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Rural Energy Poverty: An Investigation into Socioeconomic Drivers and Implications for Off-Grid Households in the Eastern Cape Province, South Africa

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Abstract: Energy poverty is a significant barrier to sustainable development, limiting access to modern energy solutions and exacerbating socioeconomic inequalities in South Africa. This research identifies key socioeconomic factors contributing to energy poverty among off-grid households using the household-specific energy poverty line. A cross-sectional study was conducted using a well-structured questionnaire among 53 households. The findings reveal significant gender disparities, with female-headed households being more vulnerable to energy poverty, which continues to subject them to economic hardship and social marginalization. Additionally, while larger households generally face higher energy demands, they were found to be less likely to experience energy poverty. The findings also challenge the 'energy ladder hypothesis' by showing that education, while potentially enabling better energy awareness, does not guarantee improved energy access in off-grid areas due to infrastructural limitations. Social grant dependency was found to be strongly correlated with energy poverty, underscoring the inadequacy of income transfers in addressing the systemic barriers to energy access. The findings emphasize the need for multidimensional, gender-responsive policy interventions that address both infrastructural and socioeconomic barriers to energy access, particularly in rural South Africa. These insights are crucial for developing targeted interventions to alleviate energy poverty and foster sustainable development in off-grid communities.

Keywords: energy access; energy poverty; off-grid households; socioeconomic drivers

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1. Introduction

Energy poverty is widely understood as a form of deprivation from adequate essential energy services like heating, cooling, lighting, and household appliance power (Lozano & Taboada, 2020). This issue is particularly acute in developing regions like ub-Saharan Africa, where millions of households lack both the financial means to afford modern energy services and the physical infrastructure needed for reliable access (Ritchie et al., 2019). Economic downturns, such as the global financial crisis and the 2020 COVID-19 pandemic, have worsened this situation, pushing over 100 million people into extreme poverty in the region (Masuku, 2024; World Bank, 2020). Consequently, poor and low-income households continue to struggle to meet basic energy needs such as cooking, heating, and lighting, limiting their opportunities for education, income generation, and overall socioeconomic development (Lesala et al., 2024).

South Africa is no exception, with energy poverty deeply rooted in socioeconomic and geographic disparities limiting access to essential services and economic opportunities.

Many rural and peri-urban areas in South Africa still lack access to clean energy. Even as about 86% of the population has access to electricity (Longe, 2021), the remaining 14% who live primarily in rural areas still experience energy insecurity. Though income inequality does not act as a barrier to accessing energy, it has rendered modern energy services too expensive for many low-income households (Sarkodie & Adams, 2020), with the poor spending about 27% of their income to energy (Lu et al., 2020; van Niekerk et al., 2022).

The South African challenge is further worsened by the fact that policies aimed at alleviating energy poverty, such as free basic electricity (FBE), primarily benefit households already connected to the grid. As a result, off-grid rural communities remain excluded from such support, deepening their energy insecurity. The slow pace of grid expansion continues to disproportionately affect rural areas (Masuku, 2024), leaving many communities without access to modern energy. Without targeted interventions, rural communities' risk being trapped in a cycle of chronic energy poverty, posing serious challenges to South Africa's broader development goals. However, for years, the discussion of energy poverty in South Africa has received limited attention. Energy poverty was often overshadowed by broader discussions on general poverty and national development challenges, treated as just another aspect of socioeconomic deprivation rather than a distinct challenge requiring targeted solutions. This approach overlooked the unique struggles of off-grid rural communities, where geographical isolation and infrastructural neglect further compound energy access issues. As a result, the literature surrounding energy poverty was sparse, with little focus on the specific experiences and needs of those living in energy-deprived conditions. However, recent years have witnessed a significant shift in this narrative. A growing body of research in South Africa has begun to highlight the significance of energy poverty and its multifaceted nature. This transition is particularly pertinent to the rising energy costs, which have placed a financial burden on households already struggling to make ends meet, while also affected by the frequent power outages or load-shedding that disrupts their daily activities (Isandla Institute, 2024). As the urgency to address this phenomenon becomes evident, studies have begun to explore its various dimensions, including regional disparities, offering insights into its nature and the factors contributing to persistent energy deprivation.

