Barriers and Opportunities for Renewable Energy Adoption in Rural Communities of Kabwe District, Zambia

Eunice Mulenga[1]; Lusungu Ndovi[2]

[1,2]Department of Natural Resources and Environmental Sciences, Mulungushi University, Zambia

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Abstract: Zambia generates over 80% of its electricity from hydropower, but climate-induced droughts and long dry spells have greatly reduced reservoir levels, making this energy source less reliable. Even though the country has plenty of solar energy, only a small number of rural areas have access to electricity, and about 7 million rural Zambians still live without reliable power. This study looks at the challenges and opportunities for using renewable energy in rural areas of Kabwe District, Zambia. The research used a mixed-methods approach, combining data from a survey of 163 households with interviews and group discussions with 30 key people and 3 groups. The study used the Technology Acceptance Model and the Diffusion of Innovation Theory to guide the analysis. The results show that nearly half of the households have used some form of renewable energy, mostly solar home systems. Most people who haven't adopted renewable energy are willing to do so. The biggest problems are high installation costs, lack of local maintenance, and low household income. Education was the strongest factor influencing adoption. The study concludes that large-scale and small-scale solar projects could help achieve Sustainable Development Goal 7 and improve Zambia's climate resilience and energy variety.

Keywords: *Renewable Energy, Sustainable Development, Solar PV, Zambia, Kabwe District, SDG 7, Energy Transition, Rural Electrification.*

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I. INTRODUCTION

➢ *Background and Research Context*

Zambia relies heavily on hydropower for electricity, which has historically provided affordable power to urban and industrial areas.

However, climate change, especially prolonged droughts, has caused water levels in important hydroelectric dams, like Kariba Dam, to drop. This has led to frequent power cuts that have negatively impacted businesses, industries, and household well-being. The ongoing energy crisis has made it clear that Zambia's electricity system is vulnerable and highlights the need to explore alternative energy sources.

Zambia has access to various renewable energy resources such as solar power with an average of 5.0–5.5 kWh/m² per day, potential for hydroelectric power, and biomass from agricultural and forestry waste.

Despite these resources, energy access in Zambia is still limited, especially in rural areas. According to the Rural Electrification Authority (REA), the national electrification rate is around 44%. However, this hides a significant difference between urban and rural areas: urban places have over 70% electrification, but rural areas have less than 11%. This means that over 80% of Zambia's rural population about 7 million people don't have access to modern electricity services.

➢ *Research Problem*

Although Zambia has good solar resources and the government has shown a commitment to expanding renewable energy through the Eighth National Development Plan (2022–2026) and the National Energy Policy (2019), there are few studies that have thoroughly examined the barriers and opportunities for renewable energy adoption in rural settings.

Existing research mainly focuses at the national level or in urban and peri-urban areas, leaving a gap in understanding the particular socio-economic, technological, and institutional factors that influence adoption in rural communities. Without this knowledge, efforts to promote renewable energy may not be aimed correctly, resources may

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be used inefficiently, and the goal of achieving universal energy access will not be realized.

➤ *Aim*

This study aims to evaluate the barriers and opportunities for renewable energy adoption in the rural communities of Kabwe District, Zambia, providing empirical data to help make policy, guide practice, and support future research.

➤ *Objectives*

- To identify the socio-economic factors that affect renewable energy adoption in rural areas of Kabwe.
- To examine the technological and infrastructural barriers that prevent renewable energy adoption.
- To assess the policy, institutional, and financial factors that influence renewable energy adoption.
- To understand the community's views and readiness to adopt renewable energy technologies.
- To identify specific opportunities that can help boost renewable energy adoption in rural Kabwe.

➤ *Research Questions*

- What socio-economic factors (such as education, income, family size, gender, and occupation) affect renewable energy adoption in rural areas of Kabwe?
- What technological and infrastructural barriers (like installation costs, access to maintenance, reliability, technical knowledge, and distance to suppliers) affect renewable energy adoption?
- How do policy, institutional, and financial factors (such as government programs, NGO support, pay-as-you-go models, subsidies, and loans) influence renewable energy adoption?
- What are the community's perceptions of renewable energy technologies and how ready are they to adopt them?
- What specific opportunities (such as financial models, training, awareness campaigns, local maintenance, and using energy for productive purposes) exist to enhance renewable energy adoption?

II. LITERATURE REVIEW

➤ *Global Renewable Energy Transition*

The world's energy system is changing a lot, with renewable energy becoming the main source for new electricity generation.

