sub-Criteria	Sub-criteria Weights	Average CI	CR
HISC	0.4148	0.0444	0.0396
HOMC	0.3538	0.0824	0.0735
LS	0.0872	0.1044	0.0932
ROI	0.0736	0.1088	0.0971
LIF	0.0706	0.1163	0.1038

It was observed that high initial startup costs (HISC) emerged as the most critical economic barrier, carrying the highest weight of 0.4148, indicating its perceived significance among the experts. high maintenance and operating costs (HOMC) followed closely with a weight of 0.3538, suggesting substantial importance but ranking slightly below HISC.

Limited subsidies or financial incentives on biogas technologies (LS) held a weight of 0.0872, and Uncertain profitability and return on investment in biogas projects (ROI) obtained a weight of 0.0736. Finally, limited investment and funding opportunities for biogas projects (LIF) carried the least weight of 0.0706, implying its relatively lower impact compared to other barriers. The average CI and CRs were crucial metrics in assessing the reliability of expert judgments. The consistency ratios ranged from 0.0396 for HISC to 0.1038 for LIF, and the average consistency ratio was calculated at 0.0814, reinforcing the overall reliability of expert judgments.

From Table 4.9, a transitive inconsistency was observed among the sub-criteria; LS, ROI, and LIF. LS appeared more influential than ROI, ROI more influential than LIF, and LIF more influential than LS. AHP addressed this inconsistency by synthesizing all pairwise judgments into a unified priority structure using the eigenvalue method. This approach ensured that the final weights were derived from the overall structure of the matrix rather than from isolated pairwise inputs. As a result, the computed weights presented a coherent and internally consistent ranking of the sub-criteria, despite local judgment loops. This highlighted the strength of the AHP framework in resolving complex decision patterns and ensuring the reliability of the final prioritization.

The emergence of high initial startup costs as the most critical economic barrier, suggested several potential reasons for this outcome. It could be that the perceived risks associated with biogas technology, such as uncertainties about returns on investment, technology reliability, or market demand for biogas products, deterred potential investors from committing resources to biogas projects. Moreover, the costs associated with acquiring biogas technology components, such as digesters, generators, and gas storage systems, could be prohibitively expensive for many potential adopters in Kenya, further deterring investment in biogas systems.

In a study conducted by Mukeshimana et al., (2020) to analyze the barriers hindering the dissemination of domestic biogas in rural areas of Rwanda. The results revealed that the financial category was the most influential barrier, with high initial capital costs and lack of financial mechanisms highly ranking among all barriers. The study underscored the significance of addressing financial challenges to promote the adoption of domestic biogas technology in Rwanda thus facilitating sustainable energy practices and enhancing access to clean energy in rural communities.

From the findings that revealed HISC as a critical barrier, significant implications for both theory and practice emerged. Theoretically, HISC underscored the influence of institutional factors, including financial regulations, government policies, and market structures, in shaping economic barriers to biogas adoption. This highlighted the importance of considering institutional contexts when assessing obstacles to technology adoption. In practice, focused efforts on market development initiatives to create a conducive environment for biogas products and services were to be made whilst capacity building programs were to be essentialized in order to enhance the financial literacy and management skills of biogas adopters, empowering them to navigate financing complexities effectively.

4.2.4 Societal Barriers

Table 4.11 reveals the results of the generated societal AHP comparison matrix. The overall consistency ratio for this category was found to be 0.0743, a relatively low figure signifying the reliability of judgements. Subsequently, the weights of the sub-criteria were also computed for the above matrix as shown in Table 4.12.

Table 4.11: Societal Barriers AHP comparison matrix

Sub-Criteria	LAE	CP	CRB	LP
LAE	1.000	5.400	5.700	4.900
CP	0.185	1.000	5.400	5.120
CRB	0.175	0.185	1.000	5.213
LP	0.204	0.195	0.192	1.000
CR= 0.0743				

Table 4.12: Sub-criteria weights, Average consistency index & consistency ratio (Societal barriers)

Sub-Criteria	Sub-criteria Weights	Average CI	CR
LAE	0.4960	0.0438	0.0486
CP	0.2907	0.0688	0.0764
CRB	0.1079	0.0709	0.0788
LP	0.1054	0.0842	0.0935

From Table 4.12, the findings showed that lack of awareness and education about biogas benefits (LAE) was identified as the most critical societal barrier, carrying the highest weight of 0.4960, signifying its paramount importance according to expert opinions. Cultural perceptions and social acceptance regarding biogas projects (CP) followed with a weight of 0.2907, indicating substantial importance but ranking lower than LAE. Community resistance to biogas projects (CRB) held a weight of 0.1079, while limited participation and engagement of local communities (LP) had a weight of 0.1054. LP carried a lower weight, suggesting its comparatively lower impact among the identified societal barriers. LAE demonstrated a consistency ratio of 0.0486, CP (0.0764), CRB (0.0788), and LP (0.0935). The average consistency index was calculated at 0.0743, reinforcing the overall reliability of expert judgments.

While the pairwise comparison matrix in Table 4.11 included individual judgments that may suggest CRB as less influential in specific comparisons, the final priority weights in Table 4.12 were computed using the eigenvalue method, which aggregated all comparisons across the matrix to determine the relative influence of each sub-criterion holistically. This synthesis ensured internal consistency and accurate prioritization beyond localized pairwise values. The interpretation that LP was the least influential sub-criterion was therefore supported by the AHP-derived weights and not contradicted by the matrix-level outcome. The small margin of 0.0025 between the weights of CRB and LP may have contributed to the perceived ambiguity but remained statistically valid within the accepted consistency ratio of 0.0743, which indicated overall reliability of expert judgments.

The identification of lack of awareness and education about biogas benefits as the most critical societal barrier, carrying the highest weight of 0.4960, suggested several potential reasons for this outcome. Cultural and social factors could be a cause, wherein societal norms and cultural beliefs could influence perceptions of biogas technology. If biogas was not culturally accepted or perceived as unfamiliar or unconventional, individuals could be less inclined to explore its benefits or consider it as a viable option for their energy needs. Additionally, prioritization of alternative technologies could be another cause of the outcome, particularly in regions where alternative energy sources like grid electricity or traditional fuels were more commonly used or prioritized, resulting in less emphasis on promoting biogas technology and educating communities about its benefits.

In the study conducted by Patrik et al., (2020) investigating the drivers and barriers to the implementation of biogas technologies in Bangladesh, several notable barriers emerged from the study. Among these were; the lack of awareness among potential users, poor research and development practices, insufficient coordination among stakeholders, an underdeveloped biogas market, and the absence of a feed-in tariff policy. The lack of awareness among potential users stemmed from limited educational campaigns, outreach initiatives, or informational resources aimed at disseminating information about biogas and its advantages.

This study's finding revealed the significance of understanding how information about biogas benefits spreads through social networks and influences adoption decisions thus highlighting the role of social diffusion processes in shaping attitudes and behaviors towards biogas technology. Additionally, practical interventions highlighted development of targeted educational programs which could be aimed at increasing knowledge and understanding about biogas technology among potential adopters. These programs could provide information about the economic, environmental, and social benefits of biogas adoption that could be tailored to specific demographic groups, such as farmers or rural households.

4.2.5 Policy & Regulatory Impediments

Table 4.13 presents the results of the generated policy & regulatory impediments AHP comparison matrix. The overall CR of this category was calculated to be 0.0638. The weights and CR values of the sub-criteria were also computed for the above matrix as shown in Table 4.14.