Notable works of Ye and Koch (2021) advanced the discussion by employing the household level energy poverty line to determine the both the prevalence and severity of energy poverty among South African households. Their results showed that South African households not only suffer from energy poverty but that the severity of energy poverty is disproportionately experienced by poor households. Building on this, Ye and Koch (2023) examined energy poverty from a multidimensional perspective and showed significant urban–rural inequalities in the access and affordability of energy. Their study noted that rural households have more difficulty accessing clean energy and are hit harder by affordability concerns.

Mgwambani et al. (2018) utilized survey data from the community of Louisville in Mpumalanga and found that many households reported dissatisfaction with their energy sources since they were concerned about costs rising with a decrease in income, which contributed to the reliance on traditional fuels such as firewood for cooking, heating, and lighting. Studies by Masekela and Semenya (2021) and Netshipise and Semenya (2022) revealed similar trends in Ga-Malahlela and Thulamela (Limpopo), thus advocating for the adoption of traditional fuels. Their results showed that while electrification efforts continued, socioeconomic factors like low income, lack of education, and access to free basic electricity services persisted in promoting the use of firewood. Similarly, Oyekale and Molelekoa (2023) reported equivalent scenarios in the Western Cape and KwaZulu-Natal regions, notably with space heating, indicating that poor electricity access is prevalent in many areas of South Africa.

Ismail and Khembo (2015) used data from the National Income Dynamics Survey (NIDS) carried out in 2012 and identified several important predictors of energy poverty, including household expenditure patterns, race, education, household size, and electricity access. Their findings also revealed that, despite progress in electrification, many households, particularly in rural areas, remain reliant on traditional fuels such as firewood due to affordability constraints and other socioeconomic factors.

Ngarava et al. (2022) also revealed specific vulnerabilities, particularly among female-headed households in Black/African rural communities, where energy poverty is worsened by a combination of factors such as gender, race, and income inequalities, which compels greater reliance on traditional fuels. Ningi et al. (2020), on the other hand, using the Multidimensional Energy Poverty Index (MEPI), found that households in the Melani village in the rural areas of the Eastern Cape were generally energy secure. They found that energy security in this community was closely determined by marital status, household size, electricity affordability, and income sources. However, these results seem less reflective of off-grid, remote rural areas, where energy deprivation is more keenly felt due to the absence of modern energy infrastructure, and restrict their relevance to the off-grid, non-electrified communities. Dinis et al. (2023) expanded on this, particularly emphasizing its interaction with structural injustices and geographic isolation. Their analysis revealed that current definitions of energy poverty, as reflected in SDG indicators, do not effectively address the larger characteristics of affordability, dependability, and sustainability. They claim that weak policy frameworks that ignore systemic imbalances and a lack of modern energy infrastructure worsen energy scarcity in off-grid environments, disproportionately affecting rural, vulnerable people.

Building on this, Lesala et al. (2023) explored the energy poverty of the off-grid remote community of the Upper Blinkwater. A compelling observation emerges from their findings, indicating that despite the lack of grid electricity, alternative energy sources like paraffin, liquified petroleum gas (LPG), and firewood have provided households in this community with some level of functional energy access and enabled them to meet some basic energy needs. However, relying on these sources does not equate to access to modern energy services. Such services are essential for driving socioeconomic transformation. This highlights a critical gap in understanding the reality of off-grid areas, where energy poverty is shaped not only by access but also by the quality and sustainability of energy sources. The findings in Lesala et al. (2023) challenge the common understanding of energy poverty, which typically centers on the absence of electricity and other modern energy services, without considering the broader dynamics in energy use in off-grid communities. This highlights the urgent need to further explore energy poverty in remote, off-grid communities. Such exploration would extend the conceptual boundaries of energy poverty and articulate the experiences of vulnerable rural communities completely disconnected from modern energy services.

This study shifts the discourse from simplistic measures of energy access towards a more comprehensive understanding of the lived realities of households in off-grid communities. While many definitions focus on electricity affordability (Ngarava et al., 2022; Ningi et al., 2020; Ye & Koch, 2021), energy poverty in this study is not merely understood as the absence of grid electricity, but also as a multifaceted condition in which households lack access to clean, affordable, and sustainable forms of energy necessary to meet basic needs such as cooking, lighting, and heating. Drawing from Lesala et al. (2023), where other energy sources like paraffin and LPG provide some degree of energy security, the definition also considers the quality, efficiency, and sustainability of the energy sources and the socioeconomic constraints that hinder the transition of households to modern energy systems.

