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Exploring Off-Grid Energy Choices: Household Decisions in Upper Blinkwater, South Africa

Mahali Elizabeth Lesala *, Golden Makaka and Patrick Mukumba

Physics Department, Faculty of Science & Agriculture, University of Fort Hare, Alice 5700, South Africa; medzai9@gmail.com (G.M.); pmukumba@ufh.ac.za (P.M.)
* Correspondence: mlesala230@gmail.com

Abstract: Household energy is critical for sustainable development, but many rural and off-grid communities lack access. As global concerns about climate change prompt a re-evaluation of energy strategies, understanding rural household energy decisions becomes increasingly complex, particularly in remote areas without grid access. This study examines the energy decisions of households in the Upper Blinkwater community to uncover the primary drivers for their choice of energy amidst grid connections. Survey data from 53 households were analyzed using multivariate regression. The findings revealed significant economic vulnerability among the respondents, marked by high unemployment and limited resource access, with the majority of households relying on social grants. These households depend on multiple energy sources, with firewood usage significantly influenced by the availability of grants, total income, post-primary education, household size, and remittance income. The findings contradict the energy ladder hypothesis, indicating that despite economic improvements, a complete transition to modern fuels may not be possible as firewood remains a crucial energy source. These results highlight the complex interplay of economic, social, and cultural factors in household energy decisions and underscore the importance of enhancing infrastructure, providing economic incentives, and conducting educational campaigns to facilitate the transition to cleaner energy alternatives.

Keywords: energy choice; energy poverty; household surveys; multivariate regression; off-grid households

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1. Introduction

Access to adequate, reliable, and sustainable energy is essential for overall socioeconomic and modern living [1–3]. Its significance has been underscored by its inclusion in the Sustainable Development Goals (SDGs), with household energy use being pivotal for achieving these goals due to its direct impact on reducing poverty, enhancing healthcare delivery, and promoting environmental sustainability [2]. As Ref. [4] suggests, it is exceedingly challenging to attain any development goals without access to reliable, affordable, and long-term energy services. However, millions of people worldwide, especially those in rural and off-grid communities, continue to lack this fundamental necessity [3]. In South Africa, as of 2022, 7.7% of South African households still use firewood for cooking and heating, which adversely impacts health, education, and economic opportunities [5,6]. About 18% of the population remains disconnected from the national grid [7], while a staggering 43% experience energy poverty, spending a disproportionate amount of their income on meeting basic energy needs [7]. This financial strain further perpetuates socioeconomic vulnerabilities, exacerbating disparities within these communities. Even in cases where electrification efforts have been successful through non-grid connections, they often fail to provide adequate thermal energy for cooking and space heating. Approximately 60% of off-grid households are situated in remote rural areas where prospects for electrification remain distant [8–10].

Addressing rural energy poverty in South Africa is a complex challenge. For instance, expanding energy infrastructure in remote areas poses significant hurdles due to the high costs and logistical challenges associated with reaching these locations [8]. As these communities await grid connection, they often face challenges in making optimal energy choices. Recent global concerns about climate change add further complexity, resulting in diverse implications for the available energy options for households [11,12]. Consequently, individual households navigate a range of considerations, involving trade-offs between cost, convenience, efficiency, and environmental impact [13]. However, households prioritize immediate, often cheaper energy options like traditional biomass fuels over long-term investments in more efficient and sustainable energy sources [6].

While the negative consequences of reliance on traditional energy sources are becoming increasingly apparent, with far-reaching implications for the environment, quality of life, and human health [14], they disproportionately affect women and children. These groups spend considerable time collecting firewood and preparing meals, sacrificing opportunities for education and economic empowerment [15], and further exacerbating disparities in access to basic services [16–18]. Improving access to clean, affordable, and reliable energy sources is critical, but so is understanding household decision-making processes and the factors that influence their energy choices [15,19], which is critical but underexplored.

Recent research has highlighted several factors that significantly influence household energy decisions, including economic constraints [1,20,21], cultural norms, household dynamics and awareness of the benefits of alternative energy sources, play significant roles in these decisions [22–25]. However, most of this research has focused on urban populations, and less attention has been paid to the unique challenges and dynamics of rural energy access. Yet, there is evidence suggesting that rural and urban populations have distinct experiences regarding energy access and usage patterns due to a combination of infrastructure deficiencies, economic constraints, and cultural norms [15,26]. For instance, rural areas often lack the necessary infrastructure to support the transition to cleaner energy alternatives, leading to limited options for rural households, which include firewood, charcoal and agricultural waste, while urban households have access to paraffin, LPG and electricity [27]. As a result, households may continue to rely on biomass and other traditional energy sources out of necessity rather than choice. Economic constraints further complicate this issue, as many households may not have the financial means to invest in cleaner energy technologies, which often have higher upfront costs despite their long-term benefits [6].

Moreover, the gendered nature of domestic energy use and management in rural contexts is another critical factor shaping household energy choices. Across many developing regions, the responsibility for collecting and using biomass fuels for cooking and heating falls disproportionately on women and children, often at the expense of their health, safety, and economic opportunities [15]. Furthermore, women are often the primary users of household energy and thus play a critical role in energy-related decisions. However, their participation in decision-making processes is frequently limited by broader societal norms and gender inequities [28,29].

Despite extensive research on energy access, there is a notable lack of studies focusing on rural off-grid communities, particularly in the context of South Africa. Existing literature often overlooks the unique challenges and dynamics faced by these populations, such as infrastructure deficits, economic barriers, and cultural influences on energy choices. Without a clear conceptual grasp of the underlying key drivers and significant barriers to change, initiatives aimed at promoting sustainable energy practices may fall short or even have unintended consequences [30].