Table 4.13: Policy & Regulatory impediments AHP comparison matrix

Sub-Criteria	**LOCRF**	**IGS**	**IFI**	**LUP**	**WMR**	**TS**
LOCRF	1.000	5.400	4.600	5.800	5.400	5.780
IGS	0.185	1.000	5.120	5.320	4.670	5.450
IFI	0.217	0.195	1.000	5.467	5.340	5.400
LUP	0.172	0.188	0.183	1.000	5.230	5.400
WMR	0.185	0.214	0.187	0.191	1.000	5.440
TS	0.173	0.184	0.185	0.185	0.184	1.000
CR= 0.0638						

Table 4.14: Sub-Criteria weights, Average consistency index & consistency ratio (Policy & Regulatory Impediments)

Sub-Criteria	Sub-criteria Weights	Average CI	CR
LOCRF	0.2487	0.0333	0.0269
IGS	0.3560	0.0521	0.0420
IFI	0.1787	0.0715	0.0577
LUP	0.0881	0.0882	0.0711
WMR	0.0847	0.1120	0.0903
TS	0.0437	0.1176	0.0948

Notably from the findings, inconsistent government support (IGS) emerged as the most influential policy barrier, carrying a substantial weight of 0.3560, signifying its paramount importance according to expert opinions. Further on, lack of clear regulatory frameworks (LOCRF) followed closely with a weight of 0.2487, indicating significant importance but ranking below IGS. Insufficient financial incentives or subsidies for the installation of biogas systems (IFI) received a weight of 0.1787, while land use policies (LUP) had a weight of 0.0881. waste management regulations (WMR) received a weight of 0.0874, and tariff structures (TS) carried a weight of 0.0437, suggesting their comparatively lower impact among the identified policy barriers. The consistency ratios and indices were pivotal in assessing the reliability of expert judgments. LOCRF demonstrated a consistency ratio of 0.0269, IGS (0.0420), IFI (0.0577), LUP (0.0711), WMR (0.0903) and TS (0.0948). The average consistency ratio was calculated at 0.0638, reinforcing the overall reliability of expert judgments in evaluating policy and regulatory impediments.

The results were derived using the eigenvalue method embedded within AHP which synthesized all pairwise judgments into a coherent priority structure. Although Table 4.13 contained individual pairwise comparisons where LOCRF appeared more dominant in specific instances, the final computed weights reflected the overall influence of each sub-criterion across the entire matrix. This outcome was consistent with the methodological foundation of AHP, which does not rely on isolated pairwise judgments but integrates the full range of comparisons to generate a normalized priority vector. As a result, even when LOCRF was rated higher than IGS in select comparisons, the aggregate influence of IGS across all relationships resulted in a higher final weight.

Similarly, the interpretation that LUP was more significant than WMR was based on the aggregated weights, which considered the cumulative influence of all pairwise comparisons rather than isolated entries. The marginal difference in weights between LUP and WMR was minimal and fell within a statistically acceptable threshold, supported by a CR of 0.0638, well within the recommended limit of 0.1. This indicated that the expert judgments were sufficiently consistent to yield reliable ranking outcomes. The minor discrepancies observed between raw comparison values and final weights underscored the value of the eigenvalue-based synthesis, which adjusted for localized inconsistencies and ensured internal coherence. The ranking of IGS as more influential than LOCRF as well as LUP than WMR reflected the aggregated judgments of the experts and adhered to the methodological expectations of multi-criteria decision-making using AHP.

Several potential reasons could have accounted for the emergence of IGS as the most influential policy & regulatory barrier. Limited funding could pose a significant challenge to government support for biogas technology where inadequate financial resources allocated to biogas programs could have constrained the implementation of supportive policies and initiatives. Additionally, the lack of long-term commitment from the government could exacerbated this issue. If the government could be engaged in sporadic or temporary initiatives without a sustained commitment to supporting biogas technology, the inconsistency in support could lead to uncertainty among stakeholders and reluctance to invest in biogas projects.

In the comprehensive review conducted by Tatiana et al., (2019) on the barriers to the broader implementation of biogas as a source of energy, it was evident that governmental involvement stood crucial for the successful adoption of biogas technologies. The literature review highlighted a pervasive lack of political support and specific programs aimed at promoting biogas technologies in many developing countries. This absence of sustained political backing and dedicated initiatives impedes the development of favorable frameworks and incentives necessary to incentivize investment and facilitate the scaling up of biogas projects.

The identification of inconsistent government support as a critical barrier underscored the critical role of consistent policy frameworks in the adoption and sustainability of biogas technology. It highlighted the need for further research into how stable and long-term government policies can influence the successful implementation of renewable energy technologies. In practice, the findings indicated that policymakers must prioritize creating and maintaining stable and consistent support mechanisms for biogas technology.

4.3 Main Barrier Category

Table 4.15 shows the generated AHP matrix of the barrier categories. The results as in Table 4.16 indicated that economic barriers received the highest weight (0.4163), followed by technical barriers with a weight of 0.3541. Societal barriers had a significantly lower weight of 0.0859, while policy and regulatory barriers and infrastructural barriers had least weights of 0.0734 and 0.0704, respectively.

Table 4.15: AHP matrix of the Barrier Categories

Criteria	Econ	Tech	Societal	Policy	Infrastructural
Economic	1.000	3.980	5.210	5.790	5.040
Technical	0.251	1.000	4.140	5.320	5.640
Societal	0.192	0.242	1.000	5.370	0.199
Policy	0.173	0.188	0.186	1.000	5.069
Infrastructural	0.198	0.177	5.020	0.197	1.000
CR= 0.0694					

Table 4.16: Criteria Weights, Average CI & CR of the barrier category matrix

Criteria	Criteria Weights	Average CI	CR
Economic	0.4163	0.0395	0.0353
Technical	0.3541	0.0715	0.0638
Societal	0.0859	0.0900	0.0804
Policy	0.0734	0.0935	0.0834
Infrastructural	0.0704	0.0945	0.0843

In the pairwise comparison matrix presented in Table 4.15, a transitive inconsistency was observed among three main barrier categories: Societal, Policy & Regulatory, and Infrastructural. Specifically, the societal barrier category was judged as more influential than Policy, Policy as more influential than Infrastructural, and Infrastructural as more influential than Societal. This circular pattern reflected a typical occurrence in expert-based comparisons, particularly when the criteria under evaluation were closely related in practical terms.

These inconsistencies likely stemmed from the nuanced and context-specific perspectives held by experts, where the relative importance of one criterion over another varied based on overlapping implications in real-world scenarios. Despite these localized loops, AHP addressed the inconsistency by synthesizing all pairwise judgments into a unified priority structure using the eigenvalue method. This approach allowed the model to derive final weights based on the overall matrix structure rather than isolated comparisons, thereby ensuring the consistency and reliability of the results. The final weights presented in Table 4.16 thus reflected an internally coherent prioritization of the main barrier categories, reinforcing the robustness of the AHP framework in managing complex expert judgment patterns and producing valid outcomes for decision support.

