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Assessing the Effects of Renewable Energy on Household Expenditure: A Case Study of Munali Constituency

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Abstract
As the global demand for sustainable energy intensifies in response to climate change and energy insecurity, renewable energy has become a vital component of development strategies, especially in low- and middle-income countries. In sub-Saharan Africa, where a significant portion of the population remains either unconnected to the national grid or faces unreliable electricity access, the shift toward renewable energy is not just a matter of environmental sustainability but also of economic necessity. Zambia, despite its vast hydroelectric potential, faces challenges in energy distribution and affordability, particularly in low-income urban communities. Consequently, many households are exploring renewable alternatives such as solar power to meet their energy needs. This study assessed the effectiveness of household renewable energy adoption in reducing energy-related costs within the Munali community. Specifically, the study aimed to evaluate the effects of renewable energy adoption on household energy expenditure, examined the types of renewable energy sources adopted, identified socio-economic factors associated with renewable energy adoption, established the limitations households face in transitioning from traditional to renewable energy sources and evaluated the impact of adoption on household energy costs. The study embraced an exploratory case study design, employing a mixed method approach consisting of both qualitative and quantitative methods of gathering primary data. The study employed a simple random sampling approach to ensure that every household in Munali constituency has an equal chance of being selected. Data was collected through structured surveys and interviews, utilizing standardized questionnaires. Data entry and analysis was done using STATA. Descriptive statistics, including frequencies, percentages, and means, were used to summarize data. Chi-square was used to determine associations between variables. The study found that renewable energy adoption in Munali Constituency was influenced by socio-economic factors such as income levels, employment status, household size, and expenditure patterns, with unreliable ZESCO supply as the main driver. Solar was the most widely adopted source, mainly for lighting, with financing largely through household savings and limited subsidies. Adoption significantly reduced household energy expenditure, enabling savings for food security, education, healthcare, and assets, though challenges of high upfront costs, limited technical support, poor product accessibility, and maintenance issues persisted. Despite these barriers, most households expressed strong willingness to fully transition if affordability, accessibility, and technical assistance were improved. The study recommends enhancing affordability of renewable energy through subsidies, low-interest loans, and flexible payment schemes while strengthening technical support by training local technicians and establishing service centers. Improving product accessibility through local manufacturing and stronger distribution networks, coupled with awareness campaigns and demonstration projects, can address knowledge gaps. Policies should encourage diverse use of renewable energy beyond lighting, supported by public–private partnerships to expand access through innovative financing models. Finally, clear regulatory frameworks and quality standards are needed to promote trust, affordability, and sustainable adoption.

Keywords: Adoption, Effectiveness, Household Energy Expenditure, Munali Community and Renewable Energy

1. Introduction

1.1 Overview

The chapter covers the context within which the study was conducted. This chapter explains the background of the study, statement of the problem, purpose of the study, research objectives, research question, conceptual framework, significance of the study, scope of the study, operational definitions of the study.

1.2 Background

Access to affordable and sustainable energy is a cornerstone of socio-economic development, particularly in low- and middle-income countries (Siraj, 2024). Renewable energy, defined as energy derived from natural processes that are replenished constantly such as solar, wind, and biomass has emerged as a strategic solution to energy poverty and environmental degradation (Hafezi, 2021). In recent years, the global energy discourse has increasingly emphasized the need for transitioning to renewable energy sources to meet both environmental sustainability goals and economic resilience for households (Hassan, 2024). However, the high initial investment costs and lack of infrastructure have often limited the widespread adoption of these technologies in low-income urban communities (Brown, 2020).

Globally, the shift toward renewable energy is supported by frameworks such as the United Nations Sustainable Development Goals (SDGs), particularly Goal 7, which advocates for "affordable, reliable, sustainable and modern energy for all." (Bruce, 2021). Many countries have also signed international agreements such as the Paris Climate Accord, which calls for reduced carbon emissions and increased reliance on clean energy sources. Countries like Germany, Sweden, and China have made significant strides in integrating renewable energy at both macro and micro levels (He, 2024). At the household level, renewable energy has been shown to reduce energy expenditure over time, improve air quality, and enhance energy security (Iqbal, 2021).

In Africa, the situation presents a mixed reality. While the continent possesses vast renewable energy potential especially solar and hydro access remains a challenge due to weak policy frameworks, inadequate funding, and lack of public awareness (Bishoge, 2020). In Zambia, electricity access is available to 67.3% of the urban population, but only 4.4% of those in rural areas, resulting in a national average of 31.4% (Pambwe, 2021) [53]. The government, through agencies such as the Rural Electrification Authority (REA) and initiatives like the National Energy Policy (2019), has promoted the adoption of off-grid solar systems and improved cook stoves to reduce energy-related financial burdens and environmental harm. However, implementation at the household level remains inconsistent and poorly monitored (Phiri, 2024) [54].

Munali, a densely populated middle-income constituency in Lusaka District, typifies the challenges faced by urban households in adopting renewable energy (Chakulanda, 2024) [11]. The community grapples with unreliable grid power, high dependency on charcoal, and escalating household energy costs (Lloyd, 2021) [42]. Despite the availability of solar technologies and other renewable options in the Zambian market, many households remain reliant on traditional energy sources, citing high installation costs, lack of financing options, and insufficient knowledge of the long-term economic benefits (Mhango, 2024) [46].

Historically, household energy choices in urban Zambia have been influenced by affordability, availability, and cultural preferences (Chishimba, 2024) [15]. With increasing urbanization and environmental stress, there has been growing advocacy from non-governmental organizations and donor-funded programs to encourage the transition to clean energy (Cooper, 2020) [17]. Nonetheless, studies evaluating the actual effectiveness of renewable energy adoption specifically in terms of expenditure reduction at the household level are limited (Hassan, 2024). This study seeks to fill that gap by assessing whether and how renewable energy adoption leads to measurable reductions in household energy expenditure in Munali. The findings will contribute to local policy debates on energy access, guide program implementation, and provide a practical lens through which renewable energy initiatives can be evaluated for cost-effectiveness. Understanding the socio-economic and policy dimensions of renewable energy at the community level is essential for scaling up solutions that are both inclusive and sustainable.

1.3 Statement of the Problem

Household energy expenditure continues to be a significant financial burden for many low- middle income urban households in Zambia, especially in informal settlements such as Munali in Lusaka District (Chakulanda, 2024) [11]. Despite national efforts to promote the use of renewable energy sources, the majority of households in such areas still rely heavily on traditional and non-renewable energy sources like charcoal, firewood, and electricity from the national grid often characterized by supply inconsistencies and rising costs (Pambwe, 2021) [53]. According to the Zambia Statistics Agency (ZamStats, 2022), over 82% of households in urban low-income communities depend on charcoal as their primary source of energy for cooking, with an average monthly expenditure of ZMW 250–350 per household (Felody, 2022) [19]. The magnitude of this problem is further compounded by the increasing cost of charcoal and grid electricity. According to the Energy Regulation Board, the price of charcoal has risen by over 30% in the past two years, while electricity tariffs have increased by over 19% since 2021 (Chitandula, 2024). Moreover, there is a notable gap in empirical studies that assess the actual effectiveness of renewable energy solutions in reducing household energy expenditure at the community level. Most existing research in Zambia focuses on energy access at national or rural levels, with limited evidence on urban informal settlements (Mhango, 2024) [46]. This lack of localized, data-driven evidence makes it difficult for policymakers, donors, and development partners to design targeted interventions that address the unique needs of urban poor households (Bibri, 2023) [5]. Given the urgent need to reduce energy-related financial burdens and promote sustainable energy practices in vulnerable communities, this study is necessary to examine whether the adoption of renewable energy sources can significantly lower household energy expenditure in Munali. By generating context-specific insights, the research aims to inform policy direction, guide future investment, and support community-level energy planning. Understanding the factors influencing renewable energy adoption and expenditure reduction is critical in ensuring inclusive and cost-effective energy transitions in Zambia's urban communities.

1.4 General Objective

To evaluate the effects of renewable energy adoption on household energy expenditure in Munali Constituency.

1.4.1 Specific Objectives

1. To examine the types of renewable energy sources adopted by households in Munali Constituency.
2. To identify the socioeconomic factors arising from the adoption of renewable energy among households in Munali Constituency.

3. To establish limitations faced by households in transitioning from traditional to renewable energy sources.
4. To evaluate the effect of renewable energy adoption on household energy expenditure in Munali Constituency.

1.5 Research Questions

1. What types of renewable energy sources have been adopted by households in Munali Community?
2. What socio-economic factors influence the adoption of renewable energy among households in the community?
3. What barriers do households face in transitioning from traditional to renewable energy sources?
4. What is the effect of renewable energy adoption on household energy expenditure in Munali Constituency?

1.6 Conceptual Framework

The conceptual framework for this study is structured around the relationship between renewable energy adoption and its effectiveness in reducing household energy expenditure in Munali Constituency (Guta, 2020) [22]. The independent variables include the types of renewable energy sources adopted by households. These may include solar lighting systems; solar home systems used for cooking and heating, biogas systems, and improved cook stoves (Kimutai, 2025). The availability and use of these technologies play a key role in determining the degree of renewable energy adoption at the household level.

Another set of independent variables comprises socio-economic factors that influence a household's ability and willingness to adopt renewable energy. These include household income levels, educational attainment, household size, occupation, and the level of awareness or knowledge regarding renewable energy solutions (Malik, 2020). These socio-economic elements can either facilitate or hinder the adoption process depending on the household's capacity and perceived benefits of renewable energy.In addition, the study recognizes the existence of barriers to renewable energy adoption, which may directly or indirectly impact expenditure outcomes. These barriers include the high initial cost of renewable energy systems, limited access to renewable technologies in the local market, lack of financing or subsidy options, cultural or behavioral resistance to change, and insufficient technical support or maintenance services. These constraints limit the adoption and sustained use of renewable energy technologies in low-income urban settings (Pambwe, 2021) [53].

These independent variables collectively influence the mediating variable, which is the level of renewable energy adoption within the household. This refers to how extensively and consistently households integrate renewable energy into their daily energy usagesuch as lighting, cooking, and heating. Ultimately, the dependent variable in this framework is the household energy expenditure, specifically measured by the monthly costs incurred for energy before and after the adoption of renewable energy sources. The framework assumes that higher levels of adoption of efficient and affordable renewable energy technologies lead to a reduction in household energy spending.

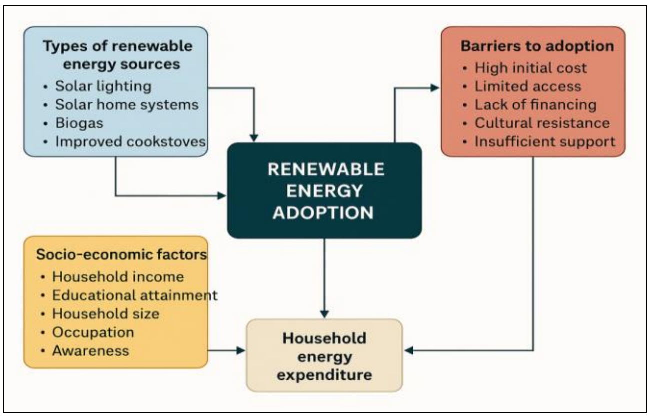

Fig 1: Study variable interaction

1.7 Significance of the Study

This study is significant as it addresses a critical issue affecting low-income urban households high energy expenditure and explores sustainable solutions through the adoption of renewable energy technologies. By focusing on the Munali Constituency in Lusaka District, the research provides localized insights into how renewable energy can be an effective tool for reducing household financial burdens associated with energy consumption. The findings will be valuable to several stakeholders.

For households and community members, the study will raise awareness about available renewable energy options, their cost implications, and long-term benefits, potentially encouraging wider adoption and improved living standards. For policy makers and government agencies, such as the Ministry of Energy and the Rural Electrification Authority, the study will offer evidence-based recommendations to guide the formulation of inclusive energy policies, subsidy schemes, and urban electrification programs targeted at low-income communities and contribute to SDG 7 which focuses on ensuring access to affordable, reliable, sustainable and modern energy for all.

The study will also benefit non-governmental organizations (NGOs) and development partners working on clean energy access, by providing empirical data to support program planning, funding allocation, and project implementation. In addition, private sector actors in the renewable energy space can use the findings to better understand consumer behavior, affordability levels, and market opportunities in informal urban settlements.

Lastly, the study contributes to the academic and research community by filling a critical gap in literature regarding urban renewable energy use in Zambia. Most existing research focuses on rural electrification, leaving a knowledge gap in the context of urban informal settlements. The outcomes of this study could inspire further research and innovation in energy solutions tailored to underserved urban populations.

1.8 Scope of the Study

This study was geographically limited to the Munali Constituency in Lusaka District, Zambia. It specifically focuses on assessing the effectiveness of renewable energy adoption in reducing household energy expenditure. The study primarily targeted households that have adopted, are in the process of adopting, or have the potential to adopt renewable energy technologies such as solar panels, solar home systems, biogas systems, and improved cook stoves.

The research examined the types of renewable energy technologies adopted, the economic impact of these technologies on household energy costs, the socio-economic factors influencing adoption, and the challenges or barriers hindering their wider use. The timeframe of analysis was restricted to current and recent trends (within the last 5 years), and the study relied on both quantitative and qualitative data collected through surveys, interviews, and secondary data sources.

The scope did not include industrial or commercial energy use, nor does it cover large-scale renewable energy projects or rural electrification schemes. Additionally, the study did not evaluate the technical efficiency of the energy systems but focused instead on their economic and social impact from a household perspective.

1.9 Definition of Operational terms

Renewable Energy: Energy derived from natural sources that are continuously replenished, such as sunlight, wind, biogas, and biomass. In this study, it primarily refers to household-level technologies like solar panels, solar home systems, and improved cook stoves used in Munali Community.

Household Energy Expenditure: The total amount of money a household spends on energy consumption, including electricity, charcoal, firewood, and alternative energy sources. This study measures how renewable energy impacts these expenses.

Effectiveness: The degree to which the use of renewable energy sources leads to a measurable reduction in household energy costs and improves access to clean, affordable energy in the context of the Munali Community.

Adoption: The process by which households begin to use and integrate renewable energy technologies into their daily activities, such as cooking, lighting, and heating.

Munali Community: A high-density urban settlement in Lusaka District, Zambia, which serves as the case study area for this research due to its socio-economic diversity and energy access challenges.

2. Literature Review

2.1 Overview

This chapter reviews literature to understand the current state of knowledge, identify critical gaps and points of disagreement in this field and how this current study can contribute to it.

2.2 The types of renewable energy sources adopted by households

Among the various forms of renewable energy technologies, solar energy stands out as the most widely adopted option at the household level across both developed and developing countries (Cantarero, 2020) [9]. Its adoption has gained significant momentum in recent years due to the increasing affordability of solar systems and the global push toward sustainable and decentralized energy solutions. Solar energy, primarily harnessed through photovoltaic (PV) systems such as solar panels or solar home systems (SHS), converts sunlight into electricity that can be used for multiple household purposes (Hasan, 2023). These systems have proven particularly beneficial in areas where grid electricity is unreliable, unaffordable, or entirely absent, making them an essential solution for energy access in off-grid and peri-urban communities (Babayomi, 2023).

In sub-Saharan Africa, solar energy has emerged as a transformative solution to energy poverty. Millions of households have adopted solar lanterns, mini solar kits, and larger SHS to meet their basic energy needs (Ukaba, 2024). According to the International Energy Agency (IEA, 2021), over 50 million people in the region rely on off-grid solar systems for lighting, mobile phone charging, and other low-power applications. In countries like Kenya, Rwanda, Nigeria, and Ethiopia, solar home systems are increasingly popular due to government support, donor-funded programs, and the growth of pay-as-you-go (PAYG) financing models that allow households to purchase systems on flexible terms (Ukoba, 2024). In urban informal settlements a, households commonly use solar energy for lighting, often through solar lanterns and bulbs, which have replaced hazardous and costly sources like kerosene lamps and candles. Solar kits also support charging mobile phones, which is a critical service in areas where commercial charging stations are either distant or expensive (Rebenold, 2020).

In addition to basic lighting and charging needs, advanced SHS now support low-wattage appliances such as radios, fans, televisions, and small refrigerators, significantly improving the quality of life (Hasan, 2023). Solar-powered water heaters are also available, though their adoption remains relatively low due to higher costs and space requirements. These systems are more common in middle- to high-income households or in areas where government subsidies and financing options are more accessible (Lukuyu, 2023) [43].

Globally, the rapid decrease in the cost of solar panels by more than 80% over the past decade has played a major role in accelerating household adoption (Ibegbulam, 2023). According to BloombergNEF (2022), solar PV has become the cheapest source of electricity in many parts of the world, including South Asia and Latin America. Moreover, solar energy is low maintenance and has no recurring fuel costs, making it ideal for long-term sustainability in low-income contexts (Ray, 2021).

Despite these advantages, barriers still exist. The initial upfront costs of solar systems, although declining, remain unaffordable for many households, especially those in informal settlements without access to financing or credit facilities (Yaguma, 2024) [74]. Maintenance issues, lack of user awareness, and limited access to qualified technicians also hinder broader adoption. Furthermore, seasonal variations and poor weather conditions can affect system performance, highlighting the need for complementary solutions such as battery storage or hybrid systems (Jha, 2023) [32].

In many low- and middle-income countries, particularly across sub-Saharan Africa, traditional biomass fuels such as firewood and charcoal remain the dominant source of energy for cooking (Ibegbulam, 2023). In urban and peri-urban areas in Lusaka District, households continue to rely heavily on charcoal due to its affordability, accessibility, and the lack of widespread alternatives (Chisonga, 2023). However, traditional cooking methods using open fires or inefficient stoves contribute significantly to household air pollution, deforestation, and greenhouse gas emissions, all of which have adverse health, environmental, and economic consequences (Kaputa, 2023). In response to these challenges, Improved Biomass Cookstoves (IBCs) have emerged as an important transitional technology to help reduce the harmful effects associated with conventional cooking practices (Kapatu, 2023).

Improved biomass cookstoves are engineered to burn fuel more efficiently, thus requiring less firewood or charcoal to achieve the same cooking output (Semenya, 2020) [62]. This reduction in fuel consumption not only helps conserve natural resources but also lowers household expenditure on energya crucial benefit in low-income settings where energy costs can consume a significant portion of family income. By improving combustion efficiency, these stoves also produce less smoke and harmful pollutants, such as carbon monoxide and particulate matter, thereby significantly reducing indoor air pollution and the associated health risks, particularly for women and children who spend more time in the cooking environment (Kimutai, 2025).

According to the World Health Organization, household air pollution from traditional cooking methods is responsible for more than 3.2 million premature deaths annually, primarily due to respiratory diseases (Valavanidis, 2020). Improved cookstoves have been shown to reduce exposure to toxic fumes by up to 70%, depending on the model and usage conditions. This makes them a critical intervention in achieving cleaner and healthier living conditions for vulnerable populations. In terms of efficiency and cooking performance, many IBC models are designed to retain heat better, thereby reducing cooking times. Some incorporate insulated combustion chambers, chimneys, or forced-draft fans that improve combustion and minimize heat loss (Kumar, 2023).

Despite these advantages, improved biomass cookstoves are not entirely clean and are considered a transitional solution on the path to cleaner energy systems such as electricity or liquefied petroleum gas (LPG) (Wright, 2020). They still rely on biomass fuels, which can contribute to deforestation and are often sourced through unsustainable practices. Nevertheless, they offer a pragmatic and affordable step forward for communities that cannot yet access or afford cleaner energy alternatives (Chen, 2021).

In Zambia, various NGOs, donor agencies, and government programs have promoted the use of IBCs through subsidies, awareness campaigns, and micro-financing initiatives (Semenya, 2020) [62]. Programs such as the Energising Development (EnDev) and the Global Alliance for Clean Cookstoves have supported stove distribution and local manufacturing capacity. The Zambian government, under its renewable energy strategy, has recognized the role of improved cookstoves in advancing its climate change mitigation goals and improving public health (Yumkella, 2021).

Biogas systems represent a sustainable and renewable energy solution that converts organic waste into usable energy through a process known as anaerobic digestion (Simwambi, 2020). This biological process involves the breakdown of organic materials such as animal manure, food scraps, sewage, and plant matter in the absence of oxygen, producing a gas mixture composed mainly of methane (CH_4) and carbon dioxide (CO_2). This biogas can be used directly for cooking, heating, or lighting, while the digestate, a nutrient-rich by-product, serves as a natural fertilizer for agricultural purposes. At the household level, biogas digesters can significantly reduce dependency on traditional fuels such as charcoal, wood, and liquefied petroleum gas (LPG) (Juma, 2020) [33].

In many developing countries, especially across Asia and parts of East Africa, biogas systems have been promoted as a clean and efficient alternative to traditional biomass energy. Countries like India, Nepal, Kenya, and Tanzania have introduced large-scale programs to encourage biogas adoption, particularly in rural and peri-urban areas where animal husbandry and farming produce a steady supply of organic waste. For example, the Kenya Biogas Program has supported thousands of smallholder farmers in constructing digesters, which has improved energy access and environmental outcomes (Kimutai, 2025).

In Zambia, the adoption of biogas technology remains relatively limited due to several barriers. These include high initial installation costs, limited access to raw materials (such as livestock manure), space constraints, and lack of technical expertise for maintenance and operation (Tembo, 2023). Many urban households do not have adequate space or the volume of organic waste required for consistent biogas production, making it less feasible than other renewable options like solar power. Moreover, the infrastructure for waste segregation and collection is often lacking, further reducing the viability of biogas systems in dense urban settings (Ketuama, 2022).

Despite these challenges, peri-urban and rural households, particularly those involved in small-scale farming, are increasingly exploring biogas as a means to achieve energy self-sufficiency (Karbo, 2024) [34]. Where implemented successfully, biogas systems offer multiple benefits. They reduce indoor air pollution, lower household energy expenditures, and minimize reliance on unsustainable fuels like charcoal, which contributes to deforestation. Additionally, the fertilizer slurry produced from the digesters enhances soil fertility and agricultural productivity, creating a circular economy that integrates energy and food production (Obaideen, 2022).