This study aims to fill this research gap by exploring the energy choices of off-grid households in Upper Blinkwater, South Africa, and investigating the factors that influence these choices. The study employs a quantitative research design, utilizing household surveys and multivariate regression analysis to examine the factors that influence energy choices. The study also contributes to efforts aimed at enhancing energy access in rural

areas, ensuring that they are designed and implemented in a way that meaningfully addresses inclusive energy solutions that benefit all, especially the most vulnerable. Therefore, a better understanding of the factors influencing household energy choice will be critical for recommending energy development pathways for the entire country.

The following sections will present a review of the theory and the relevant literature in Section 2, the study's methodology in Section 3, and the findings in Section 4, and we will discuss their implications for policy in Section 5, while Section 6 offers conclusions and recommendations for future research.

2. Theoretical Literature of Household Energy Decision

The household fuel choice model offers a framework for understanding how households decide on the types of energy fuels they use. This model is often analyzed using the "energy-ladder" concept, but it extends as a multitier approach to household energy beyond the traditional energy-ladder concept [31]. Traditionally, the energy ladder model assumes a linear progression of how households transition from traditional to modern energy sources as their economic status improves. The energy ladder emphasizes income as the primary driver of fuel choice, suggesting that economic improvement leads households to adopt cleaner, more efficient fuels [31]. However, this model oversimplifies the reality of household energy use by assuming a unidirectional transition and fails to account for the diversity of energy sources used by households. Often, it relies on simple surveys that focus only on a household's "primary fuel" [32] and does not adequately account for the phenomenon of fuel stacking, where households use multiple fuels simultaneously rather than completely switching from one type to another [33]. Although several studies have shown consistent results with the energy ladder theory, there is a gap between this theory and reality. In reality, households often engage in "fuel stacking," using traditional fuels alongside modern ones, making the situation more complex [34].

The fuel stacking concept is one in which households maintain the use of multiple energy sources, both traditional and modern, even after gaining access to cleaner and more efficient fuels [35]. This behavior is in contrast with the simplistic "fuel switching" model, which assumes that households will entirely replace traditional fuels with modern alternatives once income and access constraints are removed [36]. This multitier household energy choice approach moves beyond the limited focus on "primary fuel" and instead captures the secondary fuels utilized, as households may opt to maintain the use of traditional fuels as backup even after adopting modern energy sources [33]. It enables a more thorough assessment of usage patterns, addressing the main energy sources for cooking, heating, and lighting within a household, and it acknowledges the complexities of household energy needs and the diverse strategies employed by families to ensure a continuous energy supply and address potential access and availability challenges.

Evidence from South Africa shows that for various reasons, including affordability, individual preferences, and the reliability of energy fuels, many rural households do not fully transition away from traditional fuels as their incomes rise [37,38]. Even with electrification and the availability of alternative energy sources, some South African households will continue using firewood [6,39]. Mere access to electricity does not automatically lead to a transition from solid fuels to grid energy; rather, households consider factors like cost and the reliability of the electricity supply [7,40]. According to these authors, energy stacking behavior is more prevalent among many low-income households in South Africa. The authors of [21] also found that while energy ladder behavior exists for cooking, energy stacking is more likely for space heating. For lighting, the pattern also tends towards energy stacking, indicating that households do not fully transition to modern fuels even when they have access to them; [27] opined that for many individuals or households, a mixture of fuels is used with each for a specific use. For example, some individuals may prefer to use firewood for cooking and LPG for heating. This suggests that culturally ingrained chores like cooking with firewood may not be easily changed without considerable education and support. Dwelling type, household size, and geographical location were identified as key

determinants of the energy transition pattern. These factors significantly influence household decisions regarding energy use, demonstrating the complexity of energy transition dynamics in low-income settings.

Other studies have also investigated the factors influencing energy preferences in rural households, reevaluating the energy ladder and the use of multiple fuels in various municipalities within the Thulamela municipality of South Africa [27,29]. These studies have found that, aside from household income, educational attainment, employment status, and cultural norms and values play crucial roles in determining energy preferences. For instance, proximity to biomass sources can lead households to continue using traditional fuels even if they can afford to use modern ones, and the authors of [27] also found that cultural preferences, such as the taste and texture of food cooked with certain fuels, like firewood, play a significant role in maintaining the use of traditional fuels. The authors of [34] also assessed the primary determinants of energy fuel choice in selected South African households in Gauteng and the Northwest to alert policymakers to important energy consumption behavioral tendencies that can inform policies and assist in promoting sustainable energy growth and reducing biomass use in households. The results suggested that households generally tended to practice energy stacking.

Broadly, the household fuel choice model addresses the limitations of the energy ladder hypothesis by considering a broader range of factors that influence energy decisions. These factors encompass income levels, fuel availability, cultural preferences, and external constraints. This model acknowledges the complex nature of energy choice. By considering fuel stacking dynamics, the model more accurately reflects the diverse energy use patterns in rural, off-grid areas, where households often rely on multiple fuels to balance cost, convenience, and reliability. Additionally, the model underscores the significance of non-economic factors such as social norms and health considerations in shaping fuel choices, providing a comprehensive view of the influences on household energy decisions. This broader perspective provides a more realistic understanding of energy use patterns, their diverse energy needs and preferences, and the challenges households face in accessing energy, thereby allowing for a more accurate assessment of household energy use and the factors influencing fuel choices [25,34,41].