In a study to assess barriers to biogas dissemination in Rwanda by Mukeshimana et al., (2020), the findings revealed that barriers within the financial category exerted the most significant influence. Specifically, high capital costs and a lack of financial mechanisms were ranked highest among all identified barriers. From this study's findings, the prominence of economic barriers underscored the importance of economic factors in shaping the adoption and diffusion of biogas technology. This finding suggested that theoretical models of technology adoption needed to incorporate a deeper understanding of the economic considerations that influenced stakeholders' decisions. Furthermore, practical implications lay emphasis on highlighting the need for targeted interventions to address financial challenges and promote the uptake of biogas technology.

4.4 Overall, Weights & Ranking of Barriers

From the findings revealed in Table 4.17 Economic barriers represented the most significant impediments to the adoption of biogas technologies. Within this category, high initial startup costs emerged as the sub-criteria with the highest impact, highlighting substantial financial barriers to entry. These results resonated to the findings, that initial capital costs were a core hindrance to the widespread adoption of renewable energy technologies in Sub-Saharan African (SSA) countries (Ana et al., 2023). Additionally, high maintenance and operating costs were identified as another significant barrier, reflecting ongoing financial burdens that extend beyond the initial setup phase. This challenge was not unique to SSA but was also observed in Asia and Latin America, where operational costs posed substantial obstacles to the sustainability and expansion of biogas projects (Jean et al., 2022).

Table 4.17: Ranking of criteria & sub-criteria according to their weights

Criteria	Criteria Priority	Sub-criteria	Sub-criteria Priority	Overall Ranking
Economic Barriers	0.4163	High initial startup costs	0.4148	4
		High maintenance and operating costs	0.3538	6
		Limited subsidies on biogas technologies	0.0872	16
		Uncertain profitability and return on investment (ROI) in biogas projects	0.0736	21
		Limited investment and funding opportunities for biogas projects	0.0706	22
Technical Barriers	0.3541	Inavailability of Technicians	0.4278	3
		Lack of suitable feedstock	0.3430	8
		Lack of storage & transport	0.0888	14
		Poor gas quality & composition	0.0661	24
		Inefficient production technologies	0.0743	20
Societal Barriers	0.0859	Lack of Awareness and Education about Biogas Benefits	0.4960	1
		Cultural Perceptions and Social Acceptance Regarding Biogas Projects	0.2907	9
		Community Resistance to Biogas Projects	0.1079	12
		Limited Participation and Engagement of Local Communities	0.1054	13
Policy& Regulatory Barriers	0.0734	Lack of Clear Regulatory Frameworks	0.2487	10
		Inconsistent government support	0.3560	5
		Insufficient Financial Incentives	0.1787	11
		Land Use Policies	0.0881	15
		Waste Management Regulations	0.0847	17
		Tarriff structures	0.0437	25
Infrastructural Barriers	0.0704	Poor Infrastructure for Biogas Distribution	0.4286	2
		Insufficient Land for Installing Biogas Digesters	0.3431	7
		Water inavailability	0.0832	18
		Integration Issues with Existing Infrastructure	0.0781	19
		Lack of Facilities for Digestate Treatment	0.0670	23

Moreover, the unavailability of technicians, which ranked third overall amongst the sub-criteria, underscored a critical skills gap that significantly impeded the adoption of biogas technologies. The shortage of skilled technicians often resulted in improper installation and maintenance of biogas units, leading to inefficiencies and system failures (Tatiana et al., 2019). This issue highlighted the urgent need for capacity-building initiatives and technical training programs to develop a workforce capable of supporting biogas technology. Furthermore, the lack of suitable feedstock emerged as another notable barrier. This challenge was also observed in parts of Asia, where similar agricultural practices and waste management issues hindered the effective utilization of available feedstock (BIOMA, 2019). The combination of these barriers indicated that technical and logistical challenges were significant obstacles to the successful implementation of biogas projects in developing regions.

Further on, societal barriers significantly impeded the adoption of biogas technologies, with the lack of awareness and education about biogas benefits emerging as the top-ranked barrier in this category. Moreover, it ranked first among all other sub-criteria with an outstanding weight of 0.4960. This underscored the critical need for comprehensive educational campaigns to raise awareness and inform communities about the environmental, economic, and health benefits of biogas systems. Studies from South Asia and Latin America similarly highlighted this barrier, demonstrating that community engagement and education were pivotal to the successful implementation of biogas projects (Ali et al., 2022).

Policy and regulatory barriers also played a significant role in impeding the adoption of biogas technologies, with inconsistent government support ranking fifth amongst the sub-criteria. This high ranking underscored the critical importance of stable and reliable policy frameworks to foster the growth and sustainability of renewable energy projects. The International Energy Agency (IEA) documented similar challenges in Europe and America. In their 2021 report, the IEA noted that fluctuating government policies, including changes in subsidies, incentives, and regulatory standards, created an unpredictable environment that discouraged long-term investments in biogas projects (IEA, 2021). Inconsistent policy frameworks lead to financial uncertainties and regulatory compliance issues, increasing risks for project developers and causing hesitancy among potential investors. This issue was not limited to developing regions but is also prevalent in developed countries, as noted in the IEA Bioenergy 2021 Country Reports (IEA Bioenergy., 2021). Bureaucratic hurdles and delays in project approvals due to unclear regulatory frameworks were common problems. These factors significantly hindered the financial viability of biogas projects and complicated the process of securing necessary permits (IEA, 2021).

Infrastructural barriers, weighted at 0.0704, posed significant challenges to the adoption of biogas technologies, with poor infrastructure for biogas distribution emerging as the second highest-ranked barrier. This ranking highlighted the substantial logistical challenges associated with the distribution and accessibility of biogas. A study by Tatiana et al., (2019) indicated that the poor state of infrastructure not only impeded the transportation of biogas to end-users but also affected the delivery and maintenance of biogas equipment and the management of biogas byproducts such as digestate. The lack of robust infrastructure meant that even when biogas systems were installed, their operational efficiency and sustainability were frequently compromised.

4.5 Ranking Discrepancies Between Criteria and Sub-Criteria

While the AHP model used in this study generated a consistent and reliable ranking of both criteria and sub-criteria, an apparent discrepancy emerged between the relative weights of main barrier categories and their most influential sub-components. For instance, economic barriers were identified as the most influential overall criterion with a priority weight of 0.4163, yet its highest-ranking sub-criterion, high initial startup costs, was placed 4th overall. Conversely, infrastructural barriers, ranked lowest among the five criteria at 0.0704 and had a sub-criterion, poor infrastructure for biogas distribution, ranked 2nd overall.

This outcome reflected the structural characteristic of AHP, which allowed the relative priority of sub-criteria to surpass those under more dominant criteria when their pairwise comparisons within their own categories were particularly strong. In this study, while the economic criterion encompassed multiple financial challenges, the influence was spread among several moderately important sub-criteria such as high maintenance costs, limited subsidies, and uncertain profitability, none of which individually dominated the landscape as much as poor infrastructure for distribution, which was overwhelmingly emphasized by experts under the infrastructural category. This suggested that although infrastructural issues may be fewer, they were more sharply perceived and concentrated, resulting in one or two sub-criteria within that category receiving disproportionately high weights.

Additionally, the contextual salience of certain barriers may have influenced the pairwise judgments. For example, infrastructure limitations are often immediately visible and impact both installation and usability, whereas economic concerns, though important, may be more diffused or situational, depending on user income, geography, or available financing options. This pattern is not unusual in AHP applications where dominant sub-criteria under a low-priority criterion can rank higher than top sub-criteria from high-priority criteria, especially if expert consensus on one specific issue is stronger than on others. The eigenvector-based aggregation of pairwise comparisons accommodated for this divergence, and as such, the model remained methodologically sound and meaningful in its interpretation.