From an environmental perspective, biogas systems help in the reduction of greenhouse gas emissions by capturing methane that would otherwise be released into the atmosphere from decomposing organic matter (Babayomi, 2023). They also contribute to waste management by turning kitchen waste, animal dung, and sewage into valuable resources, thus promoting cleaner and healthier communities. Some countries have included biogas in their climate change adaptation and mitigation policies, recognizing its role in supporting low-carbon development pathways (Chen, 2021).

To scale up adoption in places like it is essential to raise awareness, provide financial incentives or subsidies, and develop training programs that build local capacity for biogas construction and maintenance (Chisonga, 2023). Partnerships between government, NGOs, and the private sector could facilitate the integration of biogas into broader sustainable energy strategies. While not suitable for every household, biogas remains a promising renewable energy option for communities with the necessary inputs and space, especially as part of a diversified and context-specific energy mix (Wright, 2020).

Solar cookers represent an innovative and eco-friendly cooking technology that harnesses the power of the sun to generate heat for cooking food (Eshetu, 2024) [18]. Unlike conventional cooking methods that rely on firewood, charcoal, or gas, solar cookers use reflectors or mirrors to concentrate sunlight onto a cooking pot, which then absorbs the heat. This process is highly sustainable, as it requires no fuel, produces no emissions, and makes use of the abundant and renewable energy from the sun. Solar cookers are considered a green technology because they contribute to reducing deforestation, mitigating indoor air pollution, and lowering greenhouse gas emissions (Rahmany, 2021). They are especially beneficial in regions where biomass fuels are scarce, expensive, or harmful to human health and the environment.

In many parts of the world, including sub-Saharan Africa, solar cookers have been promoted as a means of improving energy access in rural and peri-urban communities (Ketuaama, 22). In Zambia, for instance, solar cooking initiatives have gained attention due to their potential to reduce household reliance on charcoal and woodfuel, which are not only unsustainable but also contribute to environmental degradation and health issues related to air pollution from indoor cooking. Solar cookers are particularly attractive because of their low operational cost, as once they are installed, they require no fuel to operate sunlight is free and abundant (Arunachala, 2020).

Despite these advantages, the adoption of solar cookers has been limited in many regions, particularly in urban settings (Cantarero, 2020) [9]. One of the most significant barriers to wider adoption is their dependency on weather conditions. Solar cookers rely entirely on sunlight, making them ineffective on cloudy or rainy days or in regions with prolonged periods of overcast weather (Eshetu, 2024) [18]. This limitation makes them unsuitable as a primary cooking method, particularly in areas with unreliable sunlight. In Zambia, the seasonal variation in sunlight can further complicate their consistent use, as the rainy season often coincides with the period when energy demand is highest for household cooking (Gyan, 2022) [23].

Additionally, cultural preferences and cooking habits present significant barriers to solar cooker adoption. Many traditional cooking methods, particularly in Zambia and other sub-Saharan African countries, favor faster cooking times and flame-based methods such as open fires or gas stoves (Chen, 2021). These methods provide immediate heat and allow for easy temperature control, which is often valued for cooking certain types of food, such as stews, soups, and fried dishes. Solar cookers, on the other hand, typically take longer to reach the desired cooking temperatures and have limited temperature control, which can discourage households accustomed to quicker and more versatile cooking methods. In urban areas where time constraints and efficiency are critical, the slower cooking process of solar cookers may not meet the expectations of household cooks (Tembo, 2023).

Furthermore, solar cookers have limitations in cooking capacity and flexibility. Most solar cookers are designed for small-scale cooking, which may not be sufficient for larger families or community cooking needs (Padonou, 2020). This limitation in cooking size and capacity makes solar cookers less practical for households with high energy demands or those that cook for larger groups, especially in urban areas where families often prepare meals in bulk. Moreover, solar cookers are typically designed for specific types of cooking, and may not be able to handle all types of meals effectively, particularly those that require consistent high heat, such as grilling or baking (Saxena, 2022).

Despite these challenges, efforts have been made to overcome these limitations and promote solar cookers as a viable cooking option. In Zambia, and other parts of sub-Saharan Africa, pilot projects and NGOs have worked to demonstrate the benefits of solar cooking through awareness campaigns, demonstration programs, and subsidized distribution of solar cookers. Additionally, innovations in solar cooker design, such as improved reflectors, larger cooking capacities, and insulated cooking pots, have sought to make solar cookers more efficient and user-friendly (Mperejekumana, 2024).

Small wind turbines, which convert wind energy into electricity, are a promising renewable energy solution that has been successfully implemented in various regions across the world (Roga, 2022). These turbines are typically designed to provide power to households or small communities, offering an alternative to grid electricity or conventional energy sources like fossil fuels. The key advantage of small wind turbines lies in their ability to generate clean, renewable energy from an abundant and free natural resourcewind. This makes them an attractive option in areas with consistent and reliable wind speeds (Changa, 2020).

In regions such as the United States, parts of Europe, and India, small wind turbines have been adopted for off-grid energy production, particularly in rural and remote areas. They are often used in combination with other renewable energy sources, such as solar panels, to create a hybrid system that can provide a stable and reliable energy supply regardless of changing weather conditions (Chen, 2021). Small wind turbines can power lighting, household appliances, and even irrigation systems, offering significant cost savings and energy security to off-grid communities (Eshetu, 2024) [18].

One of the most significant factors limiting the use of small wind turbines in urban areas is the unpredictable and inconsistent wind speeds (Wilbertorce, 2023). Wind energy generation is highly dependent on the strength and consistency of the wind. In many parts of Zambia, including urban areas, the wind speed is often insufficient to support the efficient operation of wind turbines (Mutale, 2023). Areas with low or variable wind speeds cannot consistently generate enough energy to make wind turbines a viable energy source. Unlike regions with strong, consistent winds, such as coastal areas or open plains, the urban environment in does not provide the necessary wind conditions to make small wind turbines effective for electricity generation (Lukuyu, 2023) [43].

Another significant barrier to the adoption of small wind turbines is their high initial investment costs. While the operational costs of wind turbines are relatively low once they are installed, the initial costs of purchasing and installing a wind turbine system can be prohibitively expensive (Babayomi, 2023). This includes not only the cost of the turbine itself but also the associated infrastructure, such as support structures, electrical wiring, and inverters. For many households, where financial resources are often limited, these upfront costs pose a substantial barrier to adoption (Chen, 2021). The return on investment, while potentially significant over the long term, may not justify the high initial outlay for many low-income households, especially when compared to other renewable energy sources like solar power, which have lower installation costs (Saxena, 2022).

Furthermore, lack of technical support and infrastructure is another challenge hindering the adoption of small wind turbines (Bianchini, 2022). Wind energy systems require specialized knowledge and technical expertise to install, maintain, and troubleshoot. In Zambia, there is a lack of local technical capacity in the field of wind energy, and communities may not have access to trained technicians who can install and maintain small wind turbines. Additionally, the infrastructure to support wind energy systems, such as power distribution networks capable of integrating small-scale wind energy, is often lacking or underdeveloped (Chisonga, 2023). This lack of infrastructure and technical support makes it difficult for households in urban areas to adopt small wind turbines as a reliable energy source.

While small wind turbines present an attractive option for renewable energy generation in many regions, their adoption in Zambia, particularly in urban areas, faces significant barriers (Karbo, 2024) [34]. Unreliable wind speeds, high upfront costs, and a lack of technical support and infrastructure hinder the widespread implementation of wind energy. Despite these challenges, small wind turbines remain a potential energy solution for rural areas or off-grid households where wind conditions are more favorable (Ketuama, 2022). Moreover, with advancements in technology, improved financing models, and capacity building, small wind turbines could play a larger role in Zambia's renewable energy mix in the future. However, for now, other renewable energy sources such as solar power and biogas remain more practical and accessible solutions for most urban and peri-urban households in Zambia (Kumar, 2024).

Solar mini-grid projects in Zambia are designed to extend electricity access to rural and remote communities that are not served by the national grid. However, their implementation faces significant challenges, making it essential to understand the key factors contributing to their success or failure to ensure their long-term viability and scalability. Currently, there is a lack of comprehensive research assessing the performance of these systems in terms of energy security, financial sustainability, and environmental impact. Additionally, there is no centralized source of information on solar mini-grid projects in Zambia. To address this gap, this study critically evaluates the financial, technical, environmental, and social sustainability of five prominent solar mini-grid initiatives: the 48 kW Magodi mini-grid (Lundazi), 51.8 kW Katamanda and 28.35 kW Chitandika mini-grids (both in Chipangali), the 24.4 kW Sinda mini-grid (Sinda), and the 32.4 kW Chibwika mini-grid (Mwinilunga). None of these systems is currently fully sustainable from a technical or financial perspective. Economic tariffs required to cover both capital and operational costs are largely unaffordable for low-income rural populations. Other major challenges include limited technical support, inadequate maintenance, and the absence of structured operational plans and viable business models. Specific issues identified include (i) incorrect sizing during project planning, (ii) inefficient management by government or community entities lacking technical expertise, (iii) misaligned and poorly utilized subsidies, and (iv) unstructured and unsuitable tariff systems. To improve both technical and financial outcomes, greater involvement from the private sector is essential. A well-structured public-private partnership (PPP) model is recommended for the construction, operation, and maintenance of mini-grids. Instead of current upfront subsidies, smarter subsidy mechanisms should be introduced to better align the interests of government, private investors, and end users (Felody, 2022) [19].

A detailed analysis of the global shift toward renewable energy highlights notable differences in adoption rates and technological progress across countries, while pointing to a major transformation in global energy systems. Drawing on data from the renewable energy map scenario, the study suggests that renewables could account for up to two-thirds of the global primary energy supply by 2050—substantially higher than the 24% projected under the reference scenario. The European Union, especially Denmark and Germany, leads the transition with strong integration of wind and other renewable sources. In Asia, countries like China and India are making rapid progress, with solar and wind energy growing at annual rates exceeding 30%. In the Americas, the United States, Canada, and Brazil show varied yet significant contributions to renewable energy adoption. Middle Eastern nations are gradually expanding their energy mixes, while Africa, though rich in potential, continues to face barriers due to limited infrastructure. The study affirms the global momentum toward renewable energy but also highlights persistent disparities driven by geopolitical, technological, and economic factors. The findings stress the need for strategic policies, targeted investments, and international cooperation to accelerate the transition and bridge existing gaps (Hassan, 2024).

The primary focus of this study is to evaluate the socioeconomic effects of household biogas plants on rural communities. To achieve this, researchers surveyed both biogas plant users and non-users in rural areas of Muzaffar-Garh. Data were gathered through structured questionnaires administered to 40 biogas users and 40 non-users in selected villages across each Tehsil, totaling 320 households across four Tehsil districts. In the analysis, biogas usage was treated as the main input variable, alongside socioeconomic factors such as the education level of elderly household members and total household income. Intermediate variables included farm productivity, time savings, reduction in indoor air pollution, household hygiene, and expenditures. The study's output variables focused on household income, health, and the education level of young children aged 2–5. Using Structural Equation Modeling (SEM), the study demonstrated that biogas adoption significantly enhances farm productivity, reduces time burdens, improves indoor air quality and hygiene, and lowers expenditures factors that collectively improve household welfare. The findings suggest that both direct and indirect socioeconomic benefits arise from owning biogas plants. For broader adoption of this sustainable energy source, increased public engagement and participation are essential (Iqbal, 2021).

Kimutai (2025) evaluated how the adoption of biogas technology influences household energy consumption and enhances livelihoods. The study also sought to highlight the advantages of biogas as a sustainable solution for household energy needs. In the analysis, fourteen sustainability indicators were identified, validated, and categorized to assess the broader impacts of biogas use. The findings indicated that adopting biogas technology yields several benefits, such as improved air quality, decreased deforestation, and lower greenhouse gas emissions. Households that switch to biogas can replace up to 4.5 tons of firewood annually, thereby reducing CO_2 emissions by approximately 6.75 tons. This transition also results in monthly savings of around US$25 (Ksh. 3223) and frees up about 45.5 hours per week, which can be utilized for other income-generating activities. Furthermore, biogas systems produce digestate a byproduct that serves as an organic fertilizer enhancing soil fertility, water retention, and reducing erosion, while lowering dependence on chemical fertilizers. Incorporating biogas systems in livestock shelters also helps reduce unpleasant odors, harmful pathogens, and methane emissions (Kimutai, 2025).

Lloyd (2021) [42] investigated how social capital influences the adoption of improved cook stoves in Lusaka, Zambia. These stoves offer significant health benefits especially for women and children under five and also require less fuel, lower greenhouse gas emissions, and enhance general well-being. Despite Zambia's relatively strong economic standing in Africa, adoption rates for improved or clean cook stoves remain low. The study drew on data from a long-term impact evaluation conducted by the Energy Poverty PIRE in Southern Africa (EPPSA) team and its collaborators. Using baseline and rapid survey data, the research assessed how social capital affects household adoption of cook stoves and cleaner fuels promoted by two private companies VITALITE and SupaMoto in densely populated, low-income areas of Lusaka. The study surveyed 350 households in neighborhoods where cook stoves had already been introduced, and 467 households in areas where marketing occurred after baseline data collection. Among the latter group, 45% adopted the stoves following the marketing campaign, resulting in a combined sample of 503 adopters and 343 non-adopters. Findings revealed that no single measure of social capital significantly influenced adoption at a population level. However, households that affirmed at least one Trust statement such as trusting others or being able to rely on someone were more likely to adopt. In contrast, agreement with at least one Community engagement statement like participating in community decisions or feeling a strong community connection was associated with a lower likelihood of adoption. These findings are especially relevant for prospective users. Other influential factors included homeownership and female-headed households, both of which were positively linked to adoption. The results suggest that companies like VITALITE and SupaMoto could improve their marketing by targeting women-centered spaces such as women's savings or credit groups, aligning their approach with the social dynamics that encourage adoption (Lloyd, 2021) [42].

The world is currently confronted with two critical challenges: limiting global warming to 1.5 °C and promoting inclusive, equitable socio-economic development. These goals are not mutually exclusive and must be pursued in tandem, particularly in the context of post-COVID recovery. A key part of the solution lies in shifting toward sustainable and renewable energy systems. This transition involves ensuring energy efficiency, affordability, reliability, and independence. In developing countries, it also encompasses broader goals such as economic growth, social inclusion, and environmental sustainability especially as much of the untapped renewable energy potential exists within these regions.Cantarero, M.M.V., (2020) [9] examined the state of the energy transition in the Global South by reviewing both academic and grey literature. It synthesizes various strategies for advancing renewable energy through three main dimensions: technology, society, and policy. A proposed roadmap highlights how cross-sector and cross-dimensional synergies can drive the transition forward. It emphasizes the adoption of proven, commercially available technologies to enhance energy systems; the empowerment of citizens in energy decision-making; and the democratic reform of institutions to improve transparency, accountability, and public trust (Cantarero, 2020) [9].

Solar energy remains the most common renewable energy technology adopted by households (Cantarero, 2020) [9]. This trend is visible across high income and low income regions. Photovoltaic systems are used for electricity generation, while solar heaters support water heating. The rapid growth in solar energy adoption is linked to its increasing affordability and the global effort to support decentralized energy systems (Hasan, 2023). These systems allow households to convert sunlight into usable power that supports lighting, charging, and small household appliances.

Solar adoption is strong in countries with unreliable grid infrastructure or high electricity costs (Babayomi, 2023). In many sub Saharan African countries, solar energy has become a major source of basic household power because it is easier to install and does not depend on the national grid (Ukaba, 2024). This has made solar power important for energy access in rural, peri urban, and informal settlement areas. Many households begin with small solar lanterns or solar kits that support lighting and charging. Others progress to larger solar home systems that support televisions, fans, radios, and other low wattage appliances (Hasan, 2023). The use of solar in African contexts has increased due to the spread of pay as you go financing models (Ukoba, 2024). These models allow households to purchase solar systems through small periodic payments. This makes it easier for low income households to participate in solar adoption. International financing facilities and donor supported energy programs have also promoted solar systems in off grid areas. For instance, in many countries, public private partnerships have distributed solar lanterns and entry level solar kits at subsidized prices (Rebenold, 2020).

The continued reduction in the price of solar panels is a major factor supporting household adoption. The cost of solar PV systems has declined by more than eighty percent over the past decade (Ibegbulam, 2023). This shift has enabled many households to adopt solar energy as a primary or supplementary power source. Research shows that in South Asia and Latin America, solar PV is now one of the least costly sources of electricity (Ray, 2021). It also requires limited maintenance and does not depend on fuel inputs. This makes it suitable for long term use, especially for low income communities facing rising energy prices.

Despite the growth in adoption, some barriers remain. The initial cost of the systems continues to limit access for households without financing options (Yaguma, 2024) [74]. Households in informal settlements may not have the means to purchase larger systems and often rely on very small units that do not fully meet their energy needs. The need for battery storage can also add costs and create challenges for households without access to technicians who can install or maintain the systems (Jha, 2023) [32]. Environmental factors such as long rainy seasons and poor solar exposure can also affect system performance. These limitations require households to use solar energy together with other energy sources to meet their daily needs.

Biomass fuels remain central to household energy consumption in many low and middle income countries (Ibegbulam, 2023). Firewood and charcoal continue to be the main sources of cooking energy in urban, peri urban, and rural areas. This is visible in countries such as Zambia, Malawi, Tanzania, and Kenya, where charcoal is used widely due to its availability and cost (Chisonga, 2023). Traditional methods of cooking have environmental and health effects. These include increased household air pollution, forest resource depletion, and higher energy costs over time (Kaputa, 2023). In response to these issues, improved biomass cook stoves have become a major renewable energy option for households.

Improved biomass cook stoves are designed to burn fuel more efficiently compared to traditional open fire cooking systems (Semenya, 2020) [62]. They use less fuel for the same cooking needs. This reduces the amount of firewood or charcoal required by households and helps lower household expenditure on cooking energy. These stoves also reduce smoke and harmful pollutants. The World Health Organization reports that household air pollution from traditional cooking methods contributes to millions of premature deaths each year (Valavanidis, 2020). Improved cook stoves reduce exposure to harmful emissions and improve household health conditions. Many improved cook stove models include features that improve burning efficiency. These include insulated chambers and controlled air flow systems that produce cleaner combustion (Kimutai, 2025). Some models include chimneys or vents to direct smoke outside. Others use forced draft fans powered by small batteries to improve combustion. These features help save time by reducing cooking duration and lowering energy consumption.

Although improved cook stoves are considered cleaner than traditional biomass technologies, they still use biomass fuels and therefore serve as a transitional solution (Wright, 2020). They help reduce the negative effects of biomass consumption but do not fully eliminate them. Households that adopt these stoves often use them as a stepping stone while waiting for more advanced and cleaner energy technologies such as electric stoves or liquefied petroleum gas (Chen, 2021). In Zambia, NGOs, development agencies, and government partners have supported improved cook stove programs for several years. These include subsidies for low income households, awareness campaigns, and the promotion of local manufacturing of cook stoves (Semenya, 2020) [62]. Government programs such as the National Renewable Energy Strategy recognize improved cook stoves as an important tool for reducing emissions and improving public health (Yumkella, 2021).

Despite the benefits, challenges still limit adoption. Upfront costs may be high for low income households. Some households may lack information on proper stove use, which reduces efficiency. In some cases, households continue to use traditional stoves alongside improved models, limiting the full benefits. These challenges show that improved cook stoves are important but need continued support, financing models, and awareness to reach more households. Biogas energy systems. Biogas systems represent the third major renewable energy option used by households. Biogas is produced when organic waste such as animal manure, food waste, or plant matter breaks down in an anaerobic environment (Simwambi, 2020). The produced gas is used for cooking, lighting, or heating. The leftover material, called digestate, is used as fertilizer in farming households. Biogas systems can reduce reliance on charcoal, firewood, and liquefied petroleum gas (Juma, 2020) [33].

Many biogas projects are found in rural areas with strong agricultural activity. Households with livestock and space for digester installation are more likely to adopt biogas technologies. Countries such as Kenya, Tanzania, India, and Nepal have long standing biogas programs that promote the use of household digesters (Kimutai, 2025). These programs are supported by government subsidies and NGO initiatives. They aim to reduce household energy costs, improve waste management, and support climate change goals. In Zambia, biogas adoption is expanding slowly. Barriers include installation costs, space constraints, limited access to livestock manure, and limited access to technical services for construction and maintenance (Tembo, 2023). Urban households face particular challenges because they lack space or consistent supplies of organic waste. Waste management systems in many cities also lack segregation facilities, making biogas options less practical (Ketuama, 2022).

Biogas is more suitable for peri urban and rural households involved in small scale farming. These households often have livestock and produce enough organic waste to run a biogas digester effectively. For such households, biogas reduces energy costs and reduces pressure on surrounding forests by decreasing the use of charcoal and firewood (Karbo, 2024) [34]. The digestate produced also serves as a natural fertilizer, improving soil quality and supporting crop yields (Obaideen, 2022). Biogas also supports environmental goals. When organic waste decomposes naturally, it releases methane into the atmosphere. Methane is a greenhouse gas with strong warming potential. Biogas systems trap this methane and use it as fuel. This reduces emissions and promotes a circular waste management system (Babayomi, 2023). Some national climate policies now include biogas as part of the transition toward low carbon development (Chen, 2021).