3. Materials and Methods

3.1. Study Area

The research took place within the Upper Blinkwater community. Upper Blinkwater is a small, remote rural community situated in the mountainous region of the Raymond Mhlaba Municipality. This community presents a compelling case study due to its geographical isolation and disconnection from the mainstream energy infrastructure, making it a representative example of many marginalized communities in South Africa. It notably lacks essential infrastructure and access to electricity. This community consists of scattered settlements and faces substantial challenges, such as infrastructure deficiencies. The limited infrastructure and difficult accessibility result in restricted economic opportunities, leading to high levels of poverty and unemployment. Most residents work on nearby farms or seek unskilled jobs in urban centers like East London and King Williams Town, as well as locations outside the province. Consequently, many households depend primarily on social grants for income [41,42].

The selection of Upper Blinkwater for this study stemmed from its designation as the initial community to participate in a renewable energy pilot project. This project aimed to introduce a hybrid mini-grid as part of efforts to address rural electrification in South Africa [41]. By thoroughly examining the community's energy situation before the mini-grid's implementation, we can establish a comprehensive baseline. This baseline is crucial for assessing the existing state of energy access and socioeconomic conditions in Upper Blinkwater, providing a critical reference point from which future impacts and advancements can be measured. Additionally, understanding what influences the community's preferred energy sources will help tailor the mini-grid to meet their specific needs and

preferences. This will ensure greater acceptance and ensure that the intervention brings about significant and meaningful improvements. The geographical location of Upper Blinkwater is depicted in Figure 1.

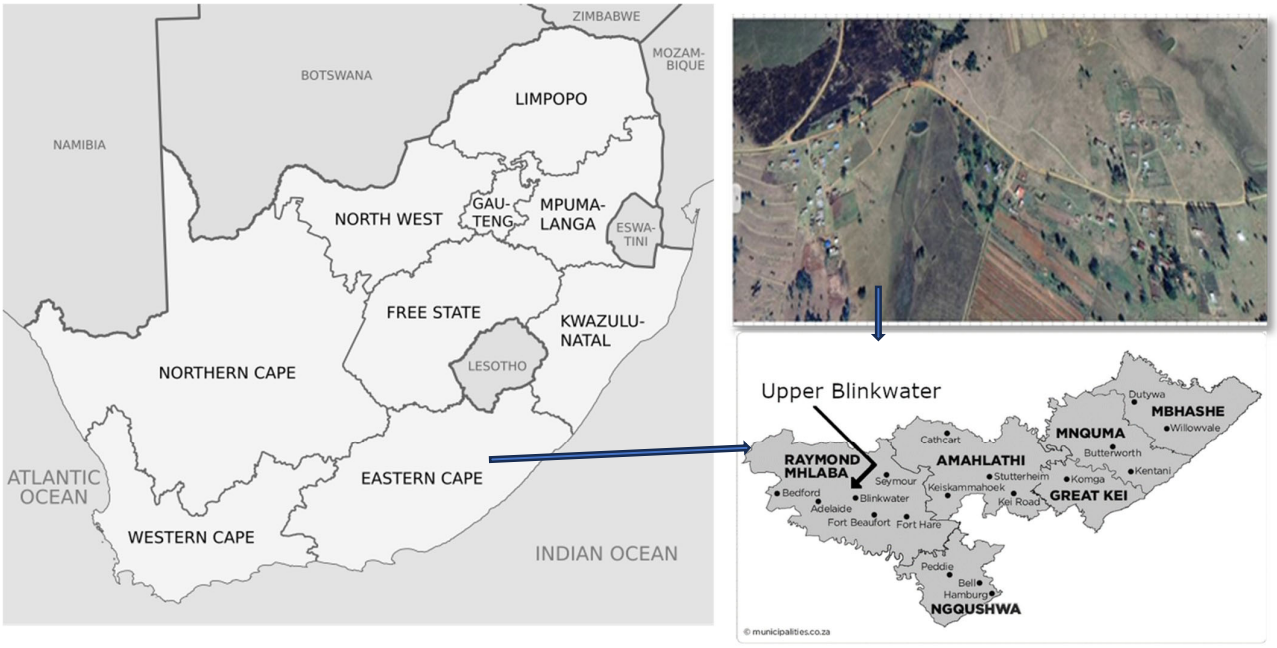


Figure 1. Geographical location of Upper Blinkwater. Source: [41,43,44].

3.2. Research Methodology and Data Collection

The study is based on a quantitative research design because it allows us to systematically collect and analyze data, as well as to identify and quantify the relationships between various factors and energy choices, revealing how those factors influence households' choices among their alternative energy options. Moreover, this approach offers the advantage of generalizability, allowing findings to be extrapolated to broader populations or contexts, thus enhancing the study's relevance and applicability. This enhances the validity and reliability of the study's findings, providing a solid foundation for drawing meaningful conclusions and informing evidence-based decisions.

The questionnaire development process involved a thorough review of existing literature on household energy use and fuel choice models, integrating key themes and variables identified from previous studies to encompass all relevant aspects of household energy decision-making [40]. A pilot test was conducted within the Upper Blinkwater community, with a small sample of ten households similar to the target population to identify and address any issues with questionnaire items, such as ambiguity or difficulty in understanding. Subsequent revisions were based on feedback from the pilot test. Furthermore, the content validity of the questionnaire was validated through evaluation by stakeholders involved in the planning of the mini-grid project, including representatives from the Raymond Mhlaba Local Municipality, the Eastern Cape Province Economic Development Department, the Department of Minerals and Energy, Lower Saxony Government Germany, GIZ, Council for Scientific and Industrial Research and other stakeholders, including the two local universities (University of Fort Hare and Nelson Mandela University) who confirmed the relevance and representativeness of the questionnaire items, affirming its adequacy in measuring the intended constructs.