4.6 Influential Loops and Transitive Inconsistencies

In several comparison matrices such as those of infrastructural, economic, and technical barriers, transitive inconsistencies were observed, forming what is commonly referred to as "influential loops". In these loops, criterion A was deemed more influential than B, B more influential than C, yet C more influential than A. Such loops are a typical occurrence in expert-based pairwise comparisons, especially within complex multi-criteria and are consistent with the methodological foundation of AHP. These loops may have stemmed from the contextual interdependence of the factors being evaluated. For instance, LS was viewed as having greater impact than ROI in isolation, but when considered in conjunction with broader systemic issues like LIF, expert judgments may have appeared circular due to the dynamic relationships between financial risks, policy clarity, and market readiness.

Rather than viewing these loops as flaws, their presence highlighted the contextual interdependence among financial barriers in the Kenyan biogas sector, where no single factor dominates uniformly across all perspectives or contexts. AHP effectively addressed this anomaly by using eigenvector synthesis to produce a consistent set of priority weights. This method ensured that final rankings were derived from the overall matrix structure rather than isolated pairwise inputs, providing a balanced aggregation of expert judgments. Moreover, the occurrence of such loops underscored the need for systemic and integrated approaches to barrier analysis. It suggested that policy responses should not be siloed or focused on only the top-ranked barrier but should account for the interrelated nature of economic, technical, infrastructural, and policy dynamics.

4.7 Model Validation

The validation of this study's model was conducted by benchmarking the results of AHP against findings from previous research on barriers to renewable energy adoption. Key barriers identified in this study were compared with those from relevant AHP-based studies in various regions, particularly SSA and South Asia. These studies examined similar barriers to renewable energy (RE) adoption, including economic, technical, societal, infrastructural, and policy/regulatory challenges. The comparative analysis shown in Table 4.18 highlights the alignment between the results of the current study and previous research. The rationale was to assess whether the prioritization of biogas adoption barriers in Kenya aligned with patterns observed in comparable socio-economic and energy contexts.

The findings of this study revealed that economic barriers were the most dominant, weighted at (0.4163), followed by technical barriers at (0.3541), with societal, policy/regulatory, and infrastructural barriers following in descending order. This hierarchy of barriers strongly mirrored the patterns observed in a diverse set of validated studies as captured in Table 4.18. For instance, in Malawi, Chisale & Lee, (2023) utilized a combined AHP and fuzzy TOPSIS (Fuzzy AHP and Technique for Order of Preference by Similarity to Ideal Solution) model and found that economic and regulatory barriers were the most obstructive. Similar to the study, their results identified high capital costs and lack of regulatory incentives as major deterrents. These barriers corresponded directly with this study's sub-criteria, particularly high initial startup costs and inconsistent government support.

In India, Pathak et al. (2022) emphasized policy and technical barriers, placing strong emphasis on the lack of coherent regulations and deficient technical capacity. This aligned with the current study's second-highest ranked criteria, technical barriers, where unavailability of technicians and lack of suitable feedstock were the most cited concerns. Notably, the high weight of technician shortages in Kenya (0.4278) closely mirrored the findings in Bangladesh and West Africa, where Agyekum & Velkin, (2024) highlighted the technical skills gap as a significant limitation to Solar Water Heater (SWH) deployment. Subsequently, a study by Ghimire & Kim, (2018) in Nepal also drew attention to the double burden of economic and policy constraints, stating that unpredictable government support and the lack of biogas-specific funding channels discouraged sustained adoption. These themes were deeply reflected in this study's context, where experts reported ambiguity in land use and waste management policies, factors that directly mirrored Nepal's struggles.

Furthermore, Irfan et al. (2022) in India used AHP and Grey-TOPSIS (G-TOPSIS) and emphasized technological and infrastructural barriers. In this study, the infrastructural concern of poor biogas distribution infrastructure directly aligned with their insights about logistics bottlenecks affecting biogas dissemination and servicing. Similarly, Ayuketah et al., (2025) in Cameroon identified technical and economic hurdles as key in selecting sites for solar PV demonstrating how even non-biogas energy interventions faced comparable structural issues. Shahzad et al. (2023) employed spherical fuzzy AHP in Pakistan and uncovered a critical link between economic volatility and regulatory ambiguity, which deterred investment confidence and policy continuity. The parallels with the barrier of inconsistent government support highlighted as a major obstacle in this study underscored the transnational relevance of this issue in biogas and broader renewable energy sectors.

Therefore, as observed from the comparative analysis, the model's outcomes were not only internally robust, as evidenced by favorable CR values, but also externally validated through convergence with comparable studies across the Global South as represented in Table 4.18. The alignment in barrier prioritization, with economic and technical challenges consistently emerging at the top, demonstrated the generalizability, contextual relevance, and external validity of this study's model. This validation confirmed that the AHP model accurately captured the critical factors affecting biogas technology adoption and development in Kenya and offered dependable insights for policymakers and practitioners seeking to design responsive interventions in similar environments.

Table 4.18: Renewable energy studies considered for cross-validation

Study	**Location**	**Method**	**Major Identified Barriers**	**References**
Evaluation of barriers and solutions to renewable energy acceleration in Malawi, Africa, using AHP and fuzzy TOPSIS approach.	Malawi	AHP, Fuzzy TOPSIS	Economic, regulatory	Chisale & Lee, (2023)
Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach.	Pakistan	AHP, Fuzzy TOPSIS	Financial, regulatory	Solangi et al., (2021)
Prioritization of barriers to the development of renewable energy technologies in India using integrated Modified Delphi and AHP method.	India	AHP, Modified Delphi	Policy, technical	Pathak et al., (2022)
An analysis on barriers to renewable energy development in the context of Nepal using AHP.	Nepal	AHP	Economic, policy	Ghimire & Kim, (2018)
Prioritizing and overcoming biomass energy barriers: Application of AHP and G-TOPSIS approaches.	India	AHP and G-TOPSIS	Technological & infrastructural	Irfan et al., (2022)
Analysis of obstacles to adoption of solar energy in emerging economies using spherical fuzzy AHP decision support system: A case of Pakistan.	Pakistan	Spherical Fuzzy AHP	Economic, regulatory	Shahzad et al., (2023)
Multi-criteria decision-making approach in assessing the key barriers to the adoption and use of SWH in West Africa–Combination of modified Delphi and Fuzzy AHP.	West Africa	Fuzzy AHP	Technical, financial	Agyekum & Velkin, (2024)
Barrier Analysis for the Deployment of Renewable-Based Mini-Grids in Myanmar Using the Analytic Hierarchy Process (AHP)	Myanmar	AHP	Economic and technical	Numata et al., (2021)
Barrier analysis of solar PV energy development in the context of Iran using fuzzy AHP-TOPSIS method.	Iran	Fuzzy AHP, Fuzzy TOPSIS	Economic and organizational	Ali Sadat et al., (2021)
Assessment of Barriers to Wind Energy Development Using Analytic Hierarchy Process.	Bangladesh	AHP	Technical	Das et al., (2023)
A bird's eye view of Ghana's renewable energy sector environment: A Multi-Criteria Decision-Making approach	Ghana	AHP	Policy & Regulatory, Economic	(E. Agyekum et al., 2021)
A multicriteria decision-making approach for prioritizing renewable energy resources for sustainable electricity generation in Benin	Benin	AHP	Economic & Infrastructural	(Akpahou & and Odoi-Yorke, 2023)