2.3 To identify the socio-economic factors influencing the adoption of renewable energy among households in the community

The adoption of renewable energy technologies at the household level is significantly influenced by various socio-economic factors that affect both individuals and communities (Arunachala, 2020). These factors determine the ability of households to access, afford, and benefit from renewable energy systems. Understanding these socio-economic factors is essential for policymakers and organizations to promote the widespread use of renewable energy, particularly in communities seeking to transition to more sustainable energy practices. Below are key socio-economic factors that influence renewable energy adoption (Babayomi, 2023):

Income level plays a crucial role in shaping the adoption of renewable energy technologies at the household level. It directly influences the ability of individuals and families to invest in and maintain renewable energy systems such as solar photovoltaic (PV) panels, small-scale wind turbines, biomass digesters, and geothermal heating systems (Bianchini, 2022). These systems often require significant initial capital outlay, which can act as a major barrier for low- and middle-income households, especially in developing countries (Chagas, 2020).

For higher-income households, the decision to adopt renewable energy is often facilitated by financial flexibility. They are better positioned to make long-term investments and can absorb the upfront costs more easily (Cantarero, 2020) [9]. This group is more likely to install energy-efficient technologies, purchase quality equipment, and even pay for professional installation and maintenance services (Chen, 2021). Furthermore, higher-income households are more likely to qualify for loans, financing schemes, or renewable energy investment programs, thereby improving access to green technologies. As a result, the adoption rate of renewable energy is typically higher among affluent households, contributing to a green energy divide between income groups (Ibegbulam, 2023).

Conversely, for low-income households, the financial burden of installing renewable energy systems can be a substantial deterrent. Although renewable energy offers long-term savings by reducing or eliminating monthly energy bills, the upfront cost of purchasing and installing the necessary infrastructure especially without subsidies or favorable financing can be overwhelming (Hasan, 2023). This issue is particularly severe in rural or marginalized areas of developing countries, where energy access is already limited, and poverty levels are high. In many cases, these communities continue to rely on traditional and less efficient energy sources like firewood, charcoal, kerosene, or diesel generators, which are not only more polluting but also more expensive in the long run (Jha, 2023) [32].

Income disparity in energy access also reinforces the cycle of poverty. Without reliable and affordable energy, low-income households may face barriers to productivity, health, and education (Hasan, 2023). Renewable energy could be a transformative solution in these contexts, but without appropriate financial support mechanisms, the cost barrier remains insurmountable. To address this gap, targeted policy interventions and inclusive financing models are essential. Government subsidies, low-interest loans, micro-financing, pay-as-you-go (PAYG) systems, and community-based renewable energy projects can help democratize access to renewable energy technologies (Wright, 2020). By designing programs that consider income level and socio-economic status, governments and organizations can reduce the financial barriers for lower-income households and promote more equitable energy transitions (Padonou, 2022).

Access to financing and the availability of government incentives are critical socio-economic factors that significantly influence household adoption of renewable energy technologies (Rabenold, 2020) [55]. Renewable energy systems, such as solar panels, wind turbines, and geothermal heating units, often come with high initial costs. For many households, particularly those in low- to middle-income brackets, these upfront expenses can be prohibitive unless mitigated by financial support mechanisms (Ray, 2021).

Governments and financial institutions can play a transformative role in enabling broader adoption of renewable energy through carefully designed incentive programs and accessible financing options (Karbo, 2024) [34]. Common financial incentives include tax rebates, grants, subsidies, and feed-in tariffs, all of which serve to reduce the capital required for installation and increase the attractiveness of renewable technologies (Kumar, 2024). systems, while subsidies can directly cover part of the purchase or installation costs. Feed-in tariffs, where households are paid for the energy they generate and feed into the grid, can also offer long-term financial returns, encouraging more homeowners to invest in renewable solutions (Lukuyu, 2023) [43].

In addition to these incentives, access to affordable financing such as low-interest loans, micro-finance programs, and pay-as-you-go (PAYG) schemes enables households that do not have sufficient savings to spread out the cost of installation over time (Ketuama, 2022). This approach can make renewable energy systems more affordable for lower-income households and reduce the reliance on traditional, polluting energy sources like kerosene or firewood. Financial institutions, both public and private, play a vital role here by designing tailored loan products for energy access and working with governments or donors to minimize lending risks (Kimutai, 2025).

However, the absence of such support mechanisms often stalls renewable energy adoption. In regions where subsidies and incentives are not available or are poorly implemented, the cost barrier remains high, particularly for financially vulnerable households (Kaputo, 2023). Even when incentives exist, households may face challenges accessing them due to bureaucratic red tape, lack of awareness, or difficulties in meeting eligibility criteria. In many developing countries, rural and underserved communities may also struggle with limited access to formal banking and credit facilities, further hampering their ability to secure financing for renewable energy investments (Semenya, 2020) [62].

Moreover, creditworthiness is a key determinant in whether a household can obtain financing. Low-income households often lack the collateral or financial history required by traditional lenders, making it difficult to qualify for loans even if they would benefit greatly from renewable energy access (Sexena, 2021). As a result, financial exclusion remains a major challenge in scaling up household-level renewable energy deployment. To overcome these barriers, inclusive financial strategies are essential (Ukoba, 2024). Governments can partner with non-governmental organizations (NGOs), microfinance institutions, and private companies to create flexible, community-based financing models. Furthermore, simplifying the process of applying for and accessing government incentives can help more households benefit from existing programs (Wilberforce, 2023).

Education and awareness play a pivotal role in shaping household decisions regarding the adoption of renewable energy technologies. These factors influence how individuals perceive, evaluate, and act upon information related to renewable energy, ultimately affecting adoption rates within communities (Ukoba, 2024). Households with higher levels of education tend to have greater access to information, improved comprehension of technical concepts, and better decision-making skills when it comes to evaluating energy options (Yumkella, 2021). Educated individuals are generally more aware of the long-term economic and environmental benefits of renewable energy, such as reduced electricity bills, lower carbon emissions, energy independence, and enhanced property value. As a result, they are more likely to adopt technologies like solar photovoltaic (PV) systems, solar water heaters, or small-scale wind turbines. Furthermore, higher education levels are often associated with greater technological literacy, which makes it easier for these households to navigate the complexities of installing and maintaining renewable energy systems (Brown, 2020).

Education also promotes a mindset that is open to innovation and change. Households with educated members are often more inclined to experiment with new technologies and embrace sustainability as a personal or community value. Such households may also have more confidence in making informed financial decisions, including taking advantage of subsidies, tax incentives, or financing options available for renewable energy installation (Bibri, 2023) [5].

In contrast, households with lower levels of education or limited exposure to renewable energy concepts may view such technologies with skepticism or indifference (Chishimba, 2024) [15]. A lack of understanding about how these systems work, how much they cost, and the savings they can generate over time can create significant barriers to adoption. Moreover, a general lack of awareness about available financial incentives and government programs supporting renewable energy can further prevent low-education communities from taking action (Chitandula, 2024). In many cases, even if incentives exist, they go underutilized due to insufficient outreach and communication. This gap highlights the importance of awareness-raising initiatives, particularly in rural or underserved communities, where educational attainment and access to information may be limited (Brown, 2020).

To overcome these barriers, governments, NGOs, and private stakeholders must invest in public education and outreach campaigns that target various demographics. These campaigns can include community workshops, school programs, media campaigns, and door-to-door information dissemination (Iqbal, 2021). Tailored communication strategies that use local languages, visual aids, and relatable examples can be particularly effective in increasing awareness and changing perceptions. Additionally, showcasing successful case studies of renewable energy adoption within the same community or socio-economic context can help build trust and encourage replication. Peer influence and community role models can be powerful motivators for change, especially when educational barriers are present (Hassan, 2024).

Chishimba (2024) [15] assessed how access to household energy influences the socio-economic wellbeing of families in Zambia. The study focused on understanding the varied effects of grid-connected versus off-grid electricity solutions specifically standalone solar home systems on households' involvement in nonfarm employment, income levels, and monthly expenditures. Findings show that households generally demonstrate a positive willingness to pay (WTP) for both grid and solar photovoltaic (PV) technologies across different payment timelines. Notably, average WTP rises as the credit repayment period extends. However, for low-capacity standalone solar systems, average WTP falls below market prices when repayment periods are shorter than 12 months. In contrast, for grid electricity and higher-capacity standalone solar systems, average WTP remains above market prices across all repayment durations. These insights highlight the importance of providing electricity that supports productive use beyond basic lighting. To enhance electricity access among unconnected households, the study recommends improving access to credit financing or offering subsidies to ease connection costs. The introduction of credit options increases WTP by enabling low-income households to better manage their consumption patterns (Chishimba, 2024) [15].

In low-income countries, poor households often rely on traditional energy sources for basic needs, which contribute to broader socio-economic and environmental challenges. To address this issue, policy interventions have promoted access to energy-efficient and renewable energy technologies. However, limited research exists on the demand-side, particularly regarding the factors influencing households' joint adoption of such technologies. This study investigates the determinants of household decisions to adopt energy-efficient and renewable energy technologies using cross-sectional data from 195 households in central Ethiopia. A generalized ordered probit model, a flexible discrete choice approach, was employed for analysis. Results indicate that wealthier households are more likely to adopt both improved cook stoves and renewable energy systems due to their greater ability to cover upfront costs. Factors such as larger household size, greater land ownership, and more livestock are positively associated with the adoption of both technologies. Additionally, higher educational attainment by the household head decreases the likelihood of not adopting any technology while increasing the likelihood of adopting renewable energy. Engagement in off-farm income activities and membership in local cooperatives also raise the likelihood of investing in renewable energy technologies. Furthermore, access to credit enhances the adoption of energy-efficient technologies. The study suggests that poverty alleviation and education policies, along with improved credit access, expanded off-farm employment, and stronger cooperative networks, are key to encouraging broader adoption of clean energy technologies (Guta, 2020) [22].

2.4 Limitations faced by households in transitioning from traditional to renewable energy sources.

The upfront cost of renewable energy systems is a major deterrent for many households. Technologies such as solar photovoltaic (PV) panels, wind turbines, biomass digesters, and geothermal heat pumps require substantial initial investment for purchase, installation, and system integration (Lee, 2020). In many cases, this cost is higher than the monthly or annual expenses of using conventional energy sources like grid electricity, charcoal, or kerosene. While renewable energy systems offer long-term savings, the high cost barrier is especially limiting for households with limited disposable income. The situation is worsened in developing countries, where the price of imported renewable energy technology remains high due to taxes, limited supply chains, and lack of local manufacturing (Infield, 2020).

Access to financial support such as loans, subsidies, grants, and affordable payment plans significantly influences the adoption of renewable energy (Mungai, 2022). Unfortunately, many households especially in low-income or rural areas lack access to credit due to inadequate financial records, informal employment, or poor credit ratings. Traditional financial institutions often view renewable energy investments as risky or unfamiliar, making them hesitant to lend (Umamaheswaran, 2024). Microfinance institutions, while more inclusive, may offer short-term loans with high interest rates, making them less attractive. As a result, even if households are motivated to adopt renewable energy, they may not be able to secure the necessary capital to invest.

A widespread barrier is the general lack of awareness regarding the benefits, availability, and functioning of renewable energy systems (Tembo, 2023). Many households are either unaware of these technologies or have misconceptions about their efficiency, durability, and cost-effectiveness. Some may not understand how renewable energy compares to traditional sources or how to access government programs or installers. This knowledge gap discourages adoption, especially among less educated communities (Chisamba, 2022). Without targeted awareness campaigns and education initiatives, many people remain skeptical or indifferent to transitioning away from the energy sources they have used for generations (Cantarero, 2020) [9].

Transitioning to renewable energy often requires technical knowledge that the average household does not possess. Installing solar panels, for instance, involves site assessment, system sizing, wiring, and inverter configuration (Ghezelayagh, 2021) [20]. In areas where skilled technicians are unavailable, households may avoid renewable energy altogether due to fears of improper installation or lack of technical support. Many households worry about the reliability of renewable energy, especially if they live in areas with inconsistent sunshine, weak wind currents, or seasonal rainfall (Williams, 2022). Unlike fossil fuels that offer continuous supply, renewable sources are weather-dependent and require proper energy storage to guarantee uninterrupted service. When energy storage systems (e.g., batteries) are not available or affordable, power outages or reduced energy supply can occur, discouraging adoption. These reliability concerns lead many households to stick with traditional energy sources, even if they are more costly or polluting in the long run (Saldarini, 2023).

Cultural preferences and long-standing habits also play a key role in energy choices. Switching to electric or solar cooking systems might be resisted not due to cost or availability, but because of entrenched cultural practices (Streimikiene, 2022) [65]. Similarly, households accustomed to kerosene lighting or coal heating may be hesitant to adopt technologies that require changes in daily routines or lifestyle. Behavior change requires time, trust, and sustained community engagement (Meried, 2021) [45].

The European Union (EU) has committed to becoming a carbon-neutral society by 2050, with a key strategy being the widespread adoption of renewable energy in households. However, numerous economic, social, technical, and behavioral challenges hinder this transition. Additionally, renewable energy technologies remain largely unaffordable for low-income households struggling with energy poverty and affordability issues. In a 2022 study, Streimikiene critically examined these barriers along with the policies and measures implemented to support renewable energy micro-generation in residential settings. The study emphasized that instead of subsidizing energy bills for low-income groups, it would be more effective to introduce well-designed policy measures that promote renewable technologies and home energy renovations. This approach not only addresses energy poverty more sustainably but also supports a just and inclusive transition to low-carbon energy, acknowledging the compounded barriers that vulnerable groups face in adopting clean energy solutions (Streimikiene, 2022) [65].

Government policies and regulations are critical enablers of renewable energy adoption. Unfortunately, in many countries, policy support is either inconsistent or insufficient (Chishimba, 2022) [13]. Bureaucratic delays in permitting, unclear subsidy programs, lack of standardized pricing structures, or inadequate regulatory frameworks often make adoption cumbersome for households. Where policies exist, lack of enforcement or inadequate dissemination means households are unaware of available support. This policy vacuum can discourage investment, especially for early adopters who need confidence in a stable regulatory environment (Lee, 2020).

Umamaheswaran *et al*. (2024) [67] examined how investors, specifically debt providers, perceive the risks involved in financing renewable energy projects in India and identified the key factors influencing these perceptions. The study focused on understanding the primary concerns of bankers and what shapes their views on risk. Through a combination of qualitative interviews and a quantitative survey including exploratory factor analysis—the researchers gathered insights from Indian banking executives. The qualitative phase helped define "risk perception" in the renewable energy context, while the survey quantified the influencing factors. The results revealed that the most significant factor influencing risk perception is the investor's experience and institutional capacity, accounting for 30% of the variance. The next most influential factor, responsible for 15% of the variance, was the comparison of risks in renewable energy financing versus other infrastructure projects. Among specific risk types, technological risk was seen as the least concerning (5%), while contractual and regulatory risks were viewed as the most significant (66%) (Umamaheswaran, 2024).

Toilet-linked anaerobic digesters (TLADs) convert organic waste, including human excreta (HE), into clean biogas and fertilizer. Although socio-cultural resistance is often cited as the main reason for local opposition to TLADs—particularly due to the use of HE as input—this explanation can oversimplify the issue. A qualitative study involving in-depth semi-structured interviews with potential TLAD users in Assam, India, found that such resistance is not uniform. Instead, it varies according to individual identities, social roles, and local contexts. The findings indicate that resistance stems from both socio-cultural and socio-technical factors and may be open to change. Adoption could be improved through methods like community-based adoption, demonstrations, and increased perceived utility of the technology. The focus on household-level decision-making and a general assumption of socio-cultural opposition has possibly obscured operational shortcomings in Assam's biogas program. For TLADs to gain broader acceptance, authorities need to engage with communities and program staff to shift perceptions of HE from being a waste to a usable resource. Furthermore, Assam's biogas strategy should improve how it identifies suitable households, reconsidering its reliance on local intermediaries and its preference for homes with many cattle, which may overlook those with real need and motivation (Williams, 2022).

The attainment of Sustainable Development Goals (SDGs) heavily relies on ensuring universal access to modern, adequate, and efficient energy. At present, developing regions, particularly sub-Saharan Africa (SSA), are most susceptible to environmental issues resulting from reliance on non-renewable energy sources. Globally, countries are working towards adopting renewable energy (RE) solutions that produce zero or minimal greenhouse gas emissions. However, SSA faces numerous obstacles that hinder the effective use of its renewable energy resources. In response to this, Bishoge *et al*. (2020) [6] investigated the potential of renewable energy to support sustainable development in SSA, offering a comprehensive analysis of the barriers to RE utilization and suggesting strategies to overcome them. The study conducted a systematic review of literature on renewable energy and sustainability in SSA, focusing on research published between 2012 and 2020. Data were sourced from bibliographic databases like Web of Science, then organized, analyzed, and presented using thematic analysis, graphs, and tables. Findings highlighted that while SSA possesses significant RE potential such as hydropower, solar, wind, biomass, and geothermal energy its development is impeded by limited technical, financial, and human resources, along with weak institutional frameworks and sociopolitical challenges. To address these issues, the study recommends strengthening institutional and regulatory systems, investing in capacity development, mobilizing financial resources, and improving security and political stability to attract investment (Bishoge, 2020).

Zambia possesses significant renewable energy potential, yet it contends with a complex blend of challenges and prospects in fully leveraging this potential. This study aimed to explore the key drivers and obstacles to adopting renewable energy technologies beyond hydropower. Drawing on expert interviews and a thorough analysis of relevant documents, the research reveals a complex interplay of regulatory, financial, infrastructural, and societal factors alongside promising opportunities presented by the country's rich alternative renewable resources. Guided by an interpretive philosophical approach, the study recognized that reality is shaped by personal experiences and social contexts. In line with this perspective, the research sought to deeply understand the enabling and limiting factors within Zambia's renewable energy sector. An inductive methodology was applied to explore emerging themes without relying on preconceived theories, generating insights directly from empirical data. A qualitative, descriptive research design specifically, a survey was used to capture the sector's complexities. The study focused on major players in the electricity sector, employing purposive sampling with maximum variation to ensure a broad range of viewpoints. Data was gathered through in-depth interviews and document analysis. Findings underscore the urgent need to diversify Zambia's energy portfolio, given the increasing unreliability of hydropower due to climate change. Major barriers identified include regulatory inefficiencies, limited access to finance, and public resistance. The study recommends regulatory reforms, the development of innovative financing solutions, and robust public education campaigns. It also encourages international cooperation to harness technical expertise, policy support, and financial resources. Overall, the research offers a strategic framework for advancing Zambia's renewable energy sector, providing practical guidance for achieving sustainable energy development and economic growth (Mhango, 2024) [46].

The growth of renewable energy particularly for electricity generation has accelerated significantly, with renewable accounting for two-thirds of all new power capacity added globally in 2018. In many countries, renewable power has become cost-competitive with fossil fuels. However, various challenges continue to hinder its full adoption. These obstacles differ by country or region and span several areas, including economic, technical, informational and awareness-related, financial, regulatory and policy-related, institutional and administrative, social and environmental, as well as demand-side barriers an area gaining recent attention. A newer technical challenge is the integration of variable renewable sources into existing power grids, particularly in countries with high renewable penetration. This paper highlights the considerable progress made in identifying these barriers and implementing solutions. Key strategies include establishing strong political will through clear renewable energy targets, as well as adopting supportive policies like feed-in tariffs, auctions, renewable energy certificates, portfolio standards, and net metering. Additional measures involve fiscal incentives such as tax credits and subsidies, along with direct public investment in renewable energy initiatives. Crucially, engaging stakeholders is essential not only in recognizing the barriers but also in formulating effective solutions to overcome them (Painuly, 2021).

Households that seek to move from traditional energy to renewable energy face many financial, technical, social, and institutional constraints. These constraints shape how people make energy decisions and explain why the shift to renewable systems progresses slowly in many regions. The first and most common limitation is the cost of renewable technologies. Solar PV panels, wind systems, biomass digesters, and geothermal pumps need a high upfront investment that many households cannot afford. This investment includes purchase, transport, installation, and the basic structural work needed to integrate these systems into homes (Lee, 2020). For most families, traditional fuels such as charcoal, kerosene, and grid electricity require lower day to day spending. This makes them easier to manage within limited budgets even though these fuels create long term expenses. The cost challenge increases in developing countries where imported technologies carry taxes and shipping charges and where local manufacturing is limited (Infield, 2020). As a result many homes remain with energy options that are less efficient and less clean.

Access to finance plays a large role in shaping adoption. Loans, subsidies, grants, and flexible payment plans create room for renewable energy uptake, but in many places these options remain out of reach. Households in rural or low income areas often work in informal sectors and cannot produce formal proof of income. They also face challenges with credit ratings or lack a savings account. Many banks treat renewable investments as risky or unfamiliar projects and hesitate to offer loans (Mungai, 2022). Microfinance institutions support small borrowers, but they often give short term loans with high interest rates that create pressure on households (Umamaheswaran, 2024). As a result, even motivated households cannot secure the capital needed to invest in long term energy systems. The lack of suitable finance tools slows progress toward clean energy adoption across many regions.

Knowledge and awareness also influence energy decisions. Many households do not have access to reliable information about renewable energy systems. They may not know the benefits, maintenance needs, or expected performance of these systems (Tembo, 2023). Misconceptions spread easily in communities where exposure to new technologies is low. Some households believe renewable systems have low durability, low efficiency, or high maintenance needs even when evidence suggests otherwise (Chisamba, 2022). Others may not know how to access government support programs or approved installers. Limited awareness increases uncertainty and creates fear of making costly mistakes. Without targeted public campaigns and simple education materials, many households remain unsure about leaving energy sources that they have depended on for many years (Cantarero, 2020) [9].

Technical constraints arise within the installation and maintenance stages. Renewable systems need correct sizing, correct wiring, and careful alignment. Solar systems need proper panel positioning and battery configuration. Wind systems need suitable land and strong wind conditions. Biomass systems need constant supply of feedstock and regular cleaning. Many households lack technical skills related to these tasks and depend on local technicians who may not be available or trained (Ghezelayagh, 2021) [20]. If a system fails or produces low power due to poor installation, users lose trust in the technology and may not attempt a second investment. Technical support is also limited in rural areas where supply chains are weak and spare parts take long to arrive. These technical gaps create a strong incentive to remain with fossil fuels or grid electricity.