This approach moves beyond conventional binary definitions and is consistent with broader definitions that recognize both material deprivation, referring to the lack of necessary infrastructure, and capability deprivation, which is characterized by limited income, access, and choices as critical dimensions of energy poverty in off-grid communities. It highlights the importance of exploring the broader socioeconomic conditions that shape rural and off-grid energy realities. It is against this backdrop that the present study is undertaken, aiming to explore the factors influencing energy poverty in the remote, off-grid community of Upper Blinkwater.

This study contributes to the body of literature by providing rare insight into the lived experiences and drivers of energy poverty in remote, marginalized communities that are often overlooked in national energy policy discourse and large-scale energy access surveys. It provides a broader and more reflective understanding of energy poverty in off-grid areas; as such, it informs policies that are better suited to the specific needs of similar communities. Additionally, the study supports broader efforts aimed at improving the quality of life for vulnerable populations by offering practical insights for policymakers seeking to expand energy access and alleviate energy poverty in remote areas.

The remainder of this article is structured as follows: Section 2 describes the methodology used in this study, including the data collection process and analytical framework. Section 3 presents the results, highlighting the key determinants of energy poverty in Upper Blinkwater. Section 4 offers a discussion of the findings, connecting them to broader policy and development implications. Finally, Section 5 concludes the article with recommendations for targeted interventions and suggestions for future research on energy poverty in off-grid rural communities.

2. Methodology

2.1. Description of the Study Area

The study was carried out in the small, isolated rural settlement known as Upper Blinkwater within the Raymond Mhlaba Municipality. Upper Blinkwater is situated at coordinates 32°34′46.7″ S and 26°33′33.8″ E at an elevation of approximately 900 m above sea level. The Municipality is characterized by dispersed settlements that make accessibility and infrastructure particularly challenging. As a result, poverty and unemployment levels are amongst the highest in Africa, with many households reliant upon social grants as their primary source of income (Ravanbach et al., 2019). Upper Blinkwater is home to some 67 households, mostly of Xhosa ancestry, housing approximately 254 people in total. The inspiration for selecting this community for this study stems from it being the first community to be identified by the Provincial government of the Eastern Cape as an intended beneficiary of a renewable energy pilot project to introduce a hybrid mini grid to meet rural electrification challenges in the Eastern Cape province, and in South Africa. Two extremely remote communities were identified, including Upper Blinkwater, which was ultimately selected due to its relatively easier accessibility. Although the project had not been implemented at the time of this study, early engagement with the community revealed a strong awareness of the limitations of their current energy sources and an expressed interest in modern energy services. As such, the project represents both the intervention and a point of reference for understanding the broader implications of energy poverty in remote areas. However, this study does not evaluate the outcomes of the mini-grid intervention but rather examines the determinants of energy poverty. Figure 1 shows the location of the community of Upper Blinkwater, Raymond Mhlaba Municipality within the Amathole District Municipality in the Eastern Cape province within South Africa.