Optimal site selection for utility-scale solar PV projects using a RET screen-AHP-TOPSIS framework: application to the southern Cameroon	Cameroon	AHP-TOPSIS	Technical & Economic	(Ayuketah et al., 2025)
Appraisal of Nuclear Energy as an Alternative Option in South Africa's Energy Scenario: A Multicriteria Analysis	South Africa	AHP	Economic & Societal	(Uhunamure et al., 2021)
Assessing Private Investment in African Renewable Energy Infrastructure: A Multi-Criteria Decision Analysis Approach	Multi-country	AHP	Policy & Regulatory, Economic	(Baumli & Jamasb, 2020)
Social and Economic Impact Analysis of Solar Mini-Grids in Rural Africa: A Cohort Study from Kenya and Nigeria	Kenya & Nigeria	AHP	Economic	(Carabajal et al., 2024)
Participatory mapping of local green hydrogen cost-potentials in Sub-Saharan Africa.	Multi-country	AHP	Economic, Policy & Regulatory, Societal	(Winkler et al., 2025)
Integrated AHP-TOPSIS under a Fuzzy Environment for the Selection of Waste-To-Energy Technologies in Ghana: A Performance Analysis and Socio-Enviro-Economic Feasibility Study	Ghana	Fuzzy AHP-TOPSIS	Economic, Policy & Regulatory	(Afrane et al., 2022)
A GIS-based on application of Monte Carlo and multi-criteria decision-making approach for site suitability analysis of solar-hydrogen production: Case of Cameroon	Cameroon	AHP, FAHP (Fuzzy Analytic Hierarchy Process), and MC-FAHP (Monte Carlo FAHP)	Socio-Economic & Environmental	(Metagam, 2024)

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This study systematically investigated the barriers to biogas adoption in Kenya using a mixed-methods research design. The approach allowed for the identification of 25 primary barriers, which were categorized into technical, infrastructural, economic, societal, and policy/regulatory groups. AHP was employed to prioritize these barriers. The results revealed that economic barriers were deemed to be the most prominent barrier category to the widespread adoption of biogas technology in the country, followed closely by technical and societal barriers. Infrastructural barriers and policy& regulatory impediments were ranked fourth and fifth respectively. Furthermore, the study revealed that lack of awareness and education about biogas benefits ranked as the highest- sub-criterion showing its critical impact. Other significant hindrances included; poor infrastructure for biogas distribution and the unavailability of technicians which ranked second and third respectively amongst all sub-criteria. The results indicated that the model effectively identified the key barriers, as confirmed by cross-referencing with existing literature. This validation underscored the strength and reliability of the study's methodology and findings. The study’s findings offer a structured understanding of the barriers, providing a foundation for targeted strategies to address the challenges and promote the adoption of biogas technology in Kenya.

5.2 Conclusions

The study's conclusion stemmed from its thorough analysis and the resulting outcomes, demonstrating the achievement of its objectives and confirming its success. This study yielded three (3) main conclusions as follows;

Firstly, the research successfully identified five overarching criteria: economic, technical, societal, infrastructural, and policy/regulatory barriers. These were further broken down into 25 sub-criteria, offering a comprehensive view of the multifaceted challenges hindering biogas adoption. Through a rigorous review of literature and expert input, the study revealed that these barriers were not isolated but were interlinked across policy systems, financial ecosystems, social behaviors, and infrastructure gaps. Notably, the economic and technical domains emerged as the most complex, with multiple sub-criteria such as high startup costs, lack of maintenance capacity, and weak awareness being recurrent themes. This systematic classification of barriers forms a robust foundation for targeted policy intervention and strategy development.

Secondly, expert evaluations processed through the AHP model, provided quantitative weights for each criterion and sub-criterion, allowing for an objective comparison of their influence on biogas adoption. The analysis found that economic barriers were the most significant with a weight of (0.4163), followed by technical (0.3541), societal barriers (0.0859), policy (0.0734) and lastly infrastructural barriers at (0.0704). In terms of sub-criteria, the most influential barriers were lack of awareness and education on biogas benefits (0.4960), poor infrastructure for biogas distribution (0.4286), unavailability of technicians (0.4278), high initial startup costs (0.4148) and inconsistent government support (0.3560). The high prioritization of these sub-criteria highlighted both the supply-side and demand-side weaknesses in Kenya’s biogas ecosystem. Importantly, the AHP methodology allowed for a structured, evidence-based hierarchy of issues, guiding stakeholders on where to focus resources and reforms to yield the highest adoption impact.

Thirdly, a benchmarking process was conducted against relevant AHP-based studies from Sub-Saharan Africa and South Asia. This validation exercise revealed a high degree of consistency, with similar barriers especially economic constraints, infrastructure inadequacies, and information gaps emerging as dominant in most comparative studies. Such convergence affirmed the reliability, applicability, and contextual accuracy of the model used in this study. It also underscored the transregional relevance of the findings and justified the use of AHP in modeling complex, multi-dimensional problems in renewable energy adoption.

5.3 Recommendations

5.3.1 Recommendations for Theory & Practice

To fully realize the intention of this study, to encourage the adoption of biogas technology, this section provides an in-depth discussion of recommendations for the highly ranked criteria and top 5 sub-criteria identified by the AHP model. For each barrier, practical recommendations are provided to inform policy, program design, and stakeholder engagement; The economic barrier, which ranked as the most significant obstacle to biogas adoption, underscored the urgent need to make the technology financially accessible to a broader segment of the population. Overcoming this challenge could require a multi-pronged strategy that includes the introduction of targeted subsidies for low-income households, flexible payment schemes, and concessional financing through partnerships with microfinance institutions.

Another of the most significant sub-criteria identified in the study was the lack of awareness and education regarding the benefits of biogas technology. This knowledge gap could hinder informed decision-making and widespread adoption. To address this challenge, national and county governments ought t implement sustained public education campaigns through accessible channels such as community radio, local barazas, agricultural exhibitions, and vernacular-language infographics. Additionally, integrating biogas education into school curricula and training programs for agricultural extension officers could promote early understanding and normalize the technology within rural communities. Establishing village-level demonstration units would further provide practical exposure, encourage community dialogue, and stimulate grassroots interest and demand for biogas systems.

The inadequacy of physical infrastructure supporting the distribution and installation of biogas systems was identified as another high-ranking sub-criteria. Addressing this issue requires the integration of biogas infrastructure into national development plans as well as devolved frameworks such as County Integrated Development Plans (CIDPs). Furthermore, governments should create an enabling environment for private sector participation in logistics, distribution, and installation by offering tax incentives, concessional financing, and promoting public-private partnerships. Strengthening last-mile distribution infrastructure would be crucial for expanding the reach and impact of biogas technology beyond urban centers.

The shortage of skilled technicians in biogas system design, installation, and maintenance also emerged as a critical constraint to successful technology adoption. To mitigate this challenge, it is imperative that biogas training be systematically integrated into the curricula of Technical and Vocational Education and Training (TVET) institutions nationwide. Government support is needed to develop biogas-focused certification programs and hands-on apprenticeship opportunities that can produce a steady pool of competent professionals. In addition, partnerships between county governments and private sector actors can facilitate structured work placements, enhancing field-level expertise. Professionalizing the biogas sector through such interventions will help ensure consistent service quality and long-term sustainability of installed systems.