Reliability concerns influence household choices as well. Renewable energy depends on natural patterns. Solar systems depend on sunlight. Wind systems depend on wind speed. Biomass systems depend on continuous feedstock. In regions with unpredictable weather patterns or seasonal change, households worry about energy shortages during cloudy or rainy periods (Williams, 2022). Energy storage systems play a role in solving these gaps, but batteries remain costly for many families. Without storage, households fear that they will not have power at night or during storms. These concerns push families toward traditional fuels that supply constant power and reduce the risk of interruptions. Many homes remain with charcoal, kerosene, or grid power because these fuels appear more stable even though they cost more in the long run (Saldarini, 2023).

Social and cultural factors also influence the pace of transition. Energy use connects with daily routines and long standing habits. Cooking is one example. Many families prefer cooking with charcoal or firewood because these fuels produce heat patterns that suit local dishes. Some do not trust electric or solar stoves because of taste or speed concerns. These household preferences slow the spread of renewable cooking systems (Streimikiene, 2022) [65]. Lighting habits also change slowly. People who grew up using kerosene lamps may not accept new technologies until other community members adopt them. Behavior change needs time, community leadership, and trust building (Meried, 2021) [45]. When renewable programs fail to involve local leaders or ignore cultural habits, adoption remains low.

Policy environments shape household decisions as well. A country's regulatory framework can support or weaken the transition. Clear rules, stable pricing structures, and transparent subsidy schemes give households confidence. Many countries lack these conditions. Households face long bureaucratic procedures, unclear policies, or shifting rules about incentives (Chishimba, 2022) [13]. Information about policies often does not reach remote areas. Some governments introduce renewable programs but fail to monitor or enforce them. Without stable support, households delay investment because they fear that future changes may raise costs or remove benefits. Investors, banks, and suppliers also wait for stable rules before entering a market. These policy gaps slow renewable adoption and keep households dependent on traditional fuels (Lee, 2020).

Research on investor perspectives provides insight into how financing institutions shape the availability of household loans. A study in India examined how bankers understand risk in renewable energy financing and found that past experience and institutional capacity strongly influence risk perception (Umamaheswaran, 2024). Banks compare renewable projects with other infrastructure investments and often view contractual and regulatory risks as the largest concern. Technological risks rank much lower. This means many banks trust the technology but remain unsure about policy stability and contract enforcement. If banks remain hesitant, households cannot access the loans needed to adopt clean energy systems. This link between investor confidence and household transition shows how renewable energy adoption depends on conditions across the entire energy chain.

Other studies examine socio technical barriers linked to specific technologies. Research on toilet linked anaerobic digesters (TLADs) in Assam provides insight into how social norms, identities, and community roles shape adoption (Williams, 2022). Many programs assume that households reject digesters because they use human waste, but the study found that resistance varies across families. Some people oppose the technology for cultural reasons while others consider it acceptable if the system is demonstrated and if they see the value of the produced biogas. The study also found that local program design and weak institutional support limit adoption. Many households that could use the technology are not reached because selection processes favor homes with cattle instead of focusing on motivation or need. These findings show that renewable programs must mix social engagement with technical planning to overcome household level barriers.

Studies from sub Saharan Africa reveal broader structural challenges. The region holds strong potential for solar, wind, biomass, and geothermal energy, yet progress remains slow. A review of renewable energy barriers in sub Saharan Africa shows that limited technical skills, low financial capacity, weak institutional systems, and political instability prevent full use of the region's resources (Bishoge, 2020). These barriers extend to households because technical support is scarce, credit systems are weak, and policy structures change often. These conditions make renewable energy appear complex and risky for ordinary families. For many people, the choice is not about preference but about survival. They stay with traditional fuels because they are easy to access and require no complex rules or technical support. This keeps the region locked in fossil fuel dependence even though renewable resources are abundant.

In the Zambian context, renewable adoption faces regulatory, infrastructural, financial, and social constraints. Research using an interpretivist approach and inductive analysis shows that stakeholders in the energy sector observe limited policy clarity, weak coordination, and poor investment incentives as major barriers. Households face unreliable information, weak grid conditions, low income, and limited access to finance. Document reviews and expert interviews point to the need for capacity building, improved institutional frameworks, and support for households that wish to adopt non hydro renewable technologies. Zambia's potential remains strong, but households need support systems that match their socio economic situations.

Across all these contexts, renewable energy adoption by households depends on a combination of financial capacity, technical support, cultural acceptance, and policy stability. High upfront costs, limited credit access, knowledge gaps, unreliable supply, cultural habits, and weak policy frameworks combine to slow the shift from traditional fuels. These barriers affect households in different ways depending on location, income, education, and community structures. Research from many countries show that solutions require integrated strategies that address financial, technical, and social dimensions. Without these conditions, many households will continue to face constraints in adopting renewable energy systems despite the long term benefits and global energy goals.

Chishimba (2022) [13] explores the potential and limitations of solar energy as a sustainable and renewable solution to address Zambia's ongoing power shortage. The study aims to assess how solar power, as an abundant and inexhaustible resource, can supplement existing electricity generation to eliminate the energy deficit. Employing a mixed methods research (MMR) approach which integrated both quantitative and qualitative techniques the study gathers data through questionnaires and interviews, providing a well-rounded analysis of the issue. The research proposed a general hypothesis: that fully harnessing and developing solar energy systems could resolve Zambia's power deficit and stimulate economic and national development. Findings suggest that solar power, if properly utilized, could significantly address energy shortages both globally and in Zambia. From a practical standpoint, the study highlights the urgency of tackling power issues worldwide, noting that while industrialized countries are advancing in this area, African nations, including Zambia, have made limited progress. The study concludes by recommending that governments; Zambia's in particular develop comprehensive solar energy policies and invest significantly in solar infrastructure (Chishimba, 2022) [13].

Tembo (2023) investigated the challenges impeding the development and adoption of biogas energy, with a specific focus on identifying the obstacles affecting local government efforts to promote this renewable energy source in Mokambo's peri-urban area. Utilizing a qualitative approach and case study methodology, the research uncovered multiple barriers limiting biogas implementation. Through purposive sampling, 25 key informants were interviewed using a structured guide. The findings categorized the barriers into four key themes: institutional, situational, technical, and dispositional. Stakeholders, particularly non-beneficiaries and private sector representatives, expressed growing concern over the slow progress. Local officials also admitted to shortcomings in meeting energy needs and cited various limitations contributing to this failure. The study calls for the Zambian government to adopt a strategic and structured approach, including the creation of robust institutional frameworks, renewable energy-focused policies, and strong public-private collaborations. It also emphasizes the need for increased research and development, improved market stability, better coordination, heightened public awareness, and enhanced local government capacity to ensure broader access to clean energy through biogas technology (Tembo, 2023).

2.5 The effect of renewable energy adoption on household energy expenditure

The initial investment cost is a significant factor influencing the adoption of renewable energy technologies at the household level. Renewable energy systems such as solar panels, wind turbines, and geothermal heating are typically more expensive to install compared to traditional energy systems (Bibri, 2023) [5]. The upfront capital required for these technologies can be a major deterrent for many households, particularly those with limited financial resources (Siraj, 2024). In many cases, these costs far exceed the financial capacity of low- or middle-income households, making it difficult for them to transition from conventional energy sources to renewable alternatives (Phiri, 2024) [54].

The cost of installing renewable energy systems varies depending on the technology used and the scale of the installation (Bruce, 2021). Wind turbines and geothermal systems, though effective, often come with even higher installation costs due to the complexity of the technology and the need for specialized installation and maintenance services (Cooper, 2020) [17]. For many households, especially those in developing regions or rural areas, these high initial costs represent a significant barrier to renewable energy adoption. Even though the long-term savings on energy bills may justify the investment, the challenge lies in the ability to afford the upfront expenditure (Felody, 2022) [19]. As a result, the adoption of renewable energy systems is often limited to higher-income households that can afford the initial outlay, while lower-income households remain reliant on more affordable, conventional energy sources, such as coal or natural gas, which often come with higher environmental and health costs (Bibri, 2023) [5].

To mitigate the financial barrier posed by the high initial capital costs, many governments around the world offer various financial incentives, subsidies, and low-interest loans to encourage renewable energy adoption. These incentives can significantly reduce the upfront cost, making it more affordable for households to install renewable energy systems (Siraj, 2024). In some cases, governments offer grants or subsidies for low-income households, specifically targeting vulnerable populations that may otherwise be unable to afford renewable energy systems (Phiri, 2024) [54]. Furthermore, low-interest loans and financing programs are often available, allowing households to spread the cost of installation over time and alleviate the financial strain of a lump-sum payment. These financial mechanisms can make renewable energy technologies more accessible, although the effectiveness of such programs ofen depends on the household's eligibility and understanding of the available options (Bishope, 2020).

However, despite the availability of incentives, the complexity of navigating these financial programs can be a barrier in itself, particularly for low-income households that may lack access to the necessary resources or information to take full advantage of these opportunities (Brown, 2020). In addition to the renewable energy systems themselves, households may also need to invest in energy storage systems to maximize the benefits of renewable energy adoption. Energy storage technologies, such as batteries, are essential for ensuring a steady and reliable supply of energy, especially in cases where renewable energy sources, like solar or wind, are intermittent in nature (Chakulanda, 2024) [11]. Batteries allow households to store excess energy generated during peak production times (e.g., midday for solar power) and use it when energy demand is higher or when the renewable energy source is not producing power (e.g., at night for solar systems). However, the installation of energy storage systems adds another layer of cost to renewable energy adoption. High-quality battery systems can be expensive, with prices typically ranging from a few thousand dollars to over ten thousand dollars, depending on the storage capacity required (Mutale, 2023).

For larger households or those situated off the grid, the need for larger energy storage systems can increase the financial burden significantly. In off-grid areas, where grid electricity is not available, the reliance on renewable energy systems and storage becomes even more critical (Mperejekumana, 2024). In such cases, the need for energy storage is essential to provide a consistent power supply, making it one of the most crucial investments in the renewable energy adoption process. While the combination of renewable energy systems and energy storage offers long-term savings on energy bills and greater energy independence, the initial investment required to install both the energy generation and storage systems can be a significant financial hurdle (Lukuyu, 2023) [43]. This is especially true for households that are already struggling with financial constraints, as the high upfront costs may prevent them from realizing the long-term benefits of renewable energy (Kumar, 2024).

The adoption of renewable energy technologies, such as solar panels, wind turbines, and geothermal heating systems, can significantly reduce household energy bills over the long term (Obaideen, 2022). Once the initial investment is made and the systems are installed, households can enjoy consistent savings by decreasing their dependence on traditional energy sources like grid electricity, oil, or natural gas for heating and other power needs. These savings are often substantial and become more pronounced over time as the system pays for itself (Yaguma, 2024) [74].

One of the most immediate financial benefits of renewable energy adoption is the reduction in utility bills. For households that rely heavily on grid electricity, installing solar panels or wind turbines can greatly diminish their monthly energy expenses (Arunachala, 2020). This reduces the amount of electricity a household needs to purchase from the grid, directly lowering their monthly utility bills. In many cases, households with solar power systems may even be able to achieve a near-zero electricity bill if they generate enough electricity to meet their needs (Chagas, 2020).

In regions where electricity prices are high, or where there are regular power outages, renewable energy can be particularly advantageous. In addition to lowering energy costs, solar and wind systems can offer more stable pricing compared to the unpredictable costs of fossil fuels. By relying on renewable energy, households are less affected by these price fluctuations, making their energy costs more predictable and manageable (Babyyomi, 2023). Moreover, the adoption of renewable energy technologies may be complemented by energy efficiency measures such as improved insulation, LED lighting, or energy-efficient appliances. These combined measures further reduce energy consumption and maximize the savings from renewable energy systems, helping households maintain lower bills over time. Households that embrace renewable energy often find that they can cut down on their energy usage, making their homes more energy-efficient and cost-effective (Biachini, 2022).

Another significant benefit of renewable energy adoption is the increased energy independence it provides to households (Biachini, 2022). By generating their own electricity, households reduce their reliance on external energy sources, which can be particularly advantageous in areas with unreliable or expensive grid electricity. For example, in rural areas where the grid may be distant or unstable, installing solar or wind energy systems can offer a reliable source of power that is not subject to the volatility of the local electricity market (Rahmany, 2021).

Energy independence also shields households from the unpredictable nature of fuel prices. Fossil fuel prices whether for natural gas, coal, or heating oil are subject to fluctuations based on factors such as global supply and demand, political instability, and changes in international trade agreements (Ray, 2021). When prices increase, households face higher energy bills, and many may struggle to afford this increase. Renewable energy, on the other hand, relies on natural resources that are not subject to the same pricing pressures (Padonou, 2022).

Wind energy also provides a similar advantage, especially in areas with consistent winds. Wind turbines can generate electricity at a steady rate, and like solar, the "fuel" for wind energy wind is free. By shifting to these renewable energy sources, households can protect themselves from fluctuating energy prices, ensuring more stable and predictable energy costs over the long term (Padonou, 2022). This is particularly valuable for households in regions that experience significant utility rate hikes or in countries where energy costs are a considerable portion of household budgets (Babayomi, 2023). In addition to financial savings, energy independence has broader implications for security and sustainability. Households that rely on renewable energy are less vulnerable to supply disruptions caused by natural disasters, infrastructure failures, or other external factors. By generating their own power, these households gain greater control over their energy usage and reduce their exposure to disruptions in the energy supply chain (Chen, 2021).

The long-term savings associated with renewable energy adoption go beyond monthly utility reductions (Arunachala, 2020). As energy prices continue to rise globally, households that have invested in renewable energy technologies will likely see an increasing gap between their low energy costs and the higher costs faced by those still dependent on traditional energy sources (Wright, 2020). Over time, the financial benefits compound, and the return on investment becomes more pronounced. Many renewable energy systems, such as solar panels, are designed to last for decades, with warranties often ranging from 20 to 30 years. This longevity means that households can continue to enjoy low or no-cost energy for the entire lifespan of the system, after recovering the initial investment. After this payback period, the household can continue to benefit from free electricity for the remaining lifespan of the system, often leading to tens of thousands of dollars in savings (Arunachala, 2020).

While renewable energy systems offer many long-term financial benefits, they do come with ongoing maintenance costs that households must consider (Chagas, 2020). Despite being less maintenance-intensive than traditional energy systems, such as fossil fuel-powered generators or heating systems, renewable energy technologies still require periodic attention to ensure optimal performance (Kaputo, 2023). These maintenance needs can vary depending on the type of technology used, the scale of the system, and the environmental conditions in which the system operates (Saxena, 2022).

The level of maintenance required for renewable energy systems is generally lower than that of conventional energy systems, particularly when it comes to solar panels, wind turbines, and geothermal systems (Roga, 2022). However, all these technologies require some level of upkeep to maximize their efficiency and lifespan. Solar panels are among the most common renewable energy systems installed in households. One of the advantages of solar power is that solar panels typically have few moving parts, which means less wear and tear compared to other energy generation systems (Saxena, 2022). However, solar panels still need regular maintenance to ensure they are functioning at peak efficiency. Over time, dirt, dust, leaves, and other debris can accumulate on the surface of the panels, blocking sunlight and reducing energy generation. In areas with high levels of dust or pollen, or in regions prone to heavy snowfall, solar panels may require more frequent cleaning (Chisonga, 2023).

Many households that adopt renewable energy also install energy storage systems, such as batteries, to store excess energy generated during the day for use at night or during periods of low production (Hasan, 2023). Batteries, while essential for maximizing the benefits of renewable energy systems, have a finite lifespan and will need to be replaced after a certain number of years, typically 5 to 15 years, depending on the type of battery (Lee, 2020).

Although less common in residential settings, wind turbines are another renewable energy system that requires maintenance (Cantarero, 2020) [9]. Wind turbines have moving parts, such as blades and a rotor, which are subject to wear and tear from constant movement. Regular inspection and lubrication of these components are necessary to ensure the turbine operates efficiently and doesn't experience mechanical failure. Maintenance may include checking for corrosion, ensuring that the blades are not obstructed by debris, and ensuring that the turbine is balanced (Lee, 2020).

As research and development continue to improve renewable energy systems, maintenance requirements are becoming less frequent and more cost-effective. For example, solar panels are becoming more efficient, meaning they require less cleaning and less maintenance to achieve high performance (Ghezelayagh, 2021) [20]. In addition, solar panel manufacturers are now offering warranties of 25 years or more, which significantly reduces the need for repairs or replacements during the early life of the system. Similarly, energy storage technologies are evolving, with newer battery systems being more durable and requiring fewer replacements (Meried, 2021) [45]. Advances in battery technology have led to the development of longer-lasting and more efficient batteries, reducing both the cost of installation and the frequency of battery replacements. As battery costs continue to decrease and performance improves, households will likely see reduced maintenance costs associated with energy storage systems (Infield, 2020).

Lee and Shepley (2020) [41] examined the impact of South Korea's sustainable energy policy aimed at equipping low-income residents in public rental housing in metropolitan Seoul with solar photovoltaic (PV) systems. The study evaluated the policy's effectiveness in delivering affordable and reliable energy to energy-poor households. This assessment involved analyzing government energy policy documents, along with conducting surveys and focus group interviews with tenants, installers, and public officials. Findings revealed that the policy was part of broader efforts to transition from fossil fuels to renewable energy sources, with a focus on reducing CO_2 emissions. A key component was installing solar panels on apartment verandas for low-income residents. The primary motivations for adoption among tenants were the potential reduction in electricity bills and financial support from the government. Participants generally expressed satisfaction with the installation process, their involvement in the policy, and the quality of the solar PV systems. However, satisfaction declined concerning the systems' capacity and the actual savings achieved on energy bills. The study suggests the need for future research with larger sample sizes and longer-term evaluations. It also recommends continued post-installation education, feedback on energy usage, and the integration of smart technologies such as smart grids, meters, and sensors to monitor and enhance system performance (Lee, 2020).

As renewable energy adoption increases, market competition drives down costs across the board. The renewable energy sector has seen significant cost reductions in both installation and maintenance services due to increased competition among manufacturers and service providers (Chen, 2021). More companies entering the market lead to better pricing for consumers, making renewable energy more affordable in the long term. Additionally, as more technicians and specialists are trained to install and maintain renewable energy systems, the cost of labor for maintenance services is likely to decrease (Hasan, 2023). This increased availability of skilled workers helps keep maintenance costs lower than in the early years of renewable energy technology adoption (Eshetu, 2024) [18].

Government subsidies and incentives play a crucial role in the adoption of renewable energy systems, helping households to overcome the significant upfront costs that are often associated with these technologies (Ibegbulam, 2023). Renewable energy adoption can be expensive, particularly for households with limited financial resources, which is why many governments around the world offer financial assistance to encourage individuals and businesses to transition to cleaner energy sources. These incentives typically come in the form of tax rebates, grants, and subsidies that can substantially reduce the initial cost burden, making renewable energy more accessible and affordable (Jha, 2023) [32].

Access to reliable, uninterrupted, and environmentally sustainable energy is essential for maintaining household health and environmental quality in developing nations like Ethiopia. However, to ensure the effective adoption of adequate energy solutions, household preferences must be considered. This study aimed to assess the factors influencing rural household preferences for shifting from traditional to renewable energy sources and to estimate their willingness to pay (WTP) for different energy alternatives. Data were collected in 2019 from 212 randomly selected households in Ethiopia's North Gondar zone. Descriptive findings indicated that hydropower was the most favored option, with an average monthly WTP of 36.86, followed by solar energy and transitional fuels. The total estimated annual WTP for hydropower among respondents was 93,771.86, suggesting a strong willingness among households to contribute financially toward renewable energy services. The multinomial logit model results showed that a majority of respondents supported the move to cleaner energy sources. Key socioeconomic factors influencing energy preferences included age, family size, income, education level, and access to credit. However, the study found an inconclusive relationship between income levels and the adoption of improved energy sources. Overall, the findings underscore the importance of understanding household preferences when planning energy transitions. The study recommends that policymakers and stakeholders consider both the preferences and WTP of rural households to successfully implement sustainable and effective energy strategies, while also promoting access to mechanisms that support the use and development of improved energy alternatives (Meried, 2021) [45].

Sub-Saharan Africa is uniquely positioned to benefit from the socio-economic and environmental advantages of renewable energy and energy efficiency, especially as energy demand continues to rise across the region. Evaluating the financing opportunities and identifying barriers to investment in these sectors is a critical step toward attracting financial flows. With the region's rapid population growth, increasing urbanization, and expanding economies combined with the global push under the Sustainable Energy for All Initiative the urgency for accessible, clean energy is greater than ever. Mungai (2022) explored the investment potential and policy-related challenges in renewable energy (RE) and energy efficiency (EE) across Sub-Saharan Africa. The study assessed five key investment indicators using secondary data and interviews with relevant stakeholders. It quantified the investment potential, existing investment gaps, and policy constraints across 14 countries in West, Central, Southern, and East Africa. Findings reveal a promising future for renewable and energy-efficient technologies in the region, though progress remains vulnerable due to significant funding shortages from both private and public sources. To improve electricity access, ensure energy security, and support sustainable economic growth, the region must address major institutional and policy-related deficiencies. Closing these knowledge and policy gaps is vital to unlocking the full financing potential for RE and EE across the African continent (Mungai, 2022).

Energy is essential for economic and social development, yet in Zambia, national electricity access remains low 67.3% in urban areas and only 4.4% in rural areas—resulting in a national average of 31.4%. Frequent load shedding and power outages further exacerbate the problem. This study assessed the efforts by ZESCO to reduce power outages in Lusaka's high-density areas using a mixed-methods approach with 196 participants. Findings reveal that ZESCO has made significant strides, including constructing new power stations (e.g., Kariba North, Musonda Falls), installing transformers for load balancing, and engaging independent producers through bulk power purchase agreements. Additionally, ZESCO is diversifying energy sources by investing in solar power, including a 50MW plant in Lusaka and a 300MW project supported by Japanese partners. These efforts have led to a drastic reduction in power outages from 16 hours to less than 2 hours daily in most areas improving social and economic conditions. Benefits include enhanced use of household appliances, reduced fire and crime incidents, improved business productivity, and better healthcare and education services due to reliable electricity supply (Pambwe, 2021) [53].