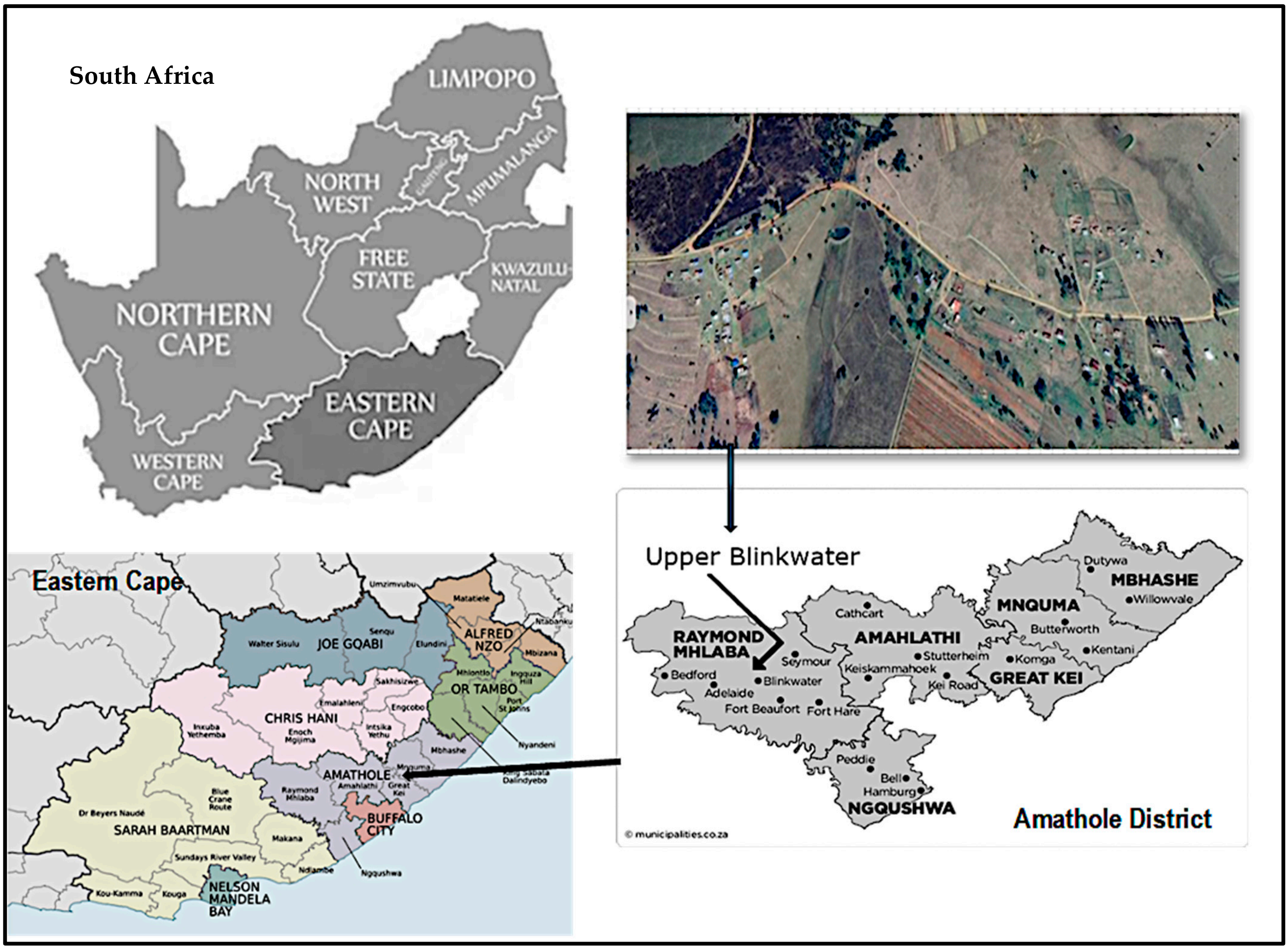

Figure 1. Upper Blinkwater location. Source: (Kühnel et al., 2021; Lesala et al., 2024).

2.2. Research Design

The research design of this study is quantitative, which allows for data to be systematically collected and analyzed, and thus being able to identify and quantify what attributes contribute to energy poverty while highlighting how they may be impacting household access to and usage of energy. Using this method of research ensures generalizability, meaning that results observed in a small sample can be generalized to a larger group of people or within comparable situations, making the study more relevant and practical. As a result, the conclusions can be considered valid and reliable, which in turn forms a strong basis for evidence-based policy recommendations and decision-making.

2.3. Data Collection

The data collection process included developing a questionnaire through a thorough examination of the existing literature on energy poverty and household energy consumption. Data for this study were collected in November 2019. The questionnaire contained household demographics, household-level data on energy expenditures, including all existing forms of energy. Pre-testing was conducted in the community for questionnaire and content validity and the necessary adjustments were made accordingly. To ensure understanding of the process, rights, and expectations, the survey was conducted in Xhosa, the local language. Respondents were also made to understand that participation was entirely voluntary, and assured of respect for their privacy.

Since the Upper Blinkwater community is small, we aimed to include all 67 households in the survey because it is challenging to obtain a representative sample due to the small population size. Sample size classes of this magnitude often result in even smaller samples, further limiting the generalizability of any conclusions drawn (Faber & Fonseca, 2014; Korngiebel, 2015). To address this limitation, Korngiebel (2015) recommends assessing the entire population to reduce distortion in the findings. Following this recommendation, all 67 households in Upper Blinkwater were considered eligible for the survey. However, due to availability constraints, interviews were conducted with 53 heads of household.

Data were cleaned extensively after collection then analyzed using STATA software version 15. Descriptive statistics (frequency distributions, percentages, and mean values) were used in addition to regression analysis to investigate the main drivers of energy poverty in Upper Blinkwater.