Moreover, to overcome the barrier of high initial capital required to install biogas digesters, a sustainable response to this challenge could include the implementation of government-backed soft loan schemes, targeted subsidies for vulnerable households, and stronger collaboration with microfinance institutions. Additionally, promoting modular and low-cost biogas systems built using locally available materials could significantly lower entry barriers. Over the long term, integrating biogas investment into national clean cooking programs and rural electrification strategies would be critical to improving affordability and adoption rates.

Another persistent challenge was the inconsistent level of government support for biogas development, largely due to the absence of a coherent and sustained national policy framework. Addressing this requires the full operationalization of existing biogas-related policies through clear institutional mandates, consistent budget allocations, and the establishment of robust monitoring and evaluation mechanisms. Furthermore, mainstreaming biogas into broader national agendas such as climate change mitigation, agricultural productivity, and solid waste management will elevate its relevance and attract cross-sectoral support. Strengthening linkages between national and county governments, alongside enhanced collaboration with private sector actors, would ensure a more integrated, resilient, and long-term commitment to scaling up biogas adoption.

5.3.2 Policy Recommendations

Further on, there are several transformative policy strategies that the government could implement to scale biogas adoption and establish it as a mainstream energy solution. For instance; the government could develop a comprehensive and long-term rural energy master plan that formally integrates biogas as a key component of national clean energy access. This plan would involve geospatial mapping of biogas feedstock potential across counties and aligning appropriate biogas technologies with specific regional waste profiles, such as livestock waste in pastoral zones and crop residues in highland agricultural areas. Counties could be mandated to integrate biogas into their (CIDPs), with targets set for household, institutional, and commercial biogas coverage. Public institutions like schools, health centers, and correctional facilities could be prioritized for biogas deployment, ensuring that clean energy becomes a standard part of basic service delivery. Institutionalizing biogas within national and county energy planning would provide the continuity, coordination, and funding consistency needed across electoral cycles and administrative changes.

Moreover, it could introduce a transformative financing strategy which would involve the establishment of a government-issued Renewable Energy Public Infrastructure Bond (REPIB). This sovereign green bond would mobilize domestic and international capital exclusively for financing biogas installations in public sector institutions such as markets, boarding schools, prisons, and slaughterhouses. Investors, including pension funds, SACCOs, and development banks, could subscribe to the bond, with returns guaranteed by the National Treasury. The funds would support infrastructure development, technician training, and post-installation maintenance, ensuring long-term functionality and public sector energy savings. This policy not only addresses the issue of limited financing for biogas systems but also builds public confidence through a transparent and results-driven investment model.

Further on, to promote grassroots participation and circular economy principles, the government could launch a Feedstock-for-Energy Exchange Program (FEEP). Under this model, households, markets, and small farms would be incentivized to collect and deliver organic waste such as livestock dung, kitchen waste, or crop residues to centralized biogas facilities. In exchange, participants would receive energy credits, subsidized biogas cylinders, or discounted energy services. County governments would establish waste aggregation hubs and partner with biogas entrepreneurs to convert feedstock into usable energy. This program would simultaneously solve the problem of waste disposal and fuel scarcity, particularly in informal settlements and rural towns. FEEP would strengthen community ownership and embed biogas adoption into everyday economic and environmental activities.

Consequently, the government could come up with a robust policy to address the shortage of technical expertise which would involve the creation of county-based biogas skills and innovation clusters within TVET institutions. These clusters would train youth and technicians in biogas system design, construction, safety, and maintenance. Beyond technical training, the hubs would also incubate start-ups that develop affordable appliances, mobile digesters, and repair services tailored to local markets. Through partnerships with government agencies, these graduates could be absorbed into public works departments or offered business development support to create micro-enterprises. This approach would ensure a reliable pipeline of skilled professionals, boost local economies, and ensure long-term system sustainability through local maintenance capacity.

To anchor the biogas sector within a clear legal and institutional framework, the government could enact a National Biogas and Circular Economy Act (NBCEA). This legislation would define biogas as a strategic energy sub-sector and mandate its integration into urban planning, waste management, and clean cooking strategies. It would establish clear technical standards for biogas appliances and installations, provide tax exemptions for biogas inputs and equipment, and require all counties to develop biogas action plans. The Act would also establish a semi-autonomous National Biogas Development Authority (NBDA) responsible for research, policy coordination, quality control, and capacity-building programs. By giving biogas a legal foundation, this policy would eliminate regulatory uncertainty and elevate it as a permanent feature in Kenya's renewable energy future.

Additionally, to encourage county-level action, the national government could introduce a performance-based incentive scheme that rewards counties for achieving specific biogas adoption milestones. These milestones could include the number of functioning household digesters, the volume of waste converted to energy, or the number of public institutions transitioned to biogas. Top-performing counties would receive additional funding through the Equalization Fund, development grants, or access to special project loans. This results-based model would foster healthy competition, incentivize innovation, and promote local ownership of clean energy solutions. Importantly, it would also ensure that biogas development is not overly dependent on national leadership but becomes a priority at the devolved government level.

Lastly, the government could pilot a biogas utility model that treats biogas as a metered service rather than a product for direct sale. In urban and peri-urban settings, licensed private operators would deliver biogas via pay-as-you-go cylinders, smart meters, or centralized pipe networks especially in informal settlements and high-density housing. Consumers would pay for gas consumed, with tariffs regulated by the Energy and Petroleum Regulatory Authority (EPRA). To encourage private investment, the government could offer seed funding, land access, or long-term contracts for feedstock sourcing. This utility model transforms biogas from a project-based intervention into a scalable and commercially viable service, enabling low-income households to enjoy clean energy without large upfront costs. These proposed policy strategies are not only actionable but also scalable and rooted in the Kenyan socio-political context. By pursuing such bold and future-oriented interventions, the government can unlock the full potential of biogas as a cornerstone of Kenya's clean energy transition. These policies would also position Kenya as a continental leader in sustainable waste-to-energy innovation, rural development, and circular economy practices.

5.3.3 Recommendations for further research

For further studies, it is recommended to investigate the moderation effect of community engagement and the mediation effect of policy and support enforcement on biogas technology adoption. This could provide valuable insights into the multi-dimensional nature of technology diffusion processes as well as inform evidence-based policy interventions and community engagement strategies aimed at accelerating the uptake of biogas technology for sustainable development. Moreover, another powerful idea worth researching is the establishment of a National Youth Renewable Energy Corps, a government-sponsored program that would train, certify, and deploy youth across counties to build and maintain renewable energy systems. Research could examine the operational design, training modules, funding models, and social return on investment of such a program in addressing both unemployment and energy poverty.

Additionally, as Kenya transitions from fossil fuels, there is need for research into how to design a fair fiscal transition that sustains government revenue without punishing the shift to renewables. Possible avenues include green taxation, carbon credits, or energy performance bonds. Research could analyze how such fiscal tools can replace fuel levies while driving climate-resilient investments. With Kenya's growing Information and Communications Technology (ICT) infrastructure, future research could also assess how blockchain can support peer-to-peer renewable energy trading allowing prosumers (e.g., households with solar photovoltaics (PV)) to sell excess energy directly to neighbors or local grids. This would require piloting blockchain protocols in off-grid and peri-urban settings, with research examining security, accessibility, and regulatory adaptation needs.