The adoption of renewable energy has a direct influence on household energy expenditure because it changes how households invest in energy systems, how they meet daily energy needs, and how they manage long term costs. Renewable energy technologies such as solar panels, wind turbines, and geothermal systems require an initial investment that is often higher than the cost of connecting to or maintaining conventional energy systems. This initial cost remains a strong limiting factor for many households, and it shapes the pace and scale of adoption across different income groups. The high upfront cost of renewable technologies is discussed widely in the literature and is noted as a major barrier among households that operate under fixed or limited budgets (Bibri, 2023) [5]. These households face financial pressure when deciding whether to adopt renewable energy, and many postpone adoption because they cannot meet the initial expenditure (Siraj, 2024). The decision becomes difficult when the cost of installation is higher than the annual or monthly income available for home improvements or energy related investments (Phiri, 2024) [54].

The cost of renewable systems varies across technologies and capacities. Solar systems that power smaller households require fewer panels and smaller inverters, but the price remains higher than the basic cost of a grid connection (Bruce, 2021). Wind turbines and geothermal systems require complex installation processes, which increase the overall cost even more. Households must purchase the equipment, cover installation labour, and prepare the site. These extra requirements increase the financial burden and contribute to low adoption among low income households and households in rural areas that lack access to credit or formal financing (Cooper, 2020) [17]. The high initial cost creates a situation where renewable energy becomes an investment that only households with steady income streams or savings can afford. Households that rely on income from informal employment or seasonal work cannot commit to these systems because the upfront payment is far above what they can manage (Felody, 2022) [19]. As a result, the pattern of adoption favours higher income households, while low income households remain dependent on conventional fuels such as charcoal, kerosene, or grid electricity. These fuels often expose households to higher lifetime energy costs and negative health and environmental outcomes (Bibri, 2023) [5].

Governments in many countries attempt to reduce the financial burden associated with renewable energy through subsidies, tax reductions, grants, and low interest loans. These measures aim to reduce the cost at the point of adoption and support households that lack the financial capacity to pay the full price at once (Siraj, 2024). Some programmes target low income households directly to support equitable access to renewable technologies (Phiri, 2024) [54]. These interventions are intended to allow households to invest in renewable systems and reduce long term dependence on conventional energy sources. When these incentives work well, households can install renewable systems with lower initial payments and repay the remaining costs through structured loan systems. However, the effectiveness of these programmes depends on how easy it is for households to access financial information and navigate the application procedures (Bishope, 2020). Low income households often lack access to financial advice or literacy programmes that explain how the incentives work. As a result, the subsidies remain underused, and the financial barrier continues to influence adoption patterns (Brown, 2020).

Energy storage remains another cost that influences renewable energy adoption and household expenditure. Renewable energy systems that rely on solar or wind require storage systems to supply power when the natural resource is not available. Households use batteries to store excess power, but these batteries are costly to purchase and install. A storage system that can support daily household use may require several battery units, which increases total expenditure before the system becomes functional (Chakulanda, 2024) [11]. Battery systems designed to last longer require even higher investment, and households must factor this into the total cost of adoption (Mutale, 2023). Larger households need larger storage systems, which increases expenditure further. In off grid areas where renewable energy is the primary source of power, the need for storage systems is essential because there is no backup electricity source available during periods of low production. Off grid households must purchase more storage capacity to maintain a consistent power supply, and this raises the initial investment requirement (Mperejekumana, 2024). Although renewable energy and storage systems reduce monthly energy bills over the long term, the upfront cost remains a major factor that shapes the adoption process. The investment is often too high for households with limited income, which restricts long term benefits to households that can handle the initial financial commitment (Lukuyu, 2023) [43]. This creates an uneven distribution of benefits because high income households gain energy independence and lower bills while low income households remain tied to conventional energy costs that rise over time (Kumar, 2024).

While high initial costs influence adoption negatively, renewable energy offers significant cost savings once systems are installed. The most direct financial impact is the reduction in monthly energy bills (Obaideen, 2022). Households that install solar panels or wind turbines reduce dependence on grid electricity because the system produces power daily. When households are able to generate enough electricity to meet their needs, their monthly expenditure on grid electricity decreases. Some households may achieve near zero electricity bills during months when production is high (Arunachala, 2020). This reduction in monthly expenditure is significant for households that face high electricity tariffs or constant price changes. Renewable energy offers a stable source of power that is not tied to the fluctuating cost of national electricity or fossil fuels (Chagas, 2020).

In areas where electricity supply is unstable or unreliable, renewable energy systems provide consistent power without daily or weekly outages. This reduces the cost of running backup generators or purchasing alternative fuels, which are more expensive on a per unit basis. When combined with energy efficiency practices such as improved insulation, energy efficient appliances, and LED lighting, renewable energy systems help households lower energy consumption and reduce overall costs (Babyyomi, 2023). Energy efficiency measures increase the value of renewable energy systems because households require less energy to perform similar tasks, and lower energy consumption translates into additional savings (Biachini, 2022).

Renewable energy also increases household energy independence. Households that generate their own electricity rely less on conventional systems, which protects them from sudden price changes in fuel markets or electricity tariffs (Biachini, 2022). Fossil fuel prices change often due to supply shortages, market conditions, and political conditions. When prices rise, households that rely on conventional fuels experience higher monthly expenditure and reduced financial flexibility (Ray, 2021). Renewable energy sources such as sunlight and wind are not influenced by these market pressures, which allows households to maintain stable energy costs over long periods (Padonou, 2022). Households with renewable systems experience greater control over their energy use because they produce the electricity they need instead of purchasing it from external suppliers. This control strengthens household planning and budgeting because energy costs remain predictable each month (Rahmany, 2021). This predictability is important for households in regions where energy prices increase often or where utility costs form a large share of monthly spending.

Long term savings represent the strongest financial benefit of renewable energy adoption. Energy prices continue to rise in many countries, and households that invest in renewable systems avoid these increases because their systems generate power at no cost once installation is complete (Arunachala, 2020). Over time, the difference between the cost faced by households with renewable systems and those without becomes larger. Renewable energy systems such as solar panels have long lifespans, and many remain functional for more than twenty years. During this period, households avoid monthly costs that would have been spent on electricity or fuel, and this allows the system to pay for itself. After the payback period, households enjoy free electricity for the remainder of the system's life (Wright, 2020). This creates cumulative savings and reduces financial pressure on households.

Maintenance costs also influence the effect of renewable energy on household expenditure. Renewable systems require regular checks to ensure they operate well. These checks might include cleaning, small repairs, or replacement of minor components. These costs are lower than the maintenance costs associated with conventional systems such as fuel generators, which require fuel purchases, frequent servicing, and mechanical repairs (Kaputo, 2023). Households must still include maintenance costs in their budgeting, but these costs do not outweigh the long term savings generated by renewable energy systems (Chagas, 2020).

2.6 Personal critique of literature review

The reviewed literature provides a rich foundation for understanding the types and adoption dynamics of renewable energy sources among households, particularly in Zambia and comparable developing country contexts. A notable strength across the studies is the diversity of renewable energy sources analyzed including small wind turbines, solar mini-grids, biogas, and improved cook stoves each offering unique insights into both their technical and socio-economic dimensions.

Studies by Kumar (2024) and Felody (2022) [19] consistently highlight solar energy as the most widely accessible and practical renewable energy source for households in Zambia. This is primarily due to the country's high solar irradiation, which makes solar mini-grid systems particularly viable in both rural and peri-urban settings. These systems have been lauded for their potential to improve energy access, reduce dependence on traditional biomass, and foster socio-economic development through electrification. However, despite these promising attributes, several critical challenges undermine the sustainability and effectiveness of these solar energy projects.

One major issue identified in both studies is the lack of adequate technical expertise required to manage, maintain, and repair solar systems at the community level. Local capacity building is often overlooked during implementation phases, leaving communities dependent on external technical assistance. This leads to system breakdowns that remain unresolved for extended periods, effectively rendering the infrastructure useless.

Additionally, the financial models underpinning solar mini-grid initiatives are frequently flawed. Kumar (2024) notes that many projects are based on cost-recovery mechanisms that fail to account for the low-income levels of end-users. This results in unaffordable tariffs that discourage usage or cause customers to revert to traditional energy sources. Felody (2022) [19] also highlights cases where poor financial planning and absence of subsidies have led to premature project failures.

Moreover, improper system sizing where either too much or too little capacity is installed results in inefficiencies that further compromise reliability and user satisfaction. These issues point to a broader problem: a lack of holistic planning and community engagement in system design and implementation. Consequently, although solar technologies have immense potential, their long-term viability in Zambia is currently questionable without significant improvements in technical training, financial structuring, community ownership, and policy support mechanisms.

The potential application of small wind turbines in Zambia is briefly discussed by Karbo (2024) [34] and Ketuama (2022), with both authors ultimately dismissing wind energy as an impractical solution for urban environments. Their analyses emphasize several barriers, such as the unreliability of wind speeds in densely populated areas and the lack of infrastructural support for wind technology deployment. These limitations, according to the authors, make wind power a less favorable option compared to solar and biogas technologies, especially for household-level energy needs.

While the rationale presented appears technically sound, the dismissal of wind energy's potential raises critical concerns due to a lack of empirical support. Both studies draw general conclusions without grounding their claims in localized meteorological data or comprehensive wind mapping specific to Zambia. This presents a significant gap in the literature. There is minimal engagement with the regional variability in wind patterns across Zambia's diverse topography—particularly in highland or open plateau regions that may, in fact, possess viable wind speeds for small turbine operation. The absence of region-specific data weakens the reliability of these conclusions and overlooks opportunities for targeted development in off-grid or semi-urban settings. Hence, while the analysis seems realistic, it would benefit greatly from empirical wind assessments and pilot projects that could validate or contest the non-viability narrative.

The adoption of improved cookstoves, a key renewable energy initiative, is critically explored by Lloyd (2021) [42] through the lens of social capital. This study contributes significantly to the literature by shifting the focus from purely technical and economic dimensions of energy solutions to the social and behavioral aspects that influence adoption. Lloyd examines how trust within communities, peer influence, and collective decision-making processes shape household decisions to adopt improved cookstoves. The study's emphasis on the role of informal networks and community leaders is particularly important, considering that energy transitions often depend as much on cultural norms and social cohesion as on affordability or efficiency.

However, while the study identifies compelling correlations between social trust and adoption behavior, it lacks a robust causal framework. For instance, it remains unclear whether increased trust leads to higher adoption rates or if households that adopt cook stoves are simply more embedded in active community networks. The findings appear somewhat contradictory some communities with high trust levels still show resistance to adoption, indicating the presence of other influencing variables such as gender dynamics, perceived benefits, or historical mistrust in development projects.

Moreover, the methodology leans heavily on quantitative survey data, which, although valuable, is insufficient to fully capture the nuances of community behavior and attitudes. The critique here is that the study stops short of deep qualitative inquiry, which is necessary to unravel the complex interplay of social, cultural, and psychological factors in renewable technology uptake. Future research would benefit from incorporating ethnographic methods, focus group discussions, and longitudinal case studies to build a more holistic understanding. Such an approach would help design socially tailored interventions that go beyond technical fixes to achieve long-term sustainability in renewable energy programs.

Globally, Hassan (2024) and Cantarero (2020) [9] present comprehensive assessments of renewable energy transitions, showing impressive gains in countries like Denmark, China, and India. Their inclusion helps situate Zambia's experience within a global framework. However, while these sources effectively advocate for integrated policy, technology, and societal strategies, they fall short of offering actionable insights that can be directly applied to the Zambian context particularly regarding how to overcome infrastructural, economic, and governance barriers that are unique to sub-Saharan Africa.

2.7 Establishment of research gaps

Lack of Empirical Data on Wind Energy Potential: While wind energy is often dismissed as non-viable in Zambia's urban settings, the literature lacks empirical wind speed assessments and geographic mapping across different regions. This gap limits the ability to fully evaluate the feasibility of small wind turbines in specific rural or high-altitude areas where wind potential may be more favorable.

Insufficient Long-Term Evaluations of Solar Mini-Grids: Although solar energy is widely promoted as the most accessible renewable source, existing studies (e.g., Kumar, 2024; Felody, 2022 [19]) do not provide longitudinal data on the performance, maintenance, or sustainability of solar mini-grid systems. The long-term economic and technical viability of these systems remains underexplored.

Inadequate Integration of Financial Models in Renewable Energy Planning: Many studies identify affordability and tariff-related issues in renewable energy adoption but fail to explore or propose sustainable, community-sensitive financial models that could improve access and maintenance.

Limited Focus on Social and Behavioral Drivers: The literature gives minimal attention to the social and behavioral dimensions influencing the adoption of renewable technologies. While Lloyd (2021) [42] initiates this conversation, more in-depth qualitative studies are needed to understand how trust, cultural norms, gender roles, and community engagement shape adoption decisions.

Lack of Holistic Planning Frameworks: Current renewable energy interventions are often implemented in isolation, without integrated planning that considers system sizing, local energy demand, affordability, and social acceptance. This fragmented approach leads to inefficiencies and reduces the impact of such technologies on energy security.

Minimal Use of Mixed Methods Approaches: Many studies rely heavily on quantitative data without incorporating qualitative insights that could enrich understanding of user experiences, challenges, and contextual factors affecting renewable energy adoption.

3. Research Methodology

3.1 Overview

This chapter highlights the methodologies that study used in the data collection, as well as how the data was analyzed. The chapter presents the research design, the target population, the sample size, sampling and data collection procedures, analysis methods, and the instruments that was used.

3.2 Research Design

Study design refers to a collection of instruments and techniques intended for specific application, detailing the rationale and methods behind their usage (Howlett, 2023) [28]. Meanwhile, a research design serves as a roadmap that directs researchers in their data collection, analysis, and interpretation endeavors, aiming to address research inquiries. Considering this, the study embraced a exploratory case study design, employing a mixed method approach consisting of both qualitative and quantitative methods of gathering primary data. This approach allowed for the collection of data at a single point in time, offering a snapshot of the variables under investigation (Kumar, 2025).

3.3 Target Population

By definition, a population is defined as a collection of objects, events, or individuals sharing common characteristics that the researcher is interested in studying (Willie, 2024) [73]. The target population for this study were residents of Munali Constituency in Lusaka.

3.4 Sample Size

A sample is a subset of a population that is used to represent the entire group. The study consisted of 100 households in Munali Constituency.

3.5 Sampling

The study employed a simple random sampling approach to ensure that every household in Munali constituency has an equal chance of being selected. This method enhanced the representativeness of the sample and reduces selection bias. A list of households in the community was compiled, and participants were randomly chosen using random number generator, allowing for unbiased and systematic data collection within the constraints of time and resources.

3.6 Data Collection Methods

The primary research tool for this study was a structured questionnaire comprising closed-ended questions. Data was collected through structured surveys and interviews, utilizing standardized questionnaires (Akkas, 2024).

3.7 Data Analysis

Data entry and statistical analysis was done using the Statistical Package for the Social Sciences (SPSS) version 26 and STATA. For inferential statistics Chi-square analysis was employed to establish associations between variables. Thematic analysis was used to analyze qualitative data (Gikunda, 2023).

3.8 Triangulation

The study employed triangulation as a research strategy to enhance the validity and reliability of the findings. Triangulation involved the use of multiple data sources, data collection methods, and/or researchers' perspectives to corroborate and cross-verify research results. In this study, triangulation was achieved by obtaining quantitative data collected through surveys. This approach helped mitigate potential biases and provided a more comprehensive and accurate understanding of the research phenomenon, increasing the overall robustness of the study's conclusions.

3.9 Ethical Consideration

The study up held ethical aspects including obtaining informed consent, safeguarding participant confidentiality and privacy, and utilizing acquired information solely for academic reasons. Stringent confidentiality measures were maintained. Equal and unbiased treatment was given to all participants, who had the choice to participate or decline without any adverse effects. This research carried no risk of physical harm.

3.10 Study Limitations

Limited Generalizability: Findings from the Munali Community may not be applicable to other regions with different socio-economic, cultural, or infrastructural conditions. Therefore, the study's conclusions may not reflect the broader national or rural contexts.

Resource and Time Constraints: The research was conducted under limited time and financial resources, which may affect the scope of data collection and the depth of analysis, particularly in conducting longitudinal or follow-up assessments.

External Influences: Factors such as policy changes, energy subsidies, or infrastructure projects occurring during the study period may influence household energy behaviors independently of renewable energy adoption, complicating the interpretation of causality.

4. Result Presentation

4.0 Overview

This section provides a detailed analysis of the outcomes achieved, including any statistical or quantitative analysis conducted to support the findings.

4.1 Presentation of results on background characteristics of the respondents

The study findings show that 70% of respondents were female, while 30% were male.

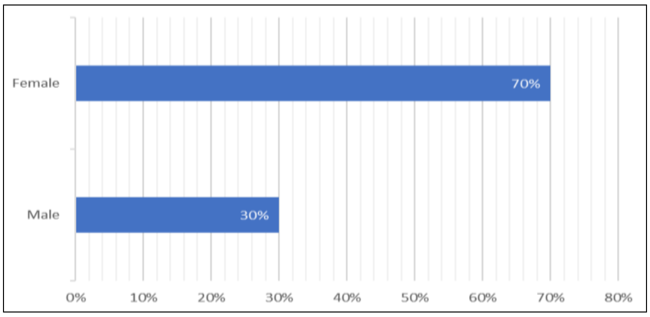

Fig 4.1.1: Participant's Gender

The results indicate that the largest age group of respondents was between 30–39 years, accounting for 37%. This was followed by 22–29 years at 30%, 40–49 years at 20%, and those above 50 years at 13%. This shows that most respondents were in the active working-age category of 30–39 years.

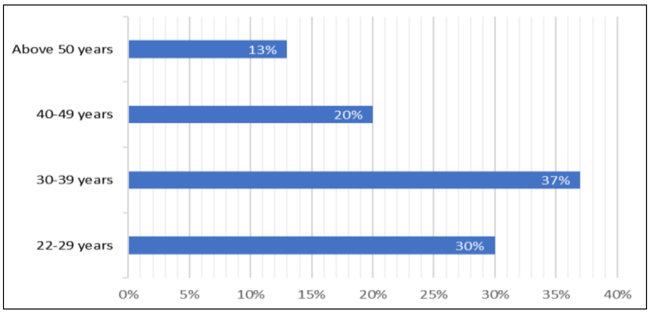

Fig 4.1.2: Participant's Age

The findings show that the majority of respondents were married, representing 57%, while 33% were single and 10% were divorced. This suggests that most participants had family responsibilities.

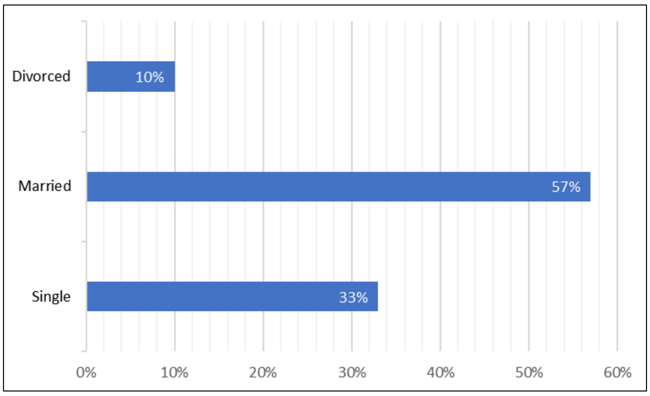

Fig 4.1.3: Marital Status

The results reveal that 30% of respondents had attained a bachelor's degree, 27% had completed secondary school, 23% held a diploma, and 20% had a primary/basic school certificate. This indicates that most respondents had at least secondary education, with a significant proportion holding higher education qualifications.

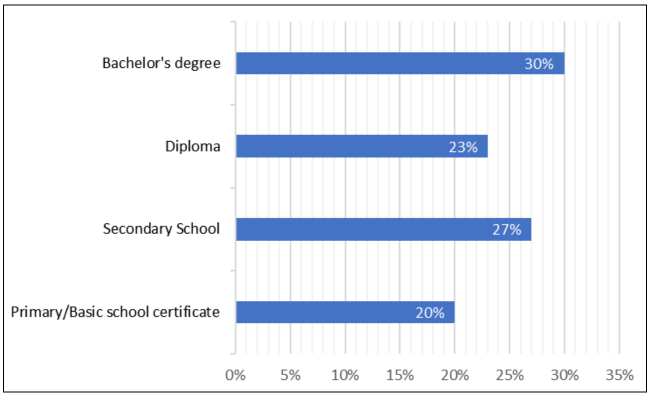

Fig 4.1.4: Education

4.2 Types of Renewable Energy Sources Adopted by Households in Munali Constituency.

The results show that 78.5% of households used solar panels, 57% used biogas, and 46.2% used biomass. This indicates that solar energy was the most widely adopted renewable source, while biogas and biomass were also significant but less common.

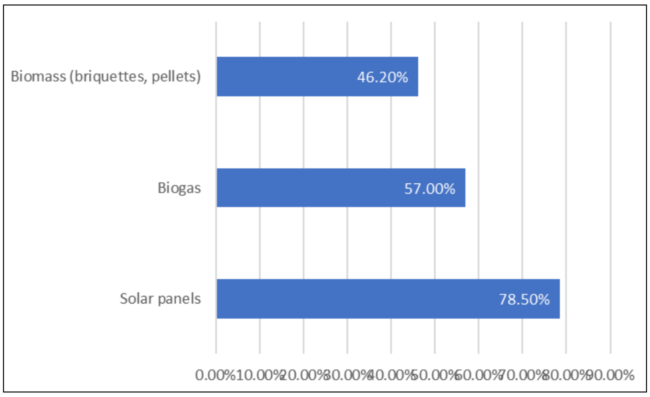

Fig 4.2.1: Renewable Energy Sources Currently Used

The results show a link between household income and the use of renewable energy. Households in all income groups reported using renewable energy, but most users had adopted it within the past three years. The chi square value and the related significance level show that income and renewable energy use were not independent. This means income levels played a role in how long households had been using renewable energy.