With the help of a social facilitator, the purpose of the survey and the scheduling of appointments for interviews were communicated. The local language, Xhosa, was used to communicate effectively, ensuring households understood their rights and the survey's expectations. Participation was voluntary, with assurances of confidentiality and the right

to skip uncomfortable questions. Ethical considerations were prioritized, maintaining a commitment to confidentiality and voluntary participation.

3.3. Sampling

Because Upper Blinkwater has a limited population, it was not feasible to select a sample, which could have led to inadequate data for drawing meaningful conclusions [45]. The scientifically sufficient sample size to represent a population is determined by various criteria, including the required confidence level, margin of error, population variability, and population size. According to the Central Limit Theorem, a sample size of at least 30 is frequently regarded as sufficient for a normal distribution to be an acceptable approximation; however, this is a general guideline that does not necessarily provide accurate representativeness in all cases. For more detailed directions, see the sampling procedures described in Ref. [46], which are commonly mentioned. Cochran's formula for sample size determination offers a scientific approach to ensuring that the sample size is statistically appropriate; the authors of [46] claim that when conducting surveys or studies on large populations, a sample size of around 384 is required in order to achieve a 95% confidence level with a 5% margin of error. However, when dealing with smaller populations, it is necessary to make adjustments in order to maintain the same degree of precision and confidence in the results.

In the case of Upper Blinkwater, the decision to study the entire population is based on the understanding that small communities require a different approach. As noted by [46], the finite population correction factor adjusts the sample size required to maintain accuracy when dealing with a small population. This means that in small populations, the sample size needed to achieve the same level of statistical power is much closer to the total population size, often making it more practical to study the entire population. Therefore, despite general guidelines, studying the entire population in Upper Blinkwater ensures the most accurate representation and eliminates the risks associated with sampling bias, enhancing the validity and reliability of the research findings. In light of this, all households in this community were included in the survey; however, the study also prioritized the willingness and voluntary participation of the community members, which resulted in 53 household heads graciously contributing to the study's depth and validity.

After the data collection phase, rigorous cleaning procedures were employed to guarantee the accuracy of the data, and the data were then analyzed using STATA software version 15, which allowed for a comprehensive analysis of the data collected, including descriptive statistics and regression analysis.

3.4. Data Analysis

When analyzing household energy choices, it is essential to account for the multifaceted factors that influence these decisions. The household energy choice model posits that households' decisions on fuel use are influenced by multiple variables, such as economic factors (household income and energy expenditures), demographic factors (gender, age, education level and household size), and socioeconomic factors (employment status). These variables suggest that household energy choices are not driven by a single factor but rather a combination of influences. Typically, the model is analyzed through a utility optimization framework, where households aim to maximize their utility from energy consumption [47], taking into account various influencing factors.

$$U = f(E) + X \tag{1}$$

where E = energy consumption and X represents other factors that may have an influence on the energy consumption. This framework allows us to explore and understand the direct relationships between these factors and household energy consumption preferences. The important question is whether there is a statistical relationship between household energy options and the selected explanatory variables [48]. Given the complexity of analyzing multiple dependent and independent variables, a multivariate regression approach is well

suited to explore and quantify these diverse factors simultaneously. This method allows for a comprehensive examination of how different variables collectively impact household energy choices, facilitating a deeper understanding of the underlying dynamics at play.

Multivariate regression is a statistical technique that allows us to understand the relationship between multiple independent variables (predictors) and one or more dependent variables (outcomes) [49]. In the context of household energy choices, multivariate regression can help us analyze how different factors simultaneously influence the choice of energy sources. It can assess the individual impact of each socioeconomic factor while controlling for the effects of other variables, allowing us to simultaneously identify the most significant determinants of energy choices and consumption patterns.

To empirically estimate the utility function and the influence of various factors on energy consumption using multivariate regression, we assume we are analyzing the probability of a household choosing a particular energy type (j) as the dependent variable. The regression model can be specified as follows:

$$P(\text{Energy} = j) = \beta_{0i} + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \varepsilon \quad (2)$$

where $P(\text{Energy} = j)$ is the probability of choosing energy type j.

The independent variables could include the following:

X_{1i} = Gender of household head.

X_{2i} = Age of household head.

X_{3i} = Household size.

X_{4i} = Education level of household head; post-primary and tertiary.

X_{5i} = Employment status of household head; employed or unemployed.

X_{6i} = Household income, which is the sum of all incomes.

X_{7i} = Income sources; income from wages, grant, remittance and own business.

β_0 represents the intercept; β_1, β_2,..., β_7, are the regression coefficients.

ε is the error term.

4. Results

4.1. Demographics and Energy Consumption Patterns of Respondents

Table 1 presents a summary of the statistical analysis examining the respondents' demographic characteristics and their existing energy sources. According to the findings, the respondents had an average age of 52 years, and their household size varied significantly, ranging from single-person households to larger families with up to eight members, with an average of at least three (μ = 3.433) family members. The average education level was 2.13, where 1 represents no formal education, 2 represents primary education, 3 represents secondary education, and 4 indicates tertiary education. This suggests that a significant portion of individuals in the sample had completed at least primary education, with some having progressed further to secondary education. Regarding employment, the mean value of 1.94 reflects a predominantly low to moderate level of employment engagement within the sample. Categories included 0 for unemployed, 1 for wage employment, 2 for self-employment and 3 for retired. This indicates that while a substantial number are engaged in wage or self-employment, a notable proportion may also be retired or not actively participating in the workforce. The data also showed that the respondents were mostly dependent on grants as their source of income, followed by wages and remittances. On average, respondents reported an income of around ZAR 2321.89 (USD 129.25), with grants contributing significantly at an average of ZAR 1093.59 (USD 60.88), while wages contributed ZAR 552.83 (USD 30.77), remittances contributed ZAR 454.72 (USD 25.31) and own business income contributed a lower average of ZAR 220.75 (USD 12.29). Interestingly, each household had at least one family member who was receiving a social grant, indicating the importance of social grants as a source of income for many households and how they can contribute to their financial stability and well-being.