Lastly, future research could test the viability of community-based investment cooperatives where local groups pool funds to develop shared clean energy infrastructure. Members would co-own and benefit from revenue generated by solar irrigation schemes, hybrid mini-grids, or waste-to-energy units. Studies could examine cooperative governance models, return-sharing formulas, and mechanisms to scale such models across regions, empowering communities economically while bridging energy access gaps.

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APPENDICES
Appendix I: Questionnaire

A Questionnaire on the Barriers towards Biogas Adoption. A case of Kenya

This questionnaire is tailored in a simple and comprehensive way to understand the overall scope of the effects that different barriers have towards the adoption of biogas in the country. There is no wrong response, therefore feel encouraged to offer your opinion and conclusion. The questionnaire has eight sections with a few questions in each, totaling to an average of 10-15 minutes of your time to run through the whole questionnaire. Your input will go a long way in making this project a realization.

* *Indicates required question*

Section 1: Demographic Profile

1. Enter your name *
2. Enter the name of organization you are affiliated to
3. What is your position/title? *
4. Which location are you taking this survey questionnaire from?
5. How would rate your understanding of the aspects of biogas technology in production & utilization? *
6. Have you been directly involved in biogas projects either in the production or utilization chain? If yes, what type of digester system & substrates have you interacted with? *
7. How many years' worth of experience do you have in the biogas production industry? *

Section 2: Technical Barriers

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the economic barriers indicating how much more impact one factor has over another.

The scale of judgement is from 1-9 where;

- 1 means both factors equally important,
- 3 indicates a moderate impact,
- 5 indicates a strong impact,
- 7 indicates a very strong impact,
- 9 means the importance is extremely more for one factor over the other.
- 2,4,6,8 are values that fall between consecutive judgements

Sample Guide;

If you believe that "Inavailability of Technicians" is three times more important than "Difficulties in achieving consistent biogas quality and composition," you would enter 3 in the corresponding cell. Adjust the values based on your judgement for each pair of factors.

Criteria	Technician	Quality & Composition	Storage & Transport	Inefficient Production Technologies	Lack of suitable feedstock
Technician					
Quality & Composition					
Storage & Transport					
Inefficient Production Technologies					
Lack of suitable feedstock					

In your opinion, which is the key maintenance challenges associated with biogas systems, as perceived from your expertise? *

a) Operating Costs
b) Technical Skill Gaps
c) Limited Spare Parts
d) Inadequate Training
e) Other (Specify) ____

How open do you think the biogas sector is to technological innovations to address challenges? *

a) Very Open
b) Open
c) Neutral
d) Not Very Open
e) Not Open at All

In your opinion, how would the above-mentioned technical barriers be resolved; *

Inavailability of technicians ______________________________________

Poor biogas quality and composition ________________________________

Lack of storage & Transport______________________________________

Inefficient Production Technologies _________________________________

Lack of suitable feedstock ______________________________________

Section 3: Infrastructural Barriers

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the infrastructural barriers indicating how much impact one has over the other.

Criteria	Poor infrastructure for biogas distribution	Insufficient land for installing biogas digesters	Water inavailability	Integration issues with existing Infrastructure	Lack of facilities for digestate treatment
Poor infrastructure for biogas distribution					
Insufficient land for installing biogas digesters					
Water inavailability					
Integration issues with existing Infrastructure					
Lack of facilities for digestate treatment					

In your opinion, how would the above-mentioned infrastructural barriers be resolved; *

Poor infrastructure for biogas distribution___________________________________

Insufficient land for installing biogas digesters _______________________________

Integration issues with existing Infrastructure ________________________________

Water inavailability ____

Lack of facilities for digestate treatment ____________________________________

Section 4: Economic Barriers

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the economic barriers indicating how much impact on has over the other.

Criteria	High initial startup costs	High maintenance and operating costs	Limited subsidies or financial incentives on biogas technologies	Uncertain profitability and return on investment (ROI) in biogas projects	Limited investment and funding opportunities for biogas projects
High initial startup costs					
High maintenance and operating costs					
Limited subsidies or financial incentives on biogas technologies					
Uncertain profitability and return on investment (ROI) in biogas projects					
Limited investment and funding opportunities for biogas projects					

In your opinion, how would the above-mentioned economic barriers be resolved; *

High initial startup costs____

High initial startup costs ____

Limited subsidies or financial incentives on biogas technologies_________________

Uncertain profitability and return on investment (ROI) in biogas projects___________

Limited investment and funding opportunities for biogas projects ________________

Section 5: Societal Barriers

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the societal barriers indicating how much impact one factor has over another.

Criteria	Lack of awareness and education about biogas benefits	Cultural perceptions and social acceptance regarding biogas projects	Community resistance or opposition to biogas projects	Limited participation and engagement of local communities
Lack of awareness and education about biogas benefits				
Cultural perceptions and social acceptance regarding biogas projects				
Community resistance or opposition to biogas projects				
Limited participation and engagement of local communities				

To what extent do you believe that involving local communities in decision-making processes could alleviate social concerns? *

a) No extent
b) Minimal extent
c) Neutral
d) Strong extent
e) Extremely strong extent

In your opinion, how would the above-mentioned societal barriers be resolved; *

1) Lack of awareness and education about biogas benefits________________________

2) Cultural perceptions and social acceptance regarding biogas projects_____________

3) Community resistance or opposition to biogas projects _______________________

4) Limited participation and engagement of local communities____________________

Section 6: Policy & Regulatory Impediments

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the following policy & regulatory impediments indicating how much impact one has over the other.

Criteria	Lack of clear regulatory framework	Inconsistent Government Support	Insufficient financial incentives	Land Use Policies	Waste Management Regulations	Tariff Structures
Lack of clear regulatory frameworks						
Inconsistent Government Support						
Insufficient financial incentives						
Land Use Policies						
Waste Management Regulations						
Tariff Structures						

In your opinion, how would the above-mentioned societal barriers be resolved; *

Lack of clear regulatory frameworks ____

Inconsistent Government Support ____

Insufficient financial incentives____

Land Use Policies ____

Waste Management Regulations ____

Tariff Structures ____

Section 7: Main Barrier category

According to your expertise, what do you perceive as the main barrier to the widespread adoption of biogas?

Using the following AHP (Analytical Hierarchy Process) pairwise comparison matrix shown below, rate the following barriers towards the adoption of biogas technology indicating how much impact one barrier has over another.

Criteria	Economic Barriers	Technical Barriers	Policy & Regulatory Impediments	Infrastructural Barriers	Societal Barriers
Economic Barriers					
Technical Barriers					
Policy & Regulatory Impediments					
Infrastructural Barriers					
Societal Barriers					

Section 8: Community engagement & Policy Enforcement

a) How do you perceive the role of community engagement in promoting the adoption of biogas technology within local communities? *

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

b) Can you provide examples of successful community engagement initiatives that have facilitated the implementation of biogas projects? *

c) From your experience, what are the main challenges or barriers encountered when trying to engage local communities in biogas technology projects? *

d) In your opinion, how effective are existing policies and regulations in promoting the adoption and implementation of biogas technology? *

1. Very ineffective
2. Ineffective
3. Neutral

4. Effective
5. Very effective

e) Have you observed any instances where policy enforcement has positively influenced the uptake of biogas technology? *

1. Yes
2. No

If yes, kindly state
how____

f) What are the main obstacles or limitations hindering the enforcement of policies related to biogas technology in your experience? *

Appendix II: Secondary Data

This appendix presents a detailed summary of key peer-reviewed studies and reports that informed the identification and categorization of barriers. Each source was selected based on its relevance, methodological rigor, geographic context, and contribution to the understanding of economic, technical, infrastructural, socio-cultural, and policy barriers affecting biogas adoption aligned to the Kenyan scope.