Table 4.2.1: The relationship between household income and the use of renewable energy

Chi-Square Tests			
	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	133.333[a]	6	.001
Likelihood Ratio	134.602	6	.002
Linear-by-Linear Association	7.419	1	.002
N of Valid Cases	100		

The findings reveal that 47% of households had been using renewable energy for 1–3 years, 30% for less than 1 year, and 23% for more than 6 years. This shows that adoption was relatively recent for most households.

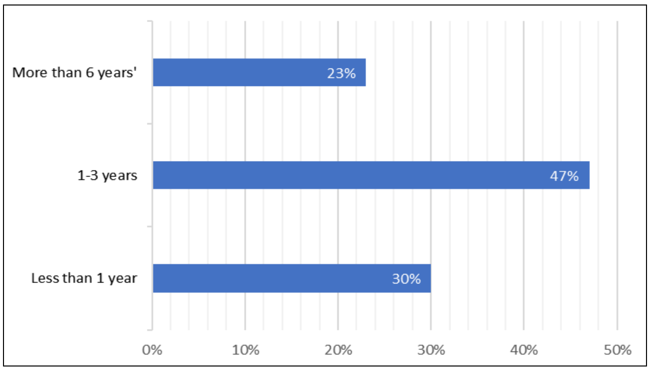

Fig 4.2.2: Duration of Renewable Energy Use

The study found that 47% of households used small solar systems for lighting only, 30% used medium systems for lighting and phone charging, while 23% had large systems capable of powering appliances. This indicates that most households relied on basic systems with limited capacity.

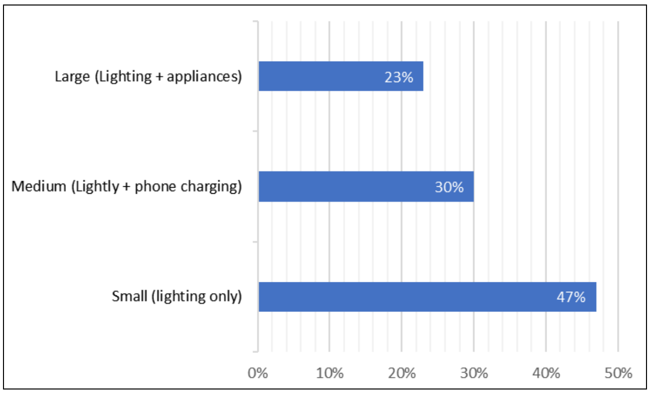

Fig 4.2.3: Capacity of Solar Systems Used

The results show that 100% of households used renewable energy for lighting, while 33% used it for cooking, 33% for water heating, and 33% for running appliances. This indicates that lighting was the main primary purpose of renewable systems.

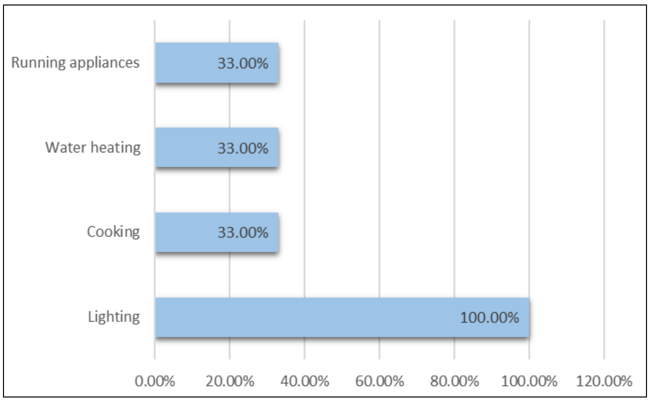

Fig 4.2.4: Primary Purpose of Renewable Energy System

The findings reveal that 46.3% of households financed their renewable energy systems through household savings, 27.8% through government or NGO subsidies, 15.3% via loans or credit facilities, and 10.6% through community projects. Savings were the most common financing approach.

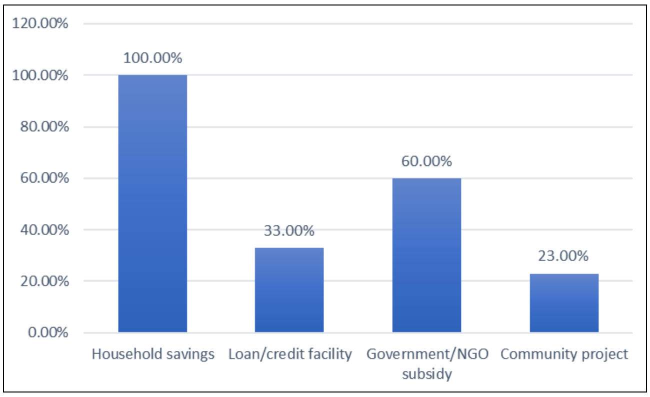

Table 4.2.5: Financing of Renewable Energy Systems

The study shows that 47% of systems were installed by local technicians, 30% by household members, and 23% by private companies. This suggests that households relied more on local, accessible installation services.

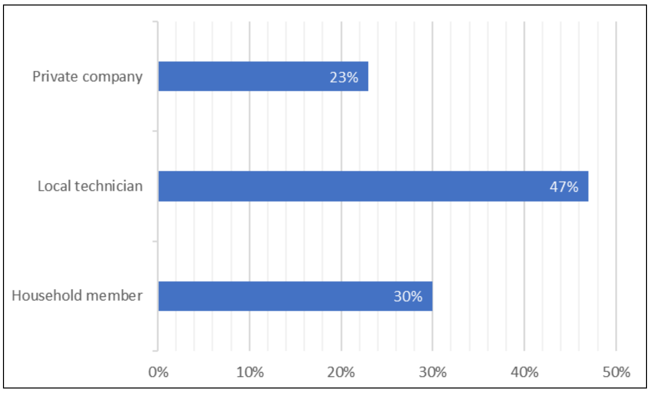

Fig 4.2.6: Installation of Renewable Energy Systems

The findings indicate that 67% of households used imported renewable energy products, while 33% used locally manufactured products. This shows a stronger preference for imported systems, possibly due to perceived quality or availability.

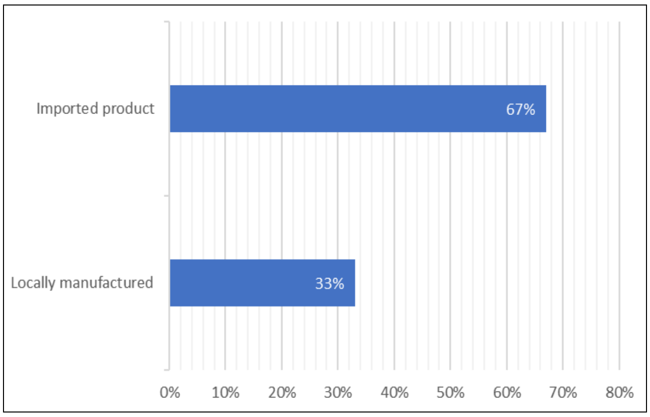

Fig 4.2.7: Renewable Energy Product Brand/Type

The findings show that 100% of households powered lights, 43% powered radios and televisions, and 33% powered refrigerators. This indicates that renewable energy was mainly used for low-consumption appliances, with fewer households running high-consumption appliances.

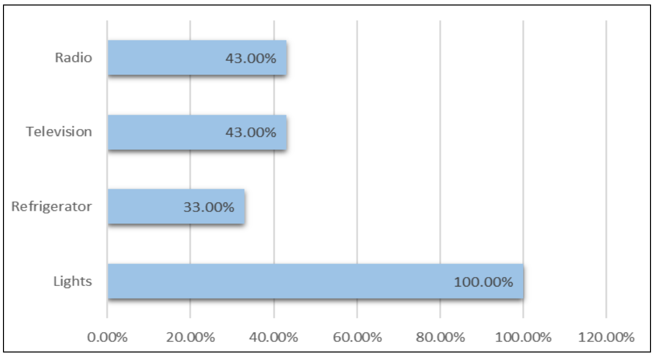

Fig 4.2.8: Appliances Powered by Renewable Energy Systems

The results show that affordability influenced 40% of households, durability influenced 20%, accessibility 17%, recommendations from others 13%, and environmental concerns 10%. This indicates that cost considerations were the most significant factor in household choices.

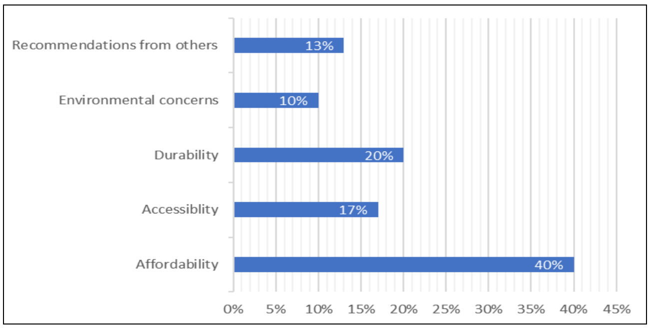

Fig 4.2.9: Factors Influencing Choice of Renewable Energy Source

4.3 Socio-Economic Factors Influencing Renewable Energy Adoption in Munali Constituency

The findings show that 30% of respondents earned less than K1, 000, another 30% earned between K3, 001 and K5, 000, and 30% earned above K5, 000. Only 10% reported earning between K1, 001 and K3, 000. This indicates that household incomes were spread across low-, middle-, and high-income ranges, with fewer households in the lower-middle income bracket.

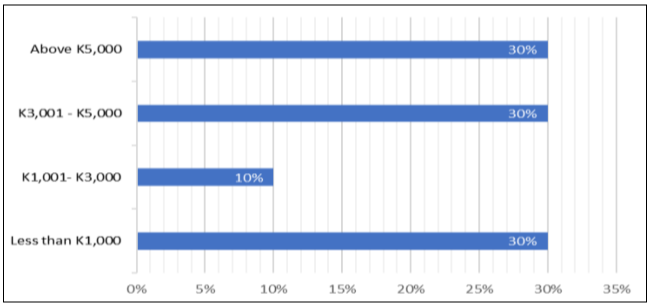

Fig 4.3.1: Household's Average Monthly Income Range

The results reveal that 40% of respondents were unemployed or engaged in household work, 33% were in formal employment, and 27% were involved in informal business or trading.

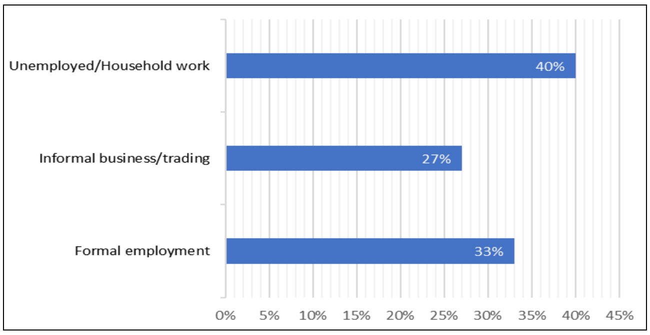

Fig 4.3.2: Employment Status

The findings indicate that 43% of respondents lived in households with 1–3 members, 37% had 4–6 members, while 20% had 7–9 members. This shows that most households were small to medium-sized, with relatively fewer large households.

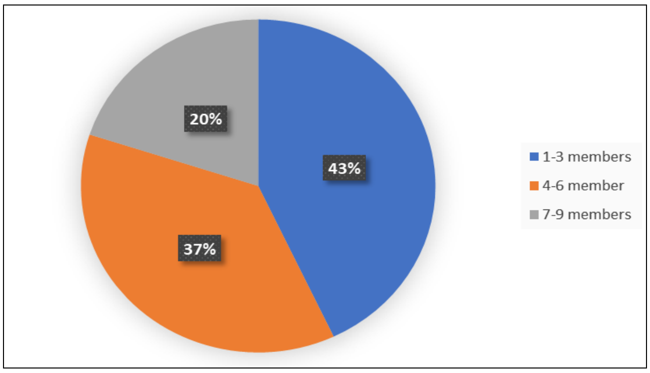

Fig 4.3.3: Household Size

The results show that 60% of households relied on salaries or wages as their main income source, while 40% depended on business activities. This suggests that both formal and entrepreneurial income streams were important for sustaining households.

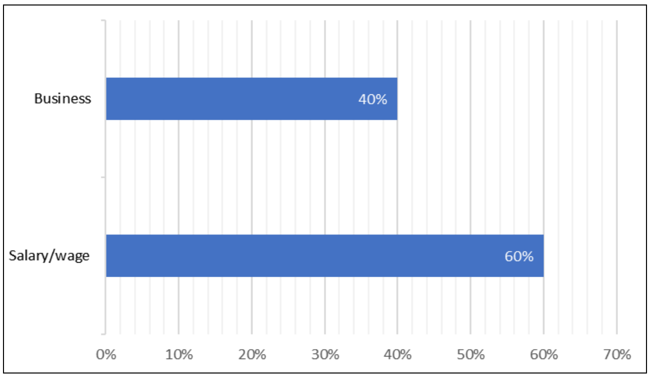

Fig 4.3.4: Main Source of Income

The study found that 40% of households spent between K1,001 and K3,000 on basic needs, 27% spent between K3,001 and K5,000, while 33% spent above K5,000. This indicates variation in household expenditure levels, with a significant number incurring relatively high expenses.

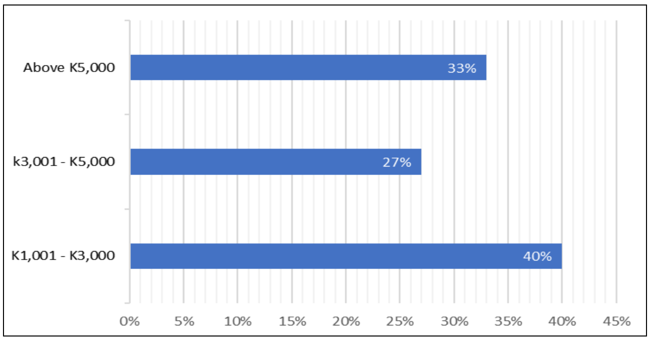

Fig 4.3.5: Household's Average Monthly Expenditure on Basic Needs (Excluding Energy)

The findings reveal that 100% of respondents experienced daily power outages from ZESCO. This indicates that load shedding or electricity unreliability was a universal challenge among households.

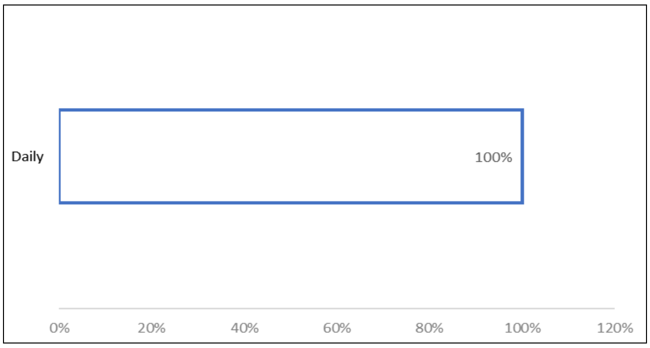

Fig 4.3.6: Frequency of Power Outages

The results show that 47% of respondents considered renewable energy mainly to improve reliability, 30% to reduce costs, 13% due to government or NGO support, and 10% for environmental conservation. This suggests that reliability of supply was the strongest driver for renewable energy adoption.

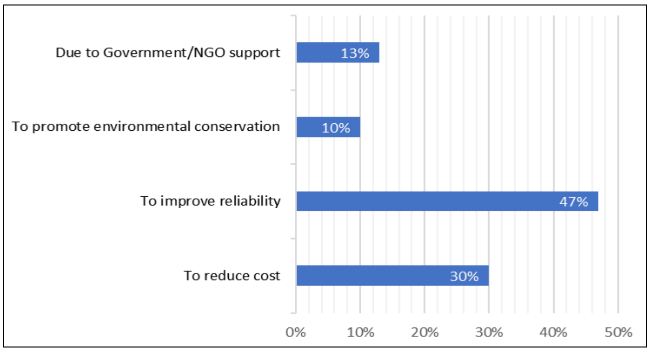

Fig 4.3.7: Main Reason for Considering Renewable Energy

The chi-square test was conducted to examine the relationship between the frequency of ZESCO power outages and the main reason households considered adopting renewable energy. The results show a Pearson Chi-Square value of 133.333 with 6 degrees of freedom and a p-value of 0.000, indicating a statistically significant association at the 0.05 level. Similarly, the likelihood ratio (134.602, p = 0.000) confirms this significant relationship.

The linear-by-linear association (7.419, p = 0.006) further suggests a positive trend between the frequency of power outages and households' consideration of renewable energy.

Table 4.3.1: The relationship between the frequency of ZESCO power outages and the main reason households considered adopting renewable energy

Chi-Square Tests			
	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	133.333[a]	6	.000
Likelihood Ratio	134.602	6	.000
Linear-by-Linear Association	7.419	1	.006
N of Valid Cases	100		

4.4 Challenges in Transitioning from Traditional to Renewable Energy Sources Among Households

The findings reveal that the main barriers were high initial costs (40%), lack of information or awareness (22.8%), technical challenges (18.8%), limited product availability (9.2%), and cultural preferences (9.2%). This indicates that affordability and knowledge gaps were the strongest barriers.

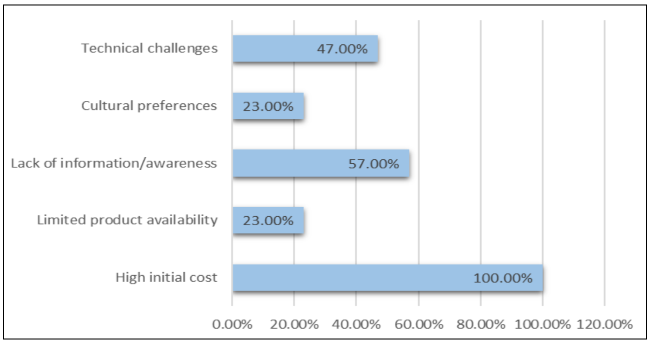

Fig 4.4.1: Barriers to Adoption of Renewable Energy

The study shows that 63% of households faced high installation costs, 30% reported lack of spare parts, while 7% cited lack of skilled installers. This suggests that cost was the dominant challenge during installation.

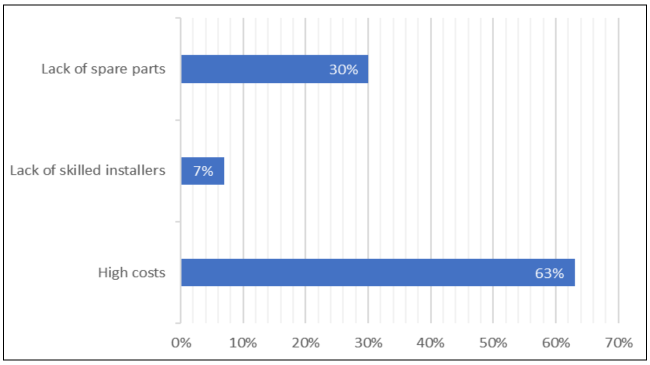

Fig 4.4.2: Difficulties Faced During Installation

The results reveal that 47% of respondents reported renewable products were rarely available, 30% said they were not available, while only 23% found them very accessible. This indicates that product accessibility was limited in many communities.

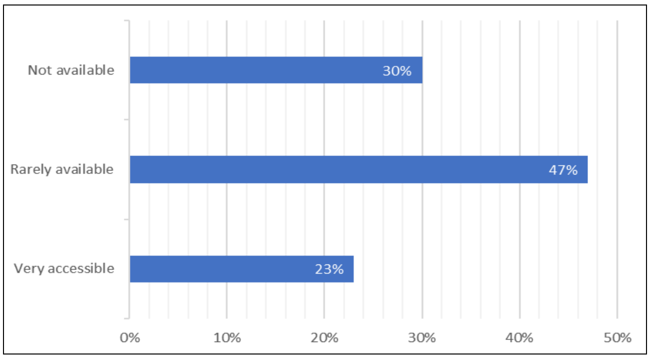

Fig 4.4.3: Accessibility of Renewable Energy Products

The findings show that the most frequent maintenance issue was battery replacement (34.5%), followed by panel cleaning and repair (27.6%), high cost of parts (24.1%), and technical breakdowns (13.8%). This highlights batteries as the most recurring maintenance burden.

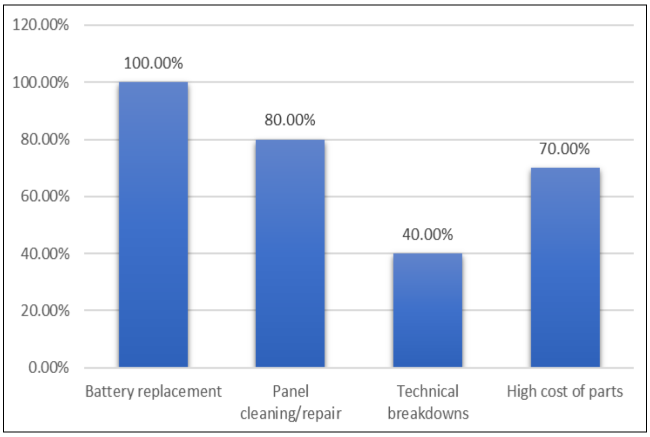

Table 4.4.4: Most Common Maintenance Challenges

The results reveal that 47% of households reported technical support was not available, 30% considered it inadequate, 10% adequate, and 13% very adequate. This indicates that the majority of households lacked sufficient technical support.