Table 1. Descriptive results of the respondents' characteristics.

Variable	Mean	Std. Dev.	Min	Max
Age	52.43396	17.57348	24	101
Household size	3.433962	2.061641	1	8
Education	2.132075	0.6804336	1	4
Employment	1.943396	0.246766	0	4
Main source of income				
* Wages	552.8302	967.6704	0	3500
* Grant amount	1093.585	1310.334	0	5500
Number of grants	1.358491	1.331488	0	6
* Remittance	454.717	1073.02	0	4300
* Own business income	220.7547	1127.516		0
* Total income	2321.887	1990.098	0	8890
Wood	0.9622642	0.1923802	0	1
Paraffin	0.9245283	0.2666788	0	1
Wood	0.3396226	0.4781131	0	1
LPG	0.8490566	0.3614196	0	1
Candles	0.9433962	0.2332953	0	1
Generator	0.1320755	0.3418128	0	1
Cooking	3.245283	1.299492	1	4
Heating	1.226415	0.6397568	1	3
Lighting	3.754717	0.874987	1	4

* Income is reported in Rands (ZAR), (1 USD = 17.90 ZAR).

With no access to centralized power grids, residents of Upper Blinkwater are compelled to navigate a complex landscape of energy alternatives for cooking, heating and lighting, which include wood, paraffin, LPG (liquefied petroleum gas), candles and generators. Based on the data, wood and candles were the most commonly used energy types, followed closely by paraffin and LPG. Approximately 96% of the respondents utilized wood, 92% used paraffin, 84.9% used LPG, 94% used candles and only 13% used a generator. Furthermore, the data revealed variations in cooking, heating and lighting preferences, indicating the diversity of lifestyles and household needs among the respondents. In terms of energy preferences for cooking, the results indicated a moderate level of variability, with an average score of 3.25. This suggests that there are different methods or energy sources available for cooking, ranging from using one energy source to using up to four different sources, including wood, LPG, coal and paraffin. Energy preferences for heating, on the other hand, showed relatively lower variability, averaging a score of 1.23. This may indicate a minimal variety in energy options for heating, with options varying from using one energy source to using up to three, specifically wood, paraffin, and coal. Regarding lighting preferences, the data showed higher variability, with an average score of 3.75. This reflects differing preferences and requirements for lighting within households, with lighting options ranging from using one energy source to using up to four, encompassing candles, paraffin, solar energy and generators.

4.2. Factors Influencing Household Energy Choices

Table 2 presents the estimates of a multivariate regression analysis with four dependent variables for energy use: wood, paraffin, liquefied gas and a generator, and some sets of explanatory and control variables across the four panels, as shown in the table. Firstly, the results revealed estimates on the choice of wood for energy use by households in the area of study. The choice of wood model demonstrates a high level of accuracy, with a Root Mean Square Error (RMSE) of approximately 0.101 and an R-squared value of 0.9672. The high R-squared value indicates that the model explains around 96.72% of the variance in wood choice. The F-statistic of 8.039 with a p-value of 0.0563 suggests that the overall model is statistically significant at a significance level of $p < 0.05$. This indicates that the included variables collectively have a significant effect on wood usage. However, for paraffin, LPG, and generator usage, the models show varying levels of accuracy and significance. The

RMSE values for paraffin, LPG, and generator are 0.3908923, 0.2681372 and 0.2818275, respectively. The R-squared values indicate that the models explain approximately 73%, 76% and 86% of the variance in paraffin, LPG, and generator choices, respectively. Despite the reasonably accurate predictions, the F-statistics and associated *p*-values suggest that the overall models for paraffin, LPG and generator usage are not statistically significant at the $p < 0.05$ significance level. This indicates that the included variables may not collectively have a significant effect on these energy sources' usage patterns.

Table 2. Summary estimates of factors affecting household energy choice.

Equation	**RMSE**		**R-Square**		**F-Statistic**		***p*-Value**	
Wood	0.101036		0.9672		8.039017		0.0563	
Paraffin	0.3908923		0.7355		0.7585491		0.6822	
LPG	0.2681372		0.7689		0.907403		1.711186	
Generator	0.2818275		0.8625		0.6106		0.3624	
Variable	Wood		Paraffin		LPG		Generator	
	Coefficient	*p* > [t]	Coefficient	*p* > [t]	Coefficient	*p* > [t]	Coefficient	*p* > [t]
Gender	0.1255706	0.584	0.1395636	0.872	−0.0216343	0.971	0.5067657	0.442
Age	−0.007872	0.921	0.2251735	0.486	0.1878567	0.406	−0.1355345	0.555
Household Size	−0.2119844	0.083 *	−0.2117932	0.555	0.1453387	0.555	0.0540753	0.829
Post-Primary	0.2965319	0.019 **	0.0965759	0.721	−0.0736925	0.692	−0.0624296	0.748
Tertiary	0.979153	0.108	−0.2422275	0.894	−0.1195042	0.923	2.183743	0.167
Employment	0.0480502	0.776	0.3858663	0.563	0.382384	0.419	−0.2051485	0.666
Total Income	−0.4015404	0.025 **	0.3030792	0.473	−0.0114656	0.967	0.2715154	0.384
Wages	0.4642113	0.221	0.0655844	0.959	−0.121757	0.889	−1.691793	0.138
Grant	0.896814	0.008 ***	0.1591144	0.787	0.1108364	0.784	−0.1504717	0.725
Remittance	0.2923549	0.061 *	−0.3557751	0.424	−0.1514442	0.607	−0.077962	0.797
Own Business	0.2777631	0.235	−0.2835682	0.722	−0.1657446	0.761	0.2509058	0.664
Cons	−2.549678	0.331	−0.9312989	0.920	0.7769963	0.903	11.98563	0.146

*** denotes significance at the 0.01 level; ** denotes significance at the 0.05 level; * denotes significance at the 0.10 level. Correlation matrix of residuals: Breusch–Pagan test of independence: chi2(6) = 40.162, Pr = 0.0000.