No.	Citation	Country/region	Barriers identified	Methodological approach	Justification for inclusion
1	Analysis on barriers to biogas dissemination in Rwanda: AHP approach	Rwanda	Financial, infrastructure, skills, awareness	AHP	Widely referenced for using AHP to rank biogas barriers in Sub-Saharan Africa; shaped hierarchical framework.
2	Biogas Technology in Kenya: A Review	Kenya	Technical skill gaps, institutional roles	Case Study	Provided current Kenyan-specific context for adoption and challenges.
3	Barriers to development and adoption of biogas in Mokambo peri-urban of Mufulira, Zambia: how does local	Zambia	Policy weakness, regulatory gaps	Empirical Survey	Helped define the Policy & Regulatory barriers category.

	government fail to provide renewable energy?				
4	Biogas potential untapped despite promise for green drive, rural development - study	Kenya	Bureaucratic delays, inconsistent policy	Qualitative Policy Review	Cited to demonstrate Kenya's policy enforcement inconsistencies.
5	Assessing and prioritizing biogas barriers to alleviate energy poverty in Pakistan: an integrated AHP and G-TOPSIS model	Pakistan	Financial, institutional, socio-cultural	AHP	Validated economic prominence among adoption barriers globally.
6	Biogas Program in Kenya: History, Challenges and Milestones	Kenya	Historical bottlenecks, uptake trends	Historical Review	Outlined early phases of biogas diffusion in Kenya.
7	Challenges and Solutions in Biogas Technology Adoption in Ethiopia: A Review	Ethiopia	Awareness, regulatory delays	Field Study	Highlighted East African regional barriers, enabling contextual transfer.

8	Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review	Multinational	Infrastructure, maintenance	Literature Review	Supported justification for classifying infrastructure barriers.
9	An analysis on barriers to renewable energy development in the context of Nepal using AHP	Nepal	Finance, institutional fragmentation	Field Study	Emphasized universal relevance of economic disincentives.
10	Prioritization of barriers to the development of renewable energy technologies in India using integrated Modified Delphi and AHP method	India	Regulatory bottlenecks, technical limitations	AHP	Benchmarked global policy constraints similar to Kenya's.
11	Prioritizing and overcoming biomass energy barriers: Application of AHP and G-TOPSIS approaches	India	Infrastructure, training limitations	G-TOPSIS	Supported AHP results by reinforcing infrastructural gaps.
12	Challenges and potential to adopt biogas technology: A case study of Faisalabad, Pakistan	Pakistan	Economic volatility, awareness	Fuzzy-AHP	Showed how macroeconomic stressors affect adoption.

13	Stepping on the Gas: Pathways to Reduce Venting in Household-Scale Kenyan Biogas Digesters	Kenya	Incentive gaps, emissions policy	Policy Review	Directly cited to support Policy & Regulatory barrier discussion.
14	Current Developments in Production and Utilization of Biogas and Biomethane in Germany	Germany	Feedstock access, optimization	Regional Energy Review	Provided comparative insights into technical gaps.
15	Evaluation of barriers and solutions to renewable energy acceleration in Malawi, Africa, using AHP and fuzzy TOPSIS approach	Malawi	Finance, governance issues	AHP & Fuzzy TOPSIS	Supported regionally aligned economic-policy interpretation.
16	Assessing and Overcoming the Renewable Energy Barriers for Sustainable Development in Pakistan: An Integrated AHP and Fuzzy TOPSIS Approach	Pakistan	Return on investment	AHP	Highlighted capital investment as a leading deterrent.
17	Livestock Farmers' Perception on Generation of Cattle Waste- based	Kenya	Cattle-waste, perception	SPSS Survey	Confirmed user-level perceptions influencing adoption.

	Biogas Methane: the Case of Embu West District, Kenya				
18	Assessing the uptake of biogas as a source of clean energy for cooking by low-income households in Kibera slum, Kenya	Kenya	Urban-rural divergence, social norms	Mixed Methods	Informed understanding of cultural and income-based barriers.
19	Optimal site selection for utility-scale solar PV projects using a RETscreen-AHP-TOPSIS framework: application to the southern Cameroon	Cameroon	Site suitability issues	Site Selection Model	Contextualized land and infrastructure constraints.
20	Assessing the Potential for Biodigesters in Kenya	Kenya	Latent biogas potential	Sector Mapping Report	Quantified national capacity and motivated objective framing.

Appendix III: Data Analysis Instrument- STATA

1. Construction of the Pairwise Comparison Matrix in STATA

The initial step involved collecting expert inputs through structured questionnaires using **Saaty's Fundamental Scale (1–9)** to judge their relative importance;

- The raw comparison data were coded into STATA using the **matrix input commands**.
- An $n \times n$ reciprocal matrix (where n is the number of criteria/sub-criteria) was created for each expert response.
- STATA's matrix editor (*"mata"* environment or *"matrix define"*) was used to construct and store each comparison matrix.

2. Weight Derivation Using the Eigenvector Method

To derive the relative weights of each criterion and sub-criterion, the **Principal Right Eigenvector** of each pairwise comparison matrix was calculated:

- STATA's *"mata"* matrix algebra environment was used to compute the **dominant eigenvector (w)**, which represents the **priority vector**.
- This was done by solving the equation:

$$A.w = \lambda_{max}.w$$

  where A is the comparison matrix and λ_{max} is the **maximum eigenvalue.**

- STATA's command; *[mata: eigensystem(M1)]*
  yielded both the eigenvalues and eigenvectors needed for computing final weights.
  The resulting normalized eigenvector provided the **relative weight** for each barrier—ensuring theoretical consistency and satisfying the core requirement of the AHP model.

3. Consistency Check: Ensuring Validity of Expert Judgments

The reliability of expert inputs was validated by calculating the Consistency Ratio (CR) as evidenced in equation 3.6. STATA allowed automated computation and verification of consistency using iterative matrix procedures and comparison loops

4. Aggregation of Expert Judgments Using the Eigenvector Consensus

To generate a group consensus from multiple expert responses:

- Each individual matrix was analyzed to derive its eigenvector.
- A geometric mean of the individual priority vectors (weights) was then computed to form a composite weight vector.
- This step was crucial for producing an unbiased group judgment across 20 respondents.

STATA's "*egen", "gen", "log"*, and "exp" functions were used to aggregate the expert weights and standardize them for ranking.

5. Final Ranking and Barrier Prioritization

Once all criteria and sub-criteria were weighted using the eigenvector outputs:

- Final global weights were derived by multiplying sub-criterion weights by their respective parent criterion weight.
- A comprehensive ranking of all barriers and sub-barriers was then established based on these global weights.
- These rankings formed the basis for answering Objective 2 of the study (barrier prioritization).

STATA's matrix manipulation and "sort" functions ensured a transparent and replicable process for computing and ordering final scores.

Appendix IV: Anti-Plagiarism Certificate

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