In 2023, the total renewable power capacity reached 3,870 gigawatts (GW), and renewables made up 86% of all new electricity generation added that year. Solar energy was the biggest contributor to this growth, adding 73% of the total renewable expansion and reaching a capacity of 1,419 GW [1]. The main reason for this growth is the big drop in the cost of solar photovoltaic (PV) technology. The average cost of solar electricity decreased by 12% between 2022 and 2023, making it 56% cheaper than the average cost of electricity from fossil fuels. The cost of battery storage projects has also fallen sharply, dropping by 89% since 2010, which helps make renewable energy systems more practical [2]. Now, renewable energy is considered the most cost-effective way to generate new electricity [2].

However, this growth isn't happening evenly around the world.

Asia added 69% of the global renewable capacity in 2023, mostly because of China's efforts. Africa's share of renewable growth was only 4.6%, reaching a total capacity of 62 GW [1]. This uneven growth could make the "decarbonisation divide" worse, as reported by IRENA, and could be a major obstacle in reaching global climate goals [1].

➤ *Energy Poverty in Sub-Saharan Africa*

Sub-Saharan Africa has the worst energy poverty in the world.

As of 2024, about 600 million people in the region, or 47% of the population, don't have access to electricity. The number of people without electricity is increasing because the rate of electrification is not keeping up with population growth, and the region accounts for 86% of the global electricity access gap [3]. Although electrification rates in Sub-Saharan Africa rose to about 51% in 2024, this hides big differences between urban and rural areas. Also, the amount of electricity used per household has gone down by 25% over the same period [3].

Getting money for electricity access remains a big challenge.

Only about $2.5 billion is invested each year in electricity access in Sub-Saharan Africa. Small-scale solutions like mini-grids and stand-alone systems have become important alternatives. The amount of money going into these solutions increased by 20% between 2019 and 2023 [4]. But there's a big gap in funding for equity investments, which stops early-stage companies from growing [4].

➤ *Zambia's Energy Sector and Policy Framework*

Zambia's electricity supply is mainly from hydropower, which makes up over 83% of the installed capacity [5].

This reliance on hydropower puts Zambia at risk from changes in the water supply caused by climate change. Recent dry periods have caused severe power shortages and economic problems. In the first half of 2024, the country's electricity generation dropped by about 14.5% compared to the same period in 2023, mainly due to lower output from major hydropower stations [5]. The Kariba Dam, which is Zambia's largest hydropower facility, has had very low water levels, making the energy crisis even worse [6].

The Zambian government has shown support for expanding renewable energy through several policies.

The National Energy Policy (NEP) 2019 outlines the main goals, which include promoting renewable and alternative energy sources, making energy supply more reliable through diversification, and improving access to electricity in both rural and urban areas [7]. Zambia has a

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variety of renewable energy resources, including hydropower, solar, wind, biomass, and geothermal energy, all with great potential for electricity and fuel production [7].

The Rural Electrification Master Plan (REMP) is the main plan for electrifying rural areas, combining expanding the power grid with off-grid solutions like solar energy [8].

The updated REMP 2.0, launched in 2026, aims to provide electricity to everyone in Zambia by 2030 [9]. The plan plans to bring electricity to underserved communities, benefiting 655 schools, 89 rural health centers, and over 51,000 households [9].

- *Utility-Scale and Decentralised Solar in Africa and Zambia*

When comparing solar energy deployments across Africa, there are common factors that have led to success and ongoing challenges.

In Zambia, the Bangweulu (54 MW) and Ngonye (34 MW) solar plants, both completed in 2019, were the first steps towards diversifying the electricity mix under the World Bank Group's Scaling Solar program [5]. These projects are part of a national strategy to diversify the electricity system and reduce the country's dependence on hydropower [5].

Beyond large-scale solar projects, small-scale solar solutions have become essential for providing electricity in rural areas [10].

However, a solar home system that can power just two light bulbs costs around $52.Rural people earn and survive on less than $1.50 per day on average [10]. This cost difference is a major obstacle to the widespread use of solar technology [10].

- *Determinants of Renewable Energy Adoption*

Using renewable energy technologies in rural areas is influenced by a mix of social, economic, technological, and institutional factors.

Despite Zambia's favorable solar conditions, with an average of 5.5 kWh/m² per day [5], the use of solar photovoltaic (PV) technology is still limited due to high initial costs, low awareness among consumers, and underdeveloped infrastructure [10].