Table 2 also provides an analysis of individual coefficients and provides further insights. The coefficients and *p*-values indicate that gender and age do not significantly influence wood usage, with a *p*-value of 0.584 for gender and a *p*-value of 0.921 for age. However, household size shows marginal significance between the $p < 0.05$ and $p < 0.10$ levels, with a coefficient of approximately −0.212 and a *p*-value of 0.083. Although not strong enough, this relationship implies that larger household sizes tend to be associated with a lower likelihood of using wood for energy. Surprisingly, access to grants has a significant positive effect on wood usage, contrary to expectations. The coefficient for access to grants is 0.8968, which is statistically significant at a $p < 0.01$ probability level. This suggests that increased access to and/or amount of grants is strongly associated with an increased likelihood of using wood as an energy source in households. This finding is surprising because, as shown in Table 1, grants contribute the most to household income in this community, as they do in many other rural communities in South Africa. Rather, this may imply that the actual grant amount does not increase; instead, the number of grant recipients within a household increases along with the number of dependents. However, the findings suggest that, despite grants being the primary income source, their impact may be constrained by the increasing number of grant recipients within households. This situation implies significant financial limitations as households struggle to allocate sufficient funds towards adopting cleaner energy alternatives.

Similarly, higher remittances are associated with increased wood usage, despite expectations for a transition to safer energy sources like LPG. The coefficient for remittances is approximately 0.2924, with a *p*-value of 0.061, which is statistically significant at a $p < 0.05$ significance level. This implies that households receiving higher remittances tend to use wood more. This finding is also unexpected, and a possible explanation for this could be inappropriate use of the grants, which necessitates the use of wood instead of safer energy sources like liquefied gas.

In addition to the previous findings, the coefficient for ownership of a business or farm is approximately 0.2778, with a *p*-value of 0.235, indicating that owning a business or farm does not significantly affect the use of wood as an energy source.

Regarding the educational status or qualifications of households, the coefficients for post-primary and tertiary educational qualifications are approximately 0.2965 and 0.9792, respectively. Post-primary educational status is statistically significant at a $p < 0.01$ level, while tertiary educational status is statistically significant at a $p < 0.05$ significance level. This suggests that a higher educational status is associated with an increased likelihood of using wood. This result is unexpected and may be due to a strong customary attachment to the use of wood as an energy source from time immemorial.

The coefficient for the employment status of the household head is approximately 0.0481, which is not statistically significant. This indicates that employment status does not significantly influence the use of wood as an energy source. This result could be attributed to the high level of unemployment and reliance on social grants in the study area.

The coefficient for total income is −0.4015, with a *p*-value of 0.025, which is statistically significant at a $p < 0.01$ probability level. The implication is that higher total income levels in households are associated with a decreased likelihood of using wood as an energy source. This is in line with expectations because the higher the income or earnings of households, the greater their chances of seeking alternative, safe energy sources. Furthermore, the findings indicate that wages have a coefficient of 0.4642 with an insignificant *p*-value of 0.221, suggesting that the log-transformed wage insignificantly affects the use of wood for energy in the study area.

In terms of the choice of paraffin, LPG, and generator, respectively, as energy sources in households in the study area, the results from both the paraffin and LPG models indicate that none of the coefficients are statistically significant at conventional significance levels. This implies that the independent variables in the models do not have a statistically significant relationship with paraffin and liquefied gas usage. In terms of the estimates for the choice of generator as an energy source, although the RMSE (0.2818) implies a reasonable level of model accuracy and the R-squared (0.8625) suggests that the model explains approximately 86.25% of the variance in the generator variable, the overall model is not statistically significant. As indicated by the variables' coefficients, apart from log-transformed wages, no other independent variables in the model effectively explain the use of generators as an energy source in households. The finding reveals that wages have a coefficient of approximately −1.6918, which is statistically significant at a $p < 0.05$ level. This suggests that increased wages are likely to reduce the use of generators in the study area. This finding reinforces the earlier submission about the possibility of long-established traditions and customs of using unsafe energy sources, such as wood, as energy sources in the study area and most of the rural locations in South Africa.

In summary, the analysis provides strong insights into the use of wood as an energy source but does not effectively explain the use of paraffin, liquefied gas, and generators. Household size, educational status, income levels, grants, and remittances appear to be statistically significant in influencing the use of wood in the study area. However, the variables in the other panels do not demonstrate strong relationships with the respective alternative energy sources due to their lack of statistical significance.

It is also important to note that the Breusch–Pagan test of independence performed is a post-estimation output from the correlation matrix of residuals of the four equations embedded in a single equation. The test is to determine whether the residuals of the equations are independent or not. The statistically significant value generated (40.162; $p = 0.0000$) implies that the residuals of the four equations are not independent and depend on each other.