2.4. Data Analysis

The primary focus of this study is to identify the drivers of energy poverty. While previous research has already established the energy poverty status of households (Lesala et al., 2023), this study builds upon those findings by examining the key factors contributing to energy poverty. The Foster–Greer–Thorbecke (FGT) approach was used to determine whether households in this community were energy poor or not. First, FGT derives the energy poverty line and uses the per capita energy expenditure. Unlike the traditional fixed thresholds, such as the 10% expenditure rule, which assumes an equal energy burden across all households, and fails to account for variations in income levels, consumption patterns, and household sizes (Ye & Koch, 2021), the FGT approach enables a more accurate and context-specific classification of energy poverty by accounting for differences in household income, size, and energy consumption patterns, rather than relying on one-size-fits-all thresholds. Although the FGT method not only identifies whether a household is energy poor but also captures varying degrees of deprivation, revealing both the depth and severity of energy poverty, for the purposes of this study, the focus is solely on determining whether or not a household is energy poor. This binary classification is essential for analyzing the socioeconomic and demographic factors that influence a household's energy poverty status. Households falling below the FGT-derived energy poverty line, regardless of the extent of their deprivation, are therefore treated uniformly as energy poor in the subsequent regression analysis.

To explore the underlying determinants of energy poverty, a probit regression model was employed. Given that the dependent variable is binary, indicating whether a household is energy poor or not, the probit model is well-suited for this type of analysis. It allows for the estimation of the probability that a household falls below the energy poverty line, based on a set of observed socioeconomic and demographic characteristics. The probit model was preferred over other binary response models such as logit models, due to its underlying assumption of latent variable formulation and its frequent application in welfare and poverty analysis literature, where the normal distribution is often considered more appropriate. Following Greene (2012), the model is specified as:

$$Y^* = \sum_{i=1}^{n} \beta_i X_i + \epsilon = \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon \quad (1)$$

where Y^* represents the dependent variable, β_i represents the parameter to be estimated, X_i represents specific household characteristics, and ϵ is the error term assumed to follow a standard normal distribution ($\epsilon \sim N(0,1)$). The observed outcome Y is binary:

$$Y = \begin{cases} 1 \text{ if } Y^* > 0 \text{ (indicating energy poverty)}, \\ 0, \text{ otherwise} \end{cases}$$

The probability that a household falls below the established energy poverty line ($P(Y = 1)$) is expressed as

$$P(Y = 1) = \Phi(\beta X + \epsilon) \quad (2)$$

$$P(Y = 0) = 1 - \Phi(\beta X + \epsilon) \quad (3)$$

where P(Y = 1) represents the parameter to be estimated, that is, the probability that a household is below the energy poverty line (indicating poverty incidence), Φ is the cumulative distribution function of the standard normal distribution, and Y* is a latent variable indicating whether the expenditure of a particular household falls below the consumption poverty line. This probability indicates the likelihood that specific household features positively or negatively influence the risk of being energy poor. Within this framework, coefficients β_i associate with each factor and represent the direction and magnitude of influence on energy poverty. Furthermore, post-estimation analysis, specifically marginal effects, was also performed to interpret the of all the independent variables on the probability of energy poverty which provides more straightforward insight into the possible targeted policymaking to reduce energy poverty of the community. Explicitly, the model variables are expressed in Table 1. These indicators provide a comprehensive understanding of how various socioeconomic factors influence households' ability to access reliable and affordable energy in the Upper Blinkwater community.

Table 1. Variable description.

Variable	Description
Y	Energy poverty status (1 if energy poor households; 0 otherwise)
X_1	Gender of household head (1 if male, 0 for female)
X_2	Age of household head (continuous variable)
X_3	Household size (number of individuals in the household)
X_4	Formal education of the household head (1 if formally educated, 0 if not)
X_5	Employment status of the household head (1 if employed, 0 if not)
X_6	Dwelling type (1 for brick house, 0 for mud house or other types)
X_7	Log of social grant amount (natural log of the amount received from social grants)

To further test the interpretability and robustness of the probit model estimates, we computed the average marginal effects (AME) after estimation. Marginal effects quantify the change in the predicted probability of being energy poor for a one-unit change in each of the explanatory variables, when other variables are held constant. This approach not only complements the probit coefficients but also serves as a robust check by providing a more intuitive feel for the direction and magnitude of effects.

3. Results

3.1. Energy