Recent studies in Zambia have looked at the role of governance, adoption, and how renewable energy affects rural livelihoods.

These studies have identified important factors like peer learning, local ownership, and the use of charcoal production to fund solar technology [11], [12].Research has also explored how community-based efforts using local networks, individual benefits, and peer advice can help increase the adoption of PV technology and willingness to pay [12], [13].However, there is still a clear lack of research and policy understanding about how rural communities adopt, use, manage, and sustain these systems over time [12].

- *Research Gap*

Even though there is growing literature on renewable energy in Zambia, there is still a big gap in empirical research on the barriers and opportunities for adoption at the community level [10], [12].

Most studies have focused on national or provincial-level analysis or the technical aspects of solar deployment [5].Current policy frameworks mainly focus on technical implementation and overlook community involvement, informal governance structures, and the long-term sustainability of small-scale solar investments [12].This study fills this gap by providing empirical data from Kabwe District, contributing to the growing understanding of renewable energy transitions in rural Sub-Saharan Africa [14].

III. MATERIALS AND METHODS

- *Research Design*

This study used a mixed-methods approach that combines both quantitative and qualitative data.

The quantitative data came from a survey of households, while the qualitative data was collected from interviews and group discussions. This method was chosen because renewable energy adoption is not just about income and education but also involves cultural and social aspects that can only be understood through deeper conversations [33].

- *Study Area*

The research took place in Kabwe District, which is in the Central Province of Zambia.

It is about 140 kilometers north of Lusaka, the capital. The study focused on three rural areas Kańgomba, Munyama, Chifukwa and the surrounding villages. The area has a tropical savannah climate with wet and dry seasons, and it receives between 800 to 1,000 mm of rain each year [4]. The villages are spread out across farmland, grasslands, and less populated areas. The main ways people make a living are through subsistence farming (41.7%), informal trading or jobs (36.2%), formal employment (19.0%), and keeping livestock (3.1%) [7].

- *Data Collection*

Primary Data: For the quantitative data, we used a questionnaire given to 163 households.

This covered their socioeconomic status, energy use, how much they use renewable energy, and their opinions measured on a 5-point scale. The qualitative data came from interviews with 30 key people like local officials, NGO members, energy service providers, and community leaders. We also had three focus group discussions with 8 to 12 participants each, including men, women, and youth. We also did observation visits to check what people actually use.

Secondary Data: We looked at reports from the Renewable Energy Agency, the World Bank, NGOs, government policies, and academic research to get more context.

- *Data Analysis*

For the quantitative data, we used descriptive stats like frequencies, percentages, averages, and standard deviations.

We did chi-square tests, correlation analysis, and logistic regression using SPSS 27 and R Programming [36]. Qualitative data were analyzed using themes to find common ideas and insights [37]. We also compared the qualitative and quantitative results to make the interpretations better [38].

- *Validity and Reliability*

Made sure the tools were valid by getting expert opinions. Checked if the questions matched the theories used (TAM, DOI) [39], [40]. Later confirmed the approach was clear by testing it with 20 households. Then checked reliability using Cronbach's Alpha, which gave a score of Î± = 0.87 for all the questions, showing they are reliable [36].

IV. RESULTS AND DISCUSSION

- *Energy Security*

The study found that none of the households surveyed had access to the national electricity grid, which shows a big problem with energy in rural areas of Kabwe [6].

The most common ways to cook are firewood (58.9%) and charcoal (36.2%). Gas and electricity are used very little (3.1% and 0%, respectively). For lighting, solar (44.2%), candles (34.4%), and kerosene/torch (21.5%) are the main sources. Most households (68.1%) spend less than K100 a month on energy, indicating that even basic needs are not met [11].

Despite these challenges, 45.4% of households have used at least one renewable energy technology, which is much higher than the national average of 11% [6].

The most common technologies used are solar home systems (58.1%), then solar water pumps (16.2%), mini-grids (9.5%), biogas (8.1%), and improved cookstoves (1.4%). This shows that solar power has a big impact on energy security at the household level, similar to what has been found in Kenya and Tanzania [41], [42].