5. Discussion

The analysis in this study sheds light on the challenges faced by the Upper Blinkwater community, depicting a pattern that resonates with many rural households across South

Africa and the continent. The community is marked by economic vulnerability, with a significant portion grappling with unemployment and restricted access to resources, leading to financial insecurity. In the midst of these hardships, their reliance on social grants emerges as a lifeline for sustaining livelihoods. As is the case in other rural communities in South Africa where there is no electricity and in confirmation with the household energy choice model [40,50], households in Upper Blinkwater utilize different energies to meet the daily energy needs for cooking, heating, and lighting, and those include wood, paraffin, LPG, candles, and generators.

The energy choice estimates revealed noteworthy findings about the determinants influencing the preference for specific energy sources. Based on the findings, while significant factors were identified that affected the inclination towards wood, no substantial relationship emerged concerning the selection of paraffin, LPG, candles and generators. This discrepancy suggests that the determinants of energy choice vary depending on the type of fuel or energy source under consideration.

Notably, household size, although reflecting limited influence, plays an important role in influencing households to choose and use firewood. Contrary to conventional expectations that large households have too many people to take care of, which puts a strain on household budgets and may likely affect the affordability of other cooking energies better than firewood, in Upper Blinkwater, the larger the household is, the less likely they are to use wood, while smaller households are more likely to use wood. Similar results were found in the Western Cape province by [31], who observed relatively low usage of firewood among Western Cape residents, with even less use among larger households. According to [51], this is because firewood consumption remains a poverty-related challenge for many rural areas. In these communities, economic constraints often limit access to alternative and more modern energy sources. Consequently, families with limited financial resources continue to rely on firewood, as it is often the most affordable and readily available option. This finding suggests that households in Upper Blinkwater are less constrained by poverty-related challenges and may have the means to acquire alternative energy sources, such as gas or paraffin. Alternatively, larger households often have higher combined incomes due to having more earners within the household, enabling them to afford alternative energy options and invest in energy-efficient technologies [52]. This aligns with the expected trend corroborating the concept of fuel substitution, the energy ladder hypothesis [31], which postulates that as households experience improved economic well-being, they are more inclined to seek out modern energy solutions that offer convenience, reliability, and environmental sustainability.

The study's findings reflect a statistically significant inverse relationship between household income and firewood use, echoing the earlier assertion that as household socioeconomic conditions improve with rising income levels, there is a corresponding decline in the reliance on wood as a primary energy source. Unlike in Ga-Malahlela in rural Limpopo, where households used firewood regardless of their income bracket [39], in Upper Blinkwater, increased household income is associated with reduced firewood usage. Similar conclusions were drawn by [31], further corroborating the inverse relationship between household income and firewood usage. This highlights the transformative potential of economic empowerment in driving energy transitions. As households experience financial growth, they tend to invest in cleaner, more efficient, and more convenient energy sources.

On the other hand, the unexpected positive influence of the relationship between access to grants and wood usage is a cause for concern. This suggests that although grants contribute the most to household income, many grant holders have limited options to use other energy alternatives to meet their domestic needs [51]. However, this is also not surprising, considering that the majority of households in this area depend largely on grants for their livelihoods. Consequently, the grant amount is allocated to energy expenditures and other family needs. This means that, as the demand for non-energy goods and services increases, the allocation for energy expenditure may be limited or nonexistent, hence the reliance on firewood. The implication of this finding is that continuous reliance on grants

without opportunities for income diversification or economic empowerment can perpetuate a cycle of dependency. This can create financial vulnerability, as depending solely on external financial assistance hinders efforts to build financial resilience and self-sufficiency. On the contrary, firewood is often readily available in many rural villages, making it a convenient and cost-effective option compared to other energy sources [39]. This allows households to stretch their grant money across various essential needs. Moreover, households may prioritize immediate or pressing needs or expenses such as food, healthcare, education, and clothing over transitioning to cleaner and more expensive energy options. This prioritization is especially acute in grant-dependent households, where every expense must be carefully considered.

Cultural factors may also play a significant role in the continued use of wood. In many rural areas, the use of firewood is deeply ingrained in the daily lives, traditions, and cultural practices passed down through generations [38]. There may be a perception that wood is a more reliable and consistent energy source compared to alternatives; that even if households have the financial means to purchase cleaner energy, the availability of these alternatives may be inconsistent; or households may lack trust in their reliability.

When remittances increase, the likelihood of a household choosing firewood as their primary energy source also increases. At first glance, one might expect that higher remittances, which typically indicate an improvement in a household's economic situation, would lead to a shift towards cleaner and more modern energy sources [53] in Nigeria and [54] in Ghana also confirmed that households receiving remittances are more likely to use modern cooking fuels, positively impacting the propensity of households to adopt clean cooking fuels. However, the unexpected correlation between increased remittances and a greater inclination for households to use firewood suggests that the decision to use firewood goes beyond simple economic improvement and is influenced by a variety of socioeconomic and cultural considerations within the household. Even with the additional income, households may still have economic constraints that make cost-effective options like firewood more favorable than other energy sources.