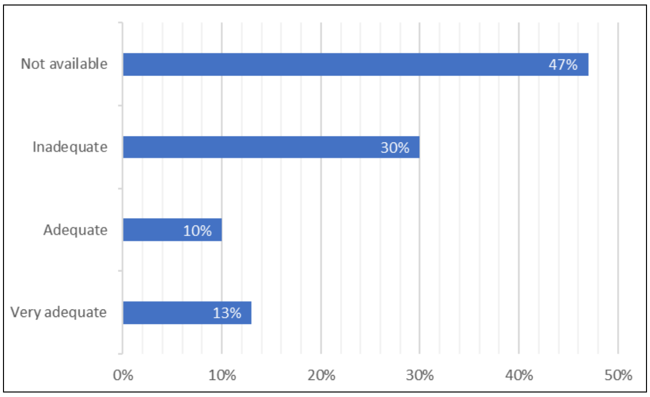

Fig 4.4.5: Adequacy of Technical Support

The study found that 47.6% of households struggled with high upfront payments, 27.1% cited lack of affordable loans, and 25.2% pointed to limited subsidy programs. This shows that the financing environment was unfavorable for many households.

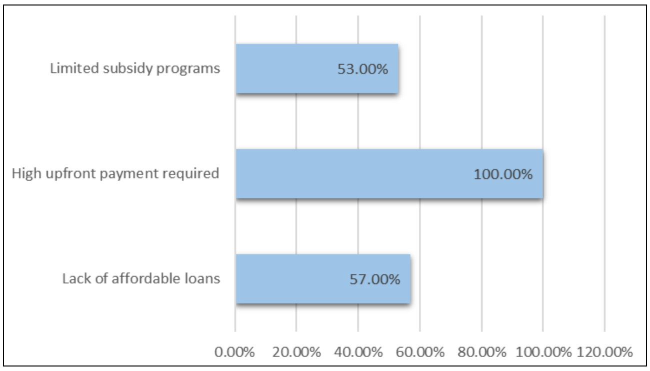

Fig 4.4.6: Challenges in Financing Renewable Energy Systems

The findings reveal that 39.5% of respondents preferred government subsidies, 27.3% needed technical assistance, 19.5% suggested training and awareness programs, and 13.6% emphasized access to affordable products. This indicates subsidies and technical support were the most sought-after interventions.

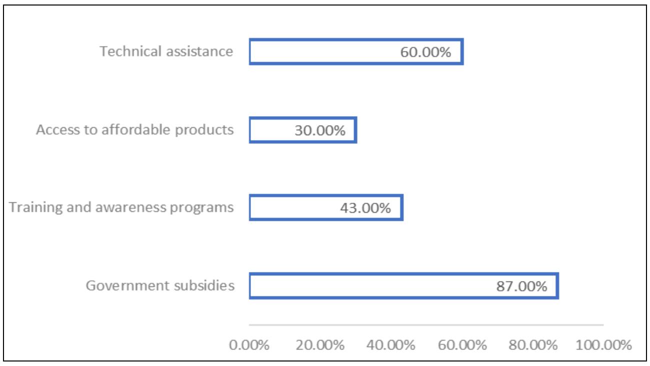

Fig 4.4.7: External Support Needed to Ease Transition

The results show that 87% of households were very willing, while 13% were somewhat willing to fully transition to renewable energy if barriers were eliminated. This suggests strong readiness for adoption provided constraints are addressed.

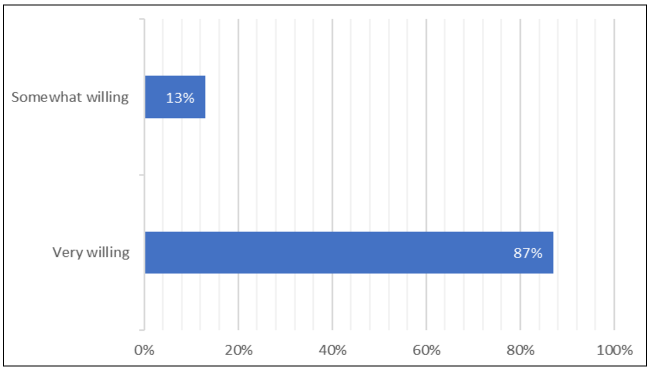

Fig 4.4.8: Willingness to Fully Transition if Barriers Were Removed

4.5 Effect of Renewable Energy Adoption on Household Energy Expenditure in Munali Constituency

The findings show that 77% of households spent between K201 and K500, while 23% spent between K501 and K1, 000. This indicates that most households had moderate energy expenses before switching to renewable energy.

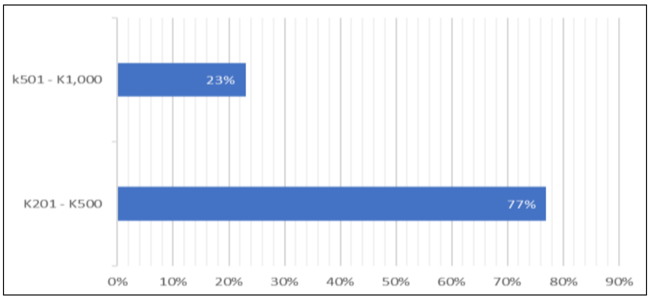

Fig 4.5.1: Average Monthly Energy Expenditure before Adopting Renewable Energy

The results reveal that 77% of households now spend below K200, while 23% spend between K201 and K500. This shows a significant reduction in energy expenditure compared to the pre-adoption period.

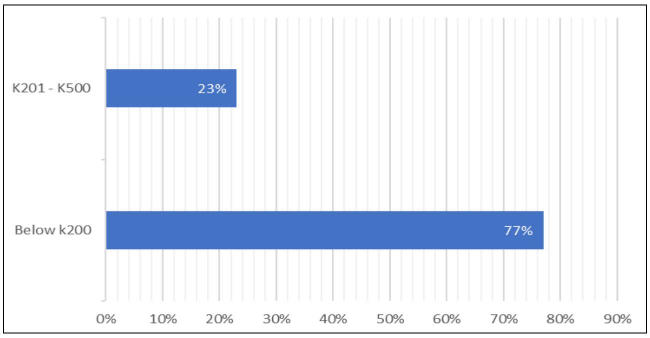

Fig 4.5.2: Current Average Monthly Energy Expenditure after Adopting Renewable Energy

The findings show that 90% of households spent less than 10% of their income on energy, while 10% spent between 10–20%. This suggests that renewable energy eased the financial burden of energy costs for the majority of households.

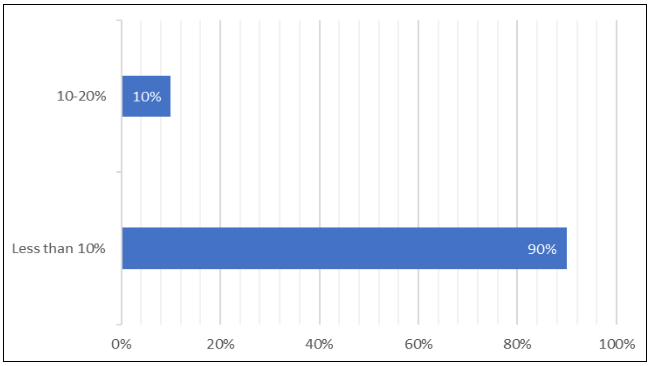

Fig 4.5.3: Proportion of Total Monthly Income Now Spent on Energy

The results reveal that 10% of households spent below K2,000, 37% spent between K2,001–K5,000, 20% spent between K5,001–K10,000, and 33% spent above K10,000. This shows a wide variation in investment costs depending on the type and capacity of systems installed.

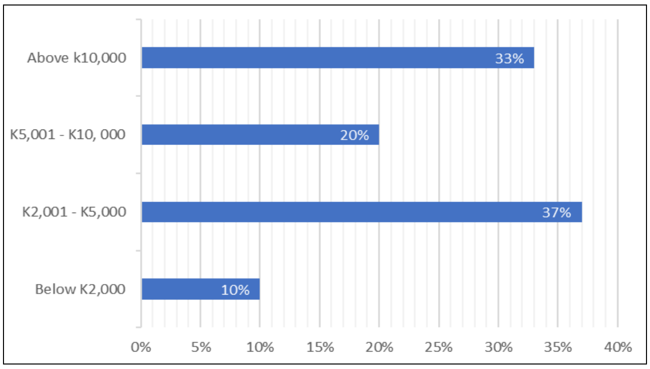

Fig 4.5.4: Household Spending on Acquiring Renewable Energy Systems

The findings indicate that 53% of households found renewable energy maintenance costs slightly lower, while 47% found them much lower compared to traditional energy sources. This suggests renewable systems were generally cheaper to maintain.

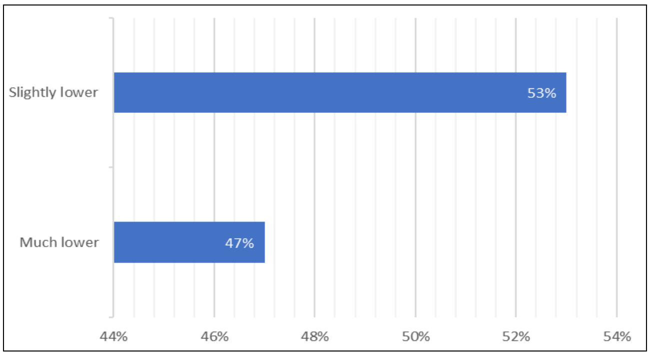

Fig 4.5.5: Comparison of Maintenance Costs with Traditional Energy Sources

The findings reveal that 100% of households improved food security, 53% improved education, 43% improved healthcare, 73% invested in household assets, and 10% supported business activities. This indicates that reduced energy costs freed resources for essential and developmental needs.

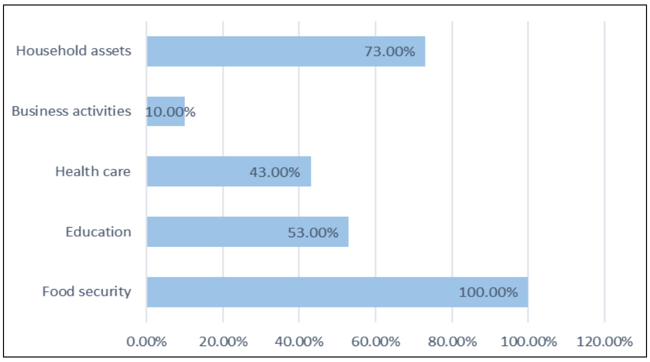

Fig 4.5.6: Expenditure Areas Improved Due to Reduced Energy Costs

4.6 Discussion of Study Findings

The findings of this study reveal that the adoption of renewable energy in Munali Constituency is significantly influenced by a complex interplay of socio-economic factors. Key among these are household income levels, educational attainment, employment status, and the frequency of power outages from the national grid. The data indicates that household income is a primary determinant, with adoption rates spread across low-, middle-, and high-income ranges. A significant 30% of households earned less than K1,000 monthly, another 30% earned between K3,001 and K5,000, and 30% earned above K5,000. This distribution suggests that while financial capacity is crucial, it is not the sole factor driving adoption. Educational attainment also emerged as important, with 30% of respondents holding a bachelor's degree, 27% having completed secondary school, and 23% holding a diploma. This educational profile indicates that awareness and understanding of renewable energy benefits may facilitate adoption. Employment status further influenced adoption patterns, with 40% of respondents unemployed or engaged in household work, 33% in formal employment, and 27% involved in informal business or trading. The high rate of power outages, experienced daily by 100% of respondents, served as a critical push factor, with 47% citing improved reliability as their main reason for considering renewable energy.

These findings align with existing literature that identifies income and education as fundamental drivers of renewable energy adoption. The observation that adoption occurs across income brackets supports the work of Chishimba (2024) [15], who found that willingness to pay for renewable energy technologies increases with longer credit repayment periods, making them accessible even to lower-income households. The presence of adopters in the lowest income category may be explained by the severe energy insecurity caused by daily power outages, forcing even resource-constrained households to seek alternatives. The role of education in facilitating adoption resonates with Malik and Ayop (2020) [44], who demonstrated that higher educational levels correlate with greater awareness and positive perceptions of renewable energy benefits. In Munali, the relatively high educational attainment of respondents, with 80% having at least secondary education, likely contributed to their ability to understand and appreciate the long-term advantages of renewable energy investments.

The finding that unemployment did not preclude adoption diverges somewhat from conventional expectations. While Brown *et al*. (2020) [8] argue that high energy burdens disproportionately affect low-income and unemployed households, limiting their capacity to invest in renewable, this study found that 40% of adopters were unemployed or engaged in household work. This discrepancy may be explained by the severe reliability issues with grid electricity, which compelled households to prioritize energy access even under financial constraints. Many unemployed households may have allocated scarce resources to renewable energy as a necessity rather than a choice, recognizing that without reliable lighting and phone charging, their prospects for securing employment or engaging in informal business would further diminish. The prevalence of informal business engagement among 27% of adopters also supports the literature on energy's role in livelihood strategies, as noted by Guta (2020) [22], who found that off-farm income activities increased the likelihood of investing in renewable energy.

The universal experience of daily power outages emerged as a dominant factor influencing adoption decisions. This finding strongly supports the energy insecurity theory articulated by Pambwe (2021) [53], who documented how unreliable grid electricity in Zambian urban areas drives households toward alternative energy sources. The fact that 47% of respondents cited improved reliability as their primary motivation, compared to 30% who cited cost reduction, indicates that energy security may outweigh economic considerations in contexts of extreme grid instability. This prioritization of reliability over cost savings reflects the practical realities faced by households who cannot conduct daily activities, preserve food, or maintain communication without dependable energy access. The emphasis on reliability also aligns with Lloyd's (2021) [42] research in Lusaka, which found that households value energy security for basic needs even when the financial benefits are not immediately apparent.

Household size and composition appeared to have a complex relationship with adoption decisions. With 43% of households having 1-3 members and 37% having 3-6 members, the data suggests that both small and medium-sized households are adopting renewable. This pattern may reflect different motivations smaller households may seek basic energy for lighting and charging, while larger households may need more substantial systems to meet higher energy demands. The fact that 60% of households relied on salaries or wages as their main income source, while 40% depended on business activities, indicates that both formal and informal income streams can support renewable energy adoption when complemented by other enabling factors.

The study's findings regarding financial prioritization are particularly insightful. Despite varying income levels, 47% of households considered energy expenditure a very high priority and 40% considered it a high priority compared to other needs. This overwhelming prioritization of energy spending, even among low-income households, demonstrates the fundamental role of energy in daily life and economic security. This observation supports Hasan (2023), who argued that energy access becomes a primary expenditure when grid electricity is unreliable. The high priority assigned to energy spending may also reflect the recognition that renewable energy systems represent a long-term solution to ongoing energy expenses, unlike recurring purchases of charcoal or kerosene.

Several discrepancies between this study's findings and the existing literature merit attention. While Umamahes waran *et al*. (2024) [67] emphasized financial barriers as the primary constraint to renewable energy adoption, this study found that even households with limited resources pursued renewable energy when faced with daily power outages. This suggests that in contexts of extreme energy insecurity, the perceived urgency of obtaining reliable energy may override financial constraints. Similarly, the literature often presents educational attainment as a prerequisite for adoption (Malik and Ayop 2020) [44], but this study found adoption across educational levels, indicating that practical energy needs can drive adoption even without advanced education.

The role of energy expenditure as a proportion of income provides further insight into adoption dynamics. The finding that 90% of households spent less than 10% of their income on energy after adopting renewable supports the economic argument for renewable energy made by Aruna chala (2020), who documented long-term cost savings from renewable investments. However, the fact that 10% still spent 10-20% of their income on energy suggests that for some households, particularly those with lower incomes, even renewable energy systems require significant financial commitment. This observation nuances the literature on energy affordability by demonstrating that while renewable can reduce energy expenditures, they may still represent a substantial cost burden for the poorest households.

The study's findings have several important implications for policy and practice. The widespread adoption across income levels suggests that renewable energy solutions can be accessible to diverse socioeconomic groups if appropriate financing mechanisms are available. Policymakers should consider developing targeted subsidy programs for low-income households, building on the model proposed by Streimikiene (2022) [65], who advocated for well-designed policy measures that promote renewable technologies rather than subsidizing energy bills. The strong influence of educational attainment on adoption decisions indicates that awareness campaigns and energy education could significantly increase uptake. These campaigns should specifically address the financial benefits of renewable, as 30% of respondents cited cost reduction as a motivation, suggesting that economic arguments remain persuasive.

The universal experience of power outages as a driver of adoption suggests that energy security is a powerful motivator that could be leveraged in policy messaging. Energy developers and policymakers should emphasize the reliability and independence offered by renewable systems, particularly in areas with unstable grid electricity. The fact that households prioritized energy spending even under financial constraints indicates a willingness to invest in solutions that address their most pressing needs. This finding supports the development of flexible payment plans and micro financing options that allow households to acquire renewable systems without large upfront payments.

The variation in adoption patterns across household sizes and income sources suggests that renewable energy solutions should be tailored to different household profiles. Smaller households with formal employment may benefit from different systems and financing options than larger households relying on informal business income. Policymakers should avoid one-size-fits-all approaches and instead develop segmented strategies that address the specific needs and constraints of different household types. The involvement of local technicians in installation, reported by 47% of households, indicates an existing capacity base that could be strengthened through technical training and certification programs.

The study's findings also suggest that renewable energy adoption is not merely a technical or economic decision but a response to broader living conditions and energy security concerns. This holistic understanding should inform policy development, which should integrate energy interventions with broader poverty reduction and social protection measures. The relationship between energy access and other aspects of wellbeing, evidenced by households redirecting energy savings to food security, education, and healthcare, underscores the importance of viewing energy policy as integral to broader development goals.

In summary, the adoption of renewable energy in Munali Constituency is shaped by a complex interaction of income, education, employment, and energy security factors. While financial constraints remain important, they are balanced against the urgent need for reliable energy access. Educational attainment facilitates adoption by increasing awareness and understanding of renewable benefits, but practical energy needs can drive adoption even among less educated households. The universal experience of power outages creates a strong incentive for adoption across socioeconomic groups. These findings suggest that successful renewable energy policies must address both financial barriers and energy security concerns while tailoring interventions to different household circumstances. Future research should explore how these factors interact over time and how adoption patterns evolve as renewable technologies become more accessible and affordable.

The types of renewable energy sources adopted by households in Munali Community

The examination of renewable energy sources adopted by households in Munali reveals a clear dominance of solar technology, with significant but limited uptake of other renewable options. Solar panels were used by 78.5% of households, making them the most widely adopted renewable energy technology in the community. This was followed by biogas systems at 57% and biomass energy at 46.2%. The solar systems adopted were primarily small to medium capacity units, with 47% of households using systems capable only of lighting, while 30% had medium systems that could support both lighting and phone charging. Only 23% of households had large solar systems capable of powering appliances. The primary application of these renewable systems was universal for lighting purposes, while only 33% of households used them for cooking, 33% for water heating, and 33% for running appliances. The duration of use patterns indicates relatively recent adoption, with 47% of households using renewable energy for 1-3 years and 30% for less than one year.

The overwhelming preference for solar energy aligns with broader regional and global trends observed in the literature. Babayomi *et al*. (2023) [3] documented that solar energy has become the most accessible and practical renewable solution across sub-Saharan Africa, particularly in off-grid and Peri-urban communities. The high adoption rate in Munali can be attributed to Zambia's abundant solar irradiation, which makes photovoltaic technology particularly viable. The finding that most systems were used for basic lighting and charging needs mirrors observations by Ukoba *et al*. (2024) [68], who reported that millions of households in the region rely on solar systems primarily for these fundamental applications. The limited capacity of most systems, with only 23% capable of powering appliances, reflects the financial constraints faced by households, as larger systems require substantially greater investment.

The secondary adoption of biogas at 57% represents a significant finding that contrasts with some literature suggesting limited biogas uptake in urban settings. While Tembo (2023) identified numerous barriers to biogas development in Zambian peri-urban areas, including space constraints and technical challenges, the relatively high adoption rate in Munali suggests that some households have found ways to overcome these obstacles. This discrepancy may be explained by the community's specific characteristics, including possible higher livestock ownership or innovative compact system designs. The biomass adoption rate of 46.2%, primarily consisting of improved cook stoves using briquettes or pellets, aligns with Kaputo *et al*. (2023) [35], who documented the continued importance of biomass technologies as transitional solutions in low-income urban communities.

The applications of these renewable technologies reveal important patterns in household energy use strategies. The universal use of renewable systems for lighting indicates that households prioritize reliable lighting above other energy needs, likely due to its importance for safety, security, and basic household activities during frequent power outages. The equal proportions using renewable for cooking, water heating, and appliances (33% each) suggest that households diversify their energy sources based on specific needs and system capabilities. This finding supports the energy stacking theory articulated by Kizilcec *et al*. (2022) [38], which posits that households typically use multiple energy sources rather than completely switching to a single option.

The financing mechanisms for these systems provide insight into adoption pathways. Household savings were the primary financing method for 46.3% of adopters, indicating significant financial commitment from families despite economic constraints. Government or NGO subsidies supported 27.8% of installations, while loans or credit facilities accounted for 15.3%. This distribution suggests that while some external support exists, most households are bearing the primary financial responsibility for their renewable energy systems. The reliance on local technicians for installation (47% of cases) rather than formal companies (23%) highlights the importance of informal sector involvement in renewable energy deployment, though this may have implications for system quality and longevity.

The technological origins of these systems reveal a dependence on imported products, with 67% of households using imported renewable energy products compared to 33% using locally manufactured items. This preference for imported technology may reflect perceptions of higher quality or reliability, or possibly limited availability of local alternatives. This finding contrasts with recommendations from Mhango (2024) [46], who emphasized the importance of developing local renewable energy industries to reduce costs and improve accessibility. The reliability assessments provided by households indicate mixed experiences, with 33% finding their systems very reliable, 27% somewhat reliable, and 40% reporting occasional or no reliability. This variation suggests significant differences in system quality, installation quality, or maintenance practices.