Table 1 Household Energy Profile

Energy Source	Cooking (%)	Lighting (%)
Firewood	58.9	-
Charcoal	36.2	-
Solar	0.0	-
Candles	-	44.2
Kerosene/Torch	-	34.4
Gas	3.1	-
Electricity	0.0	0.0

Source: Field Survey, 2026

Note: The percentages for cooking and lighting represent the proportion of households using each energy source for the respective purpose. “–” indicates that the energy source was not reported as being used for that purpose.

- *Economic Benefits*

The study found major economic barriers to adopting renewable energy.

High installation costs (Mean = 4.48/5) and low household income (Mean = 4.34/5) were the main issues. Monthly income categories show that 58.9% of households earn below K1,500, and 33.1% earn between K1,501 and K3,000. This confirms that most households are low-income [7]. However, 83.1% of those who haven't adopted renewable energy are willing to do so, indicating a strong potential demand.

Logistic regression analysis showed that education is the strongest factor in adopting renewable energy (OR = 1.87, 95% CI: 1.24-2.82, p = 0.003).

This means each increase in education level increases the chance of adoption by 1.87 times. Income was also a big factor (OR = 1.42, 95% CI: 1.03-1.96, p = 0.032). The model correctly predicted 71.2% of cases [36]. These results match other studies in sub-Saharan Africa that point to education and income as key factors in adoption [43], [44].

Table 2 Socio-Economic Determinants of Adoption

Variable	Odds Ratio	95% Confidence Interval (CI)	p-value
Education	1.87	1.24-2.82	0.003
Income	1.42	1.03-1.96	0.032
Age	0.98	0.92-1.05	0.421
Household Size	1.05	0.94-1.18	0.387

Source: Logistic Regression Analysis, 2026

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➢ *Environmental Benefits*

The study found that people strongly believe in the environmental benefits of renewable energy.

Question 32, which asked if renewable energy improves household welfare, had the highest score (Mean = 4.32, SD = 0.83), showing it is seen as very useful. Question 33, which asked if renewable energy is easy to use, had a score of 4.03 (SD = 0.91), indicating it is considered easy to use [39]. The heavy use of firewood and charcoal for cooking leads to deforestation, indoor air pollution, and greenhouse gas emissions [45]. Switching to renewable energy can help cut these environmental problems and improve health.

Qualitative findings supported this.

A community leader said, "We see solar systems, we know they are good, but K2,000 is money we don't have. We need to pay little by little." This shows the conflict between environmental awareness and financial limitations. An NGO representative mentioned, "Demonstration projects in Chisamba have created a buzz. Now everyone wants solar. The challenge is making it affordable."

Environmental Benefits of Renewable Energy Adoption

Benefit Description
Reduced Deforestation Decreased reliance on firewood and charcoal
Improved Air Quality Reduced indoor air pollution from biomass combustion
Climate Change Mitigation Reduced greenhouse gas emissions
Water Conservation Solar PV requires minimal water compared to hydropower.

➢ *Contribution to Sustainable Development Goals*

The results of this study show that using renewable energy helps achieve several Sustainable Development Goals (SDGs).

SDG 7, which focuses on affordable and clean energy, is directly supported by providing more access to solar home systems and mini-grids. SDG 1, which aims to eliminate poverty, is helped by lowering energy costs and creating better economic opportunities. SDG 3, which focuses on good health, benefits from less indoor air pollution caused by burning biomass. SDG 4, related to quality education, improves with better lighting for studying in the evenings. SDG 5, which is about gender equality, is supported by reducing the time women spend collecting firewood. SDG 8, which deals with decent work, is helped by creating jobs in the installation and maintenance of renewable energy systems. SDG 13, focusing on climate action, is supported by cutting down greenhouse gas emissions from using biomass and fossil fuels [24], [25].

Contribution to Sustainable Development Goals
SDG Contribution
SDG 7 Increased access to affordable and clean energy via solar home systems and mini-grids
SDG 1 Reduced energy costs; improved economic opportunities
SDG 3 Lower indoor air pollution from burning biomass
SDG 4 Better lighting for evening study; access to educational technology
SDG 5 Less time burden on women for fuel collection
SDG 8 Local employment in installation, maintenance, and sales
SDG 13 Lower greenhouse gas emissions from biomass and fossil fuels

➢ *Challenges*

The study found several ongoing issues.

The highest barriers are the high initial costs of setting up systems (Mean = 4.48/5) and the lack of local maintenance services (Mean = 4.44/5). Qualitative findings show that systems often stop working because there are not enough spare parts or skilled workers to fix them. One energy provider explained, "We sell systems in Kabwe town, but when a battery fails in a village 60 km away, we can't afford to send a technician. The household gives up on the system."