It could also be expected that higher educational attainment would correlate with a decreased reliance on traditional energy sources like wood. This is based on the common assumption that education promotes greater awareness of environmental sustainability, leading individuals to recognize the environmental impact of using wood as an energy source. Additionally, higher education often provides individuals with better economic opportunities, increasing their ability to afford modern energy technologies such as electricity and natural gas. As a result, educated individuals are more likely to transition from traditional energy sources to more sustainable and efficient alternatives [17,47,55]. Furthermore, the collection of wood often takes a significant portion of productive time, especially for women and girls. In many communities, they are primarily responsible for gathering wood. For instance, in some communities, fetching wood is considered women's work [16]. Therefore, women are solely responsible for wood collection, often enduring long and strenuous journeys. For example, they dedicate approximately 2 to 9 h of their time to gathering wood and handling cooking tasks. This demanding routine restricts their availability for other productive activities, consequently diminishing their overall quality of life [15,18,56]. This task not only consumes time that could be spent on education, employment, or other productive activities but also exposes them to physical strain and safety risks. For example, Ref. [17] found that in Vietnam, over 80% of school attendance was affected by the collection of firewood as the primary energy source, thereby impacting the students' future economic prospects.

However, in Upper Blinkwater, the unexpected association between higher educational status and a heightened likelihood of using wood accentuates the multifaceted nature of energy usage decisions. This implies that wood usage may stem from a strong customary attachment to wood [57] or the fact that alternative energy sources such as LPG remain prohibitively expensive [38], which emphasizes that entrenched traditions and cultural norms play a significant role in determining the utilization of particular energy resources

within societies, as resistance to change is often observed even among educated and economically stable individuals. This cultural adherence may overshadow the potential for embracing more modern and efficient energy sources [27]. Even as individuals attain higher levels of education, the enduring influence of cultural norms and historical practices may perpetuate the preference for wood as an energy source.

On the other hand, socioeconomic factors intertwined with educational status may also influence energy usage patterns. Individuals with higher educational attainment may belong to socioeconomic strata where access to alternative energy sources is costly. As a result, they may prioritize cost-conscious energy usage over modern and environmentally conscious choices. This economic consideration can lead to a continued reliance on wood, despite awareness of its environmental impact. In many cases, individuals prioritize the sustainability and affordability of energy, often finding themselves constrained by the limited availability and high cost of modern and clean energy sources. This situation may lead educated individuals to continue using traditional energy sources like wood because they provide a more immediate and economical solution to their energy needs.

In general, these results show how complicated energy use decisions are because they are affected by how socioeconomic factors and cultural norms interact. This challenges the linear progression typically associated with the energy ladder concept. Particularly noteworthy is the persistence of cultural norms embedded in daily practices, such as the continued use of firewood for cooking, despite the availability of alternative energy sources. This cultural continuity often outweighs economic incentives for adopting modern technologies. Moreover, while social grants provide crucial financial support for many families in Upper Blinkwater, they may not fully meet all household needs or drive significant changes in energy consumption behavior, causing financial strain and limiting the ability of families to invest in more efficient and cleaner energy technologies, thereby perpetuating a cycle of energy poverty.

Addressing the urgent challenges in the Upper Blinkwater community requires specific actions to help households find additional sources of income and reduce their reliance on grants. These actions should focus on promoting economic activities within the community and supporting local initiatives that align with cultural norms and preferences regarding energy use. One effective approach involves leveraging community participation and bottom–up decision-making frameworks [58]. For communities such as Upper Blinkwater, which was selected as the first beneficiary of the roll-out of a decentralized mini-grid in the country, these findings hold much significance for future implementations of the mini-grid. Involving community members in the decision-making process for the mini-grid project through a participatory planning process will help ensure that the project meets the community's needs, preferences and priorities. This will prevent the communities from being alienated from resources and will encourage a sense of ownership and commitment to the sustainability of the energy system [58].

Additionally, social mobilization and awareness efforts can effectively influence individual and community choices towards using efficient and clean energy. This approach acknowledges the complex socioeconomic and environmental dynamics influencing household energy choices in this community.

6. Conclusions

This study has highlighted the significant reliance on traditional biomass fuels by rural households in Upper Blinkwater. It revealed the economic vulnerability of these households, marked by high unemployment and limited access to resources. The majority of households rely on social grants to sustain their livelihoods, leading to the use of multiple energy sources. In the absence of electricity, households depend on various energy sources, with firewood being significantly influenced by the availability of grants, household size, post-primary education, total income, and remittance income, while other energy sources showed no substantial relationship with these factors. Grant and remittance recipients were observed to be the most likely to use firewood, reflecting their economic vulnerability.

Despite some economic improvements and higher education levels, firewood remains a primary energy source due to its availability, culturally ingrained nature, perceived reliability, and cost-effectiveness. Household size, income and remittances are pivotal in determining energy preferences. Larger households with higher combined incomes are less likely to use firewood, while smaller households and those dependent on grants continue to rely on it. This reflects economic constraints and the prioritization of immediate needs over transitioning to cleaner energy options. Additionally, cultural norms and traditions strongly influence energy choices, often outweighing economic incentives for adopting modern technologies. These findings challenge the linear progression suggested by the energy ladder hypothesis, underscoring the need to consider social and cultural dimensions in understanding household energy choices.

To address these issues, policymakers should consider the following recommendations: effective interventions must address these multifaceted influences to promote the adoption of cleaner energy technologies and launch educational campaigns to raise awareness about the benefits of modern fuels. The study emphasizes the importance of integrating economic, social, and cultural considerations in designing energy policies and programs to achieve sustainable energy transitions in rural communities and developing gender-inclusive policies to support women's participation in energy decision-making processes.

However, the study is not without limitations. The focus on a single community may limit the generalizability of the findings, and potential biases in self-reported data and the limitations of the regression analysis should be considered. Future research should aim to conduct comparative studies across different rural communities, undertake longitudinal studies to track changes over time, and explore cultural and gender dynamics in greater depth through qualitative research.

Addressing the energy needs of rural households is crucial for achieving sustainable development goals and improving the quality of life for millions. By implementing targeted policies and continuing research, we can pave the way for a more equitable and sustainable energy future.

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