The appliances powered by renewable systems further illustrate the scope of energy access achieved. While all households powered lights through renewable sources, only 43% powered radios and televisions, and 33% powered refrigerators. This graduated access pattern demonstrates how renewable energy adoption typically progresses from basic needs toward more advanced applications as system capacity and household resources allow. The factors influencing technology choices emphasize the primacy of economic considerations, with affordability influencing 40% of households' decisions, followed by durability (20%) and accessibility (17%). Environmental concerns influenced only 10% of households, indicating that practical and economic factors outweigh ecological considerations in technology adoption decisions.

These findings both support and challenge various aspects of the existing literature. The dominance of solar energy aligns with Kumar *et al*. (2024) [40] and Felody (2022) [19], who identified solar as the most feasible renewable source for Zambian households. However, the relatively high adoption of biogas contradicts Tembo's (2023) assessment of significant barriers to biogas development in similar settings. This discrepancy may be explained by community-specific factors such as stronger NGO presence, higher awareness levels, or particular housing characteristics that facilitate biogas installation. The limited use of renewables for cooking applications supports Williams *et al*. (2022) [71], who documented socio-cultural and technical barriers to adopting renewable cooking technologies.

The recent adoption timeline, with 77% of households using renewables for three years or less, suggests a rapid acceleration in renewable energy uptake that may not be fully captured in the existing literature. This recent surge could be driven by worsening grid reliability, increased awareness, or improved product availability. The mixed reliability experiences highlight an important challenge that receives limited attention in the literature, which often assumes consistent system performance once installed. The fact that 40% of households reported less-than-satisfactory reliability indicates significant quality control issues that need addressing.

The dependence on imported technology presents both opportunities and challenges. While imported systems may offer better performance or features, they typically come at higher costs and may have limited spare part availability. This finding contradicts the localization strategies recommended by Bishoge *et al*. (2020) [6], who argued for developing local renewable energy industries to ensure sustainability and affordability. The preference for imported products may stem from negative experiences with local alternatives or perceptions of inferior quality, suggesting that local manufacturers need to address quality assurance and consumer confidence.

The financing patterns reveal important insights about household investment capacity and priorities. The significant proportion of households using savings for renewable energy investments, despite economic constraints, demonstrates the high priority placed on energy access. This finding challenges assumptions that low-income households cannot invest in renewable energy without substantial external support. However, the limited use of formal credit options (15.3%) suggests that financial products are either unavailable, inaccessible, or unattractive to most households. This aligns with Umamaheswaran *et al*. (2024) [67], who identified significant barriers in renewable energy financing mechanisms.

The applications of renewable energy systems show both progress and limitations in energy access transformation. While all households have achieved basic lighting through renewable, the limited use for income-generating activities (only 10% supporting business activities) suggests that most systems are not yet enabling productive uses that could improve household economics. This finding contrasts with Guta (2020) [22], who found that renewable energy adoption often facilitates economic activities in rural settings. The urban context of Munali may present different opportunities and constraints for productive energy use.

These findings have several important implications for policy and practice. The clear dominance of solar energy suggests that policies should continue to support solar technology deployment, but with attention to system quality and capacity building. The significant biogas adoption indicates potential for further expansion if technical and space constraints can be addressed through innovative system designs. The reliance on imported technology highlights the need for policies that support local manufacturing and quality improvement, possibly through standards, certification, and support for local entrepreneurs.

The financing patterns suggest a need for more diverse and accessible financial products tailored to different household circumstances. The substantial use of personal savings indicates willingness to invest, but better financing options could enable more households to acquire higher-quality systems. The mixed reliability experiences underscore the importance of quality control, technician training, and after-sales support. Policies should address these aspects to ensure that renewable energy systems deliver consistent benefits over their lifespan.

The limited use of renewable for cooking and productive applications points to important unmet opportunities. Policies could promote targeted applications that address these gaps, such as solar-powered appliances for small businesses or efficient electric cooking devices. The recent adoption timeline suggests that support services may need scaling up to serve the growing number of system owners, particularly as systems age and require maintenance.

The dependence on local technicians for installation presents an opportunity for capacity building and quality improvement through training and certification programs. Strengthening the skills of these technicians could improve system performance and reliability while creating local employment opportunities. The preference for imported technology suggests that local manufacturers need support to improve product quality and consumer confidence, possibly through quality standards, testing facilities, and marketing support.

In summary, the types of renewable energy sources adopted in Munali reflect both global trends and local specificities. Solar energy dominates due to its suitability and accessibility, while biogas and biomass serve important complementary roles. The applications remain focused on basic needs rather than transformative uses, indicating room for growth in system capacity and functionality. The financing and installation patterns highlight the importance of informal systems and household resources in driving adoption. These findings suggest that policies should build on existing adoption patterns while addressing quality, reliability, and application limitations to maximize the benefits of renewable energy for households in Munali and similar communities.

The effect of renewable energy adoption on household energy expenditure in Munali

The evaluation of renewable energy adoption on household energy expenditure in Munali reveals significant financial benefits for adopting households, though the extent of these benefits varies based on system type and household characteristics. The data shows a substantial reduction in monthly energy expenditures after adopting renewable energy, with 77% of households now spending below K200 monthly compared to their previous expenditure range of K201-K500 for the same percentage of households before adoption. This represents a notable downward shift in energy spending categories. Furthermore, 53% of households reported a significant reduction in energy costs, while 47% experienced a slight reduction, indicating that all adopting households achieved some level of financial savings. The proportion of income spent on energy dramatically decreased, with 90% of households now spending less than 10% of their income on energy compared to pre-adoption patterns where energy costs consumed a larger share of household budgets.

These findings strongly support the economic arguments for renewable energy adoption presented in the literature. Arunachala (2020) and Wright (2020) both documented substantial long-term savings from renewable energy investments, particularly through reduced expenditure on traditional fuels like charcoal and grid electricity. The universal experience of cost reduction among adopting households in Munali aligns with these observations and demonstrates that even basic renewable systems can generate immediate financial benefits. The reduction in energy expenditure as a percentage of household income is particularly significant, as energy costs typically represent a substantial burden for low-income households. This finding supports Brown *et al*. (2020) [8], who identified high energy burdens as a major challenge for low-income families and suggested renewable energy as a potential solution.

The initial investment costs for renewable systems varied considerably among households, with 37% spending K2,001-K5,000, 33% spending above K10,000, and 20% spending K5,001-K10,000. This variation reflects the different system capacities and quality levels chosen by households. Despite these upfront costs, 53% of households found maintenance costs slightly lower than traditional energy sources, while 47% found them much lower. This maintenance cost advantage contributes to the overall financial benefits of renewable systems. The financial savings enabled households to redirect resources to other essential needs, with 100% reporting improved food security, 53% improved education spending, 43% improved healthcare access, and 73% increased investment in household assets.

The relationship between system type and financial benefits reveals important patterns. Households with larger solar systems capable of powering appliances generally reported greater absolute savings, though they also incurred higher initial costs. This finding supports Ray and Chakraborty (2021) [57], who observed that system capacity significantly influences the magnitude of financial benefits. However, even households with basic lighting-only systems reported meaningful savings, primarily through reduced expenditure on candles, kerosene, and phone charging services. The universal application of renewable systems for lighting means that all adopting households eliminate these recurring expenses, which constitute a significant burden for low-income families.

The timing of financial benefits also emerged as an important consideration. Households that had used renewable energy for longer periods (more than three years) generally reported greater overall savings, suggesting that the financial advantages accumulate over time as initial investments are recouped. This finding aligns with the long-term perspective advocated by Hasan (2023), who emphasized that renewable energy investments should be evaluated over their entire lifespan rather than through short-term accounting. However, even recently adopting households reported immediate reductions in their monthly energy expenditures, indicating that the payback period for basic systems can be relatively short.

The impact on energy expenditure patterns extends beyond direct financial savings to include indirect economic benefits. The improved reliability of energy access enabled some households to engage in income-generating activities that require electricity, though this effect was limited by system capacities. Only 23% of households strongly agreed that renewable energy adoption increased their ability to support income-generating activities, while 37% were neutral and 30% disagreed. This suggests that while renewable systems provide essential energy services, most systems in Munali lack the capacity to significantly transform household economic activities. This finding partially contradicts Iqbal *et al*. (2021) [31], who found more substantial economic impacts from biogas adoption in rural settings, possibly due to different system types and applications.

The satisfaction levels with financial outcomes varied among households, with 13% very satisfied, 37% satisfied, 40% neutral, and 10% dissatisfied. This distribution suggests that while most households appreciate the financial benefits, some may have expected greater savings or encountered unexpected costs. The neutral responses may reflect households that are still recouping their initial investments or that experience intermittent system reliability issues. The dissatisfied minority may have faced particularly high maintenance costs or system failures that diminished their expected savings.

These findings both support and challenge various aspects of the existing literature on renewable energy economics. The universal experience of reduced energy expenditures strongly supports the economic viability argument presented by Babayomi *et al*. (2023) [3]. However, the limited impact on income-generating activities suggests that the economic benefits may be more constrained in urban settings with limited space for productive energy use compared to rural agricultural applications. The variation in satisfaction levels indicates that financial outcomes are not uniform and depend on multiple factors including system quality, maintenance practices, and household energy needs.

The redirection of savings to other essential needs demonstrates important secondary benefits of renewable energy adoption. The universal improvement in food security is particularly significant, as it suggests that energy savings directly contribute to addressing fundamental household needs. The improvements in education and healthcare spending align with Meried (2021) [45], who found that energy cost reductions enabled households to invest more in human development areas. The investment in household assets represents a form of capital accumulation that could contribute to long-term economic resilience.

The maintenance cost advantage of renewable systems supports the operational efficiency arguments made by Kumar *et al*. (2024) [40]. However, the fact that 40% of households reported only occasional reliability or no reliability suggests that maintenance challenges may diminish the financial benefits for some adopters. This finding nuances the literature on renewable energy economics by highlighting that system performance and maintenance requirements significantly influence the actual financial outcomes experienced by households.

The initial investment patterns reveal important insights about household financing capacity and priorities. The substantial variation in investment levels suggests that households choose systems based on their financial capacity and energy needs rather than adopting standardized solutions. This finding supports the need for flexible financing options and tiered system offerings that can accommodate different household circumstances. The relatively high investment levels chosen by some households indicate significant willingness to invest in energy access when appropriate options are available.

These findings have several important implications for policy and practice. The demonstrated financial benefits provide a strong economic rationale for promoting renewable energy adoption, particularly through policies that address initial investment barriers. The variation in outcomes suggests that policies should support quality assurance and maintenance services to ensure that households realize the full potential benefits of their investments. The redirection of savings to essential needs indicates that renewable energy adoption can contribute to multiple development goals beyond energy access alone.

The limited impact on income-generating activities suggests a need for policies that promote larger systems or productive use applications that can generate economic returns. This could include support for energy-efficient appliances or business models that leverage renewable energy for commercial activities. The satisfaction variations indicate that consumer education about realistic expectations and system capabilities is important for ensuring positive experiences.

The maintenance cost advantage supports policies that promote high-quality systems with reliable performance, even if they require higher initial investments. The long-term financial benefits justify financing mechanisms that allow households to spread upfront costs over time, making higher-quality systems more accessible. The demonstrated savings also provide a basis for energy service companies to develop pay-as-you-save models where households pay for systems through their energy savings.

The universal improvement in food security through energy savings suggests that renewable energy policies should be integrated with food security initiatives to maximize their developmental impact. Similarly, the improvements in education and healthcare spending indicate potential synergies with social development programs. These cross-sector benefits justify coordinated policy approaches that address multiple development objectives through integrated interventions.

In summary, renewable energy adoption in Munali has generated significant financial benefits for households through reduced energy expenditures, though the extent of these benefits varies based on system characteristics and household circumstances. The universal experience of cost reduction demonstrates the economic viability of renewable energy, while the redirection of savings to essential needs shows important developmental impacts beyond energy access alone. The limited effect on income-generating activities suggests opportunities for further innovation in system design and application. These findings support policies that address investment barriers while ensuring system quality and reliability to maximize the financial benefits of renewable energy adoption for households in

Munali and similar communities.

The limitations faced by households in transitioning from traditional to renewable energy sources

The establishment of limitations faced by households in Munali reveals a complex web of financial, technical, informational, and cultural barriers that hinder the transition to renewable energy. The most significant barrier identified was high initial costs, cited by 40% of households as their primary constraint. This financial challenge was compounded by difficulties in accessing affordable financing options, with 47.6% of households struggling with high upfront payments and 27.1% citing lack of affordable loans. Technical challenges represented the third most significant barrier at 18.8%, while lack of information or awareness was the second largest obstacle at 22.8%. Limited product availability affected 9.2% of households, and cultural preferences presented barriers for another 9.2%. These limitations manifested concretely during installation, where 63% of households faced high installation costs, 30% reported lack of spare parts, and 7% cited lack of skilled installers.

The prominence of financial barriers aligns strongly with existing literature on renewable energy adoption in low-income settings. Umamaheswaran *et al*. (2024) [67] identified financial constraints as the primary obstacle to renewable energy investments, particularly in contexts where households lack access to formal credit systems. The high upfront costs of renewable systems create a significant barrier for households with limited savings and irregular income streams. This finding supports Streimikiene's (2022) [65] assessment that renewable technologies remain largely unaffordable for low-income households struggling with energy poverty. The specific challenges related to financing options reflect the broader financial inclusion issues documented by Mungai *et al*. (2022) [48], who found that limited access to credit represents a major constraint for renewable energy adoption across sub-Saharan Africa.

The technical challenges reported by households include both installation difficulties and ongoing maintenance issues. The most common maintenance challenge was battery replacement, cited by 34.5% of households, followed by panel cleaning and repair (27.6%), high cost of parts (24.1%), and technical breakdowns (13.8%). These technical limitations support Ghezelayagh's (2021) [20] findings that renewable energy systems require specialized knowledge for proper installation and maintenance. The lack of adequate technical support exacerbates these challenges, with 47% of households reporting that technical support was not available and 30% considering available support inadequate. This technical support gap aligns with Tembo's (2023) identification of technical barriers as significant constraints in renewable energy adoption in Zambian communities.

The informational barriers, representing the second largest category of constraints, reflect limited awareness about renewable energy options, benefits, and available support mechanisms. This finding supports Chisamba's (2022) observation that knowledge gaps discourage adoption, particularly among less educated communities. The lack of information about government programs, financing options, and technical specifications prevents households from making informed decisions about renewable energy investments. This informational deficit is particularly significant given that 87% of households expressed willingness to fully transition to renewable energy if barriers were removed, suggesting that addressing information gaps could significantly accelerate adoption.

The accessibility challenges, including limited product availability and difficult access to renewable energy products, affected a smaller but still significant proportion of households. Some 47% reported that renewable products were rarely available, while 30% said they were not available at all. This accessibility limitation reflects supply chain challenges and market development issues documented by Ketuama *et al*. (2022) [36] in their analysis of renewable energy markets in sub-Saharan Africa. The preference for imported products (67% of households) over locally manufactured options further complicates accessibility, as imported systems may have higher costs and limited spare part availability.

Cultural preferences and behavioral factors present additional barriers to adoption. Some households reported resistance to changing established energy use patterns, particularly for cooking applications where traditional methods are deeply embedded in cultural practices. This finding supports Williams *et al*. (2022) [71] identification of socio-cultural factors as significant influences on energy technology adoption. The persistence of traditional cooking methods despite available alternatives reflects the complex interplay between practical considerations and cultural preferences in energy decision-making.

The installation phase presents specific challenges that merit particular attention. The high installation costs reported by 63% of households include not only equipment costs but also labor expenses and any necessary modifications to household structures. The lack of skilled installers (7%) and spare parts (30%) during installation creates additional barriers that may delay or prevent successful system implementation. These installation challenges support Infield and Freris's (2020) [30] emphasis on the importance of professional installation for system performance and longevity.

The maintenance challenges represent ongoing limitations that affect the long-term viability of renewable energy systems. The high frequency of battery replacement issues reflects the technical complexity and cost of energy storage systems, which Saldarini *et al*. (2023) [59] identified as critical components requiring regular maintenance and eventual replacement. The panel cleaning and repair challenges highlight the need for ongoing maintenance that households may not be prepared to provide, particularly when technical support is unavailable. The high cost of parts creates financial barriers even after the initial investment has been made.

The external support needs identified by households indicate potential pathways for addressing these limitations. Some 39.5% of respondents preferred government subsidies, 27.3% needed technical assistance, 19.5% suggested training and awareness programs, and 13.6% emphasized access to affordable products. These preferences align with the policy recommendations made by Painuly (2021), who advocated for comprehensive approaches that address financial, technical, and informational barriers simultaneously. The strong preference for government subsidies reflects households' recognition that financial support is necessary to overcome the high upfront costs of renewable systems.

The willingness to transition if barriers were removed demonstrates significant latent demand for renewable energy solutions. The 87% of households who expressed strong willingness to adopt renewable energy if constraints were addressed suggests that current adoption rates represent only a fraction of the potential market. This finding supports Bishoge *et al.*'s (2020) [6] assessment that addressing barriers could unlock significant renewable energy potential in African communities.

These findings have important implications for policy and program development. The financial barriers suggest a need for innovative financing mechanisms, including subsidy programs, low-interest loans, and pay-as-you-go models that reduce upfront costs. The technical challenges indicate the importance of developing local technical capacity through training programs for installers and maintenance providers. The informational gaps highlight the need for comprehensive awareness campaigns that provide households with accurate information about renewable energy options, benefits, and support mechanisms.

The accessibility issues suggest a need for market development interventions that improve the availability and affordability of renewable energy products. This could include support for local manufacturing, import duty reductions, and supply chain development. The cultural barriers indicate a need for culturally appropriate approaches that respect traditional practices while demonstrating the benefits of alternative technologies.

The installation and maintenance challenges underscore the importance of quality standards, certification programs, and after-sales support services. Policies should address the entire system lifecycle from installation through maintenance and eventual replacement. The strong demand for government support suggests that public sector intervention is necessary to address market failures and accelerate adoption.

The high willingness to adopt if barriers are removed provides a strong rationale for policy action. By addressing the identified limitations, governments and development partners could significantly accelerate the transition to renewable energy in communities like Munali. This transition would generate multiple benefits including reduced energy expenditures, improved energy access, and decreased environmental impacts.

In summary, households in Munali face multiple overlapping limitations in transitioning to renewable energy sources. Financial constraints represent the most significant barrier, followed by informational gaps and technical challenges. Addressing these limitations requires comprehensive approaches that include financial support, technical capacity building, information dissemination, and market development. The high willingness to adopt renewable energy if barriers are removed suggests significant potential for accelerated transition with appropriate policy support. These findings provide valuable insights for designing effective interventions to promote renewable energy adoption in low-income urban communities in Zambia and similar contexts across sub-Saharan Africa.

5. Conclusion and Recommendation

5.1 Conclusion

The study concludes that socio-economic factors such as income levels, employment status, household size, and expenditure patterns influenced renewable energy adoption in Munali Constituency, with unreliable ZESCO supply being the strongest driver. Solar energy was the most widely adopted source, mainly for lighting and low-consumption appliances, with financing largely dependent on household savings and limited subsidies. Adoption significantly reduced household energy expenditure, enabling savings to be redirected toward food security, education, healthcare, and assets, although mixed experiences with system reliability were reported. High upfront costs, limited financing options, inadequate technical support, and poor product accessibility were major barriers, yet households showed strong willingness to fully transition if these challenges were addressed, highlighting the need for subsidies, technical assistance, and improved access to affordable products to enhance adoption and maximize socio-economic benefits.

5.2 Recommendation

Enhance Affordability through Subsidies and Financing Options: High upfront costs were identified as the main barrier to renewable energy adoption. The government, NGOs, and financial institutions should introduce targeted subsidies, low-interest loans, and flexible payment schemes to ease household investment in renewable systems.

Strengthen Technical Support and Local Capacity: Limited availability of skilled installers and inadequate technical assistance hindered adoption. Training programs for local technicians, coupled with the establishment of community-based service centers, can improve installation, repair, and maintenance support.

Improve Accessibility of Renewable Energy Products: Households faced challenges with product availability and spare parts. Strengthening supply chains, promoting local manufacturing, and creating distribution networks in underserved areas can increase accessibility and reduce reliance on imported systems.

Raise Awareness and Provide Information: Lack of information on renewable energy options was a key challenge. Awareness campaigns, community sensitization, and demonstration projects can help households understand the benefits, system reliability, and financing options available.

Encourage Diverse Use of Renewable Energy: Currently, most households use renewable energy for lighting. Expanding adoption to cooking, water heating, and powering higher-consumption appliances requires policies that promote affordable, larger-capacity systems and efficient appliances.

Promote Public–Private Partnerships: Partnerships between government, NGOs, and private companies can expand access through innovative models such as pay-as-you-go solar, bulk procurement to lower costs, and shared infrastructure for communities.

Strengthen Policy and Regulatory Frameworks: Clear policies that support renewable energy integration, quality standards for products, and consumer protection measures are needed to build trust and encourage long-term adoption.

6. Dedication

I dedicate this study to my family, especially my father, Dr Brown Chomba and my mother Dainess Kasonde. At a time when I almost gave up on my studies, their constant love, encouragement and motivation became the driving force

behind my academic journey. This achievement stands as a testament to their steadfast belief in my capabilities.

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List of Abbreviations

EE	Energy Efficiency
EPPSA	Energy Poverty PIRE in Southern Africa
EU	European Union
IBCs	Improved Biomass Cook stoves
HE	Human Excreta
IEA	International Energy Agency
PV	Photovoltaic
PAYG	Pay-as-you-go
RE	Renewable Energy
REA	Rural Electrification Authority
SHS	Solar Home Systems
SDGs	Sustainable Development Goals
TLADs	Toilet-linked Anaerobic Digesters
WTP	Willingness to Pay

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