Policy challenges include low awareness of government programs (Mean = 3.73/5), showing a big gap in how policies are communicated [6].

Even with subsidies for renewable energy and the ZOSAP project [8], most households are not aware of these programs. Financial difficulties still exist, with limited options for credit and loans for investing in renewable energy. Cultural factors, such as preferring traditional energy sources and not trusting new technologies, also affect how much people adopt renewable energy [46].

V. POLICY IMPLICATIONS

➢ *Recommendations for Government (Ministry of Energy, REA)*

The REA should develop guidelines that protect consumers, ensure product quality, and handle disputes, which will encourage private investment and protect users [8]. Include maintenance in rural electrification programs. The REA should require that all subsidized solar systems come with a 2-year maintenance plan. Set up a network of village technicians trained and certified by REA. Provide funding for spare parts in rural areas [6]. Start a targeted awareness campaign. The Ministry of Energy should work with community radio, local leaders, and mobile companies to spread information about subsidies, PAYG options, and the benefits of renewable energy using local languages and visual methods [47]. Begin a rural renewable energy technician training program. The REA should partner with training institutions to create a "Rural Renewable Energy Technician" curriculum. Graduates can be placed at district centers. Training should also include business skills to ensure sustainability [48].

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➢ *Recommendations for Implementation Agencies (NGOs, Donors)*

Shift from giving away free solar systems to making it easier for people to access them.

NGOs should move from donating systems to helping people access them through PAYG providers by setting up maintenance networks and doing awareness work. Donating systems creates dependence and is not a long-term solution [12]. Fund demonstration project. Install solar systems in schools, health centers, and village offices where the benefits are clearly visible. Being able to see the benefits encourages more people to adopt renewable energy [40]. Include income-making uses. Support solar applications for irrigation, cold storage, and processing. These uses help generate income that can cover PAYG payments, improving the sustainability of the systems [43].

➢ *Recommendations for Private Sector*

Quickly introduce PAYG solar home systems in Kabwe.

The strong interest (83.1% willingness) and mobile money infrastructure make Kabwe a good market for these systems. Companies should offer small systems (50-100W) with daily payments of K5-10, similar to the current cost of kerosene [49], [50]. Set up local maintenance centers. Companies should train and support local technicians to provide maintenance, battery replacement, and customer support. This creates local jobs and ensures customer satisfaction.

➢ *Recommendations for Communities*

Create energy savings groups.

Communities should form formal or informal groups to buy larger systems together or provide credit for individual systems. This uses the existing trust in the community and reduces the cost barrier [51]. Support renewable energy through local leaders. Chiefs and village heads should use renewable energy in their homes and public buildings, showing the benefits to the community. They should also lead awareness efforts and help with any issues people have with providers [40].

VI. CONCLUSION

This study looked at the challenges and opportunities for renewable energy adoption in the rural areas of Kabwe District, Zambia.

The results show that renewable energy, especially decentralized solar, is a good way to reach SDG 7 and improve Zambia's climate resilience and energy options.

The study found that 45.4% of households have adopted renewable energy technologies, mostly solar home systems.

83.1% of those who haven't adopted it are willing to. Education is the strongest reason for adoption (OR = 1.87), followed by income (OR = 1.42).The biggest obstacles are the high initial installation costs (Mean = 4.48/5) and the lack of local maintenance services (Mean = 4.44/5).People have a positive view of renewable energy, seeing it as useful (Mean = 4.32/5) and easy to use (Mean = 4.03/5).Community leaders play a big role in influencing adoption decisions (Mean = 4.01/5).

The study concludes that even though there are big challenges, there is strong potential for renewable energy adoption and positive community attitudes.

The findings support the use of PAYG financing models, setting up local maintenance services, and targeted awareness campaigns as key steps.

Future investment should include energy storage, policy changes, and building local capacity.

The government should improve certainty for investors, speed up licensing, and expand the power grid. Development partners should provide blended finance and help with project planning. Universities should increase training in renewable energy.

The path to universal energy access in Kabwe's rural areas—and in rural Zambia overall—requires a coordinated effort addressing economic, technical, policy, and social aspects.

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Correspondence: Eunice Mulenga, Department of Natural Resources and Environmental Sciences, Mulungushi University, Zambia.

Email: [mulengaeunice856@iclod.com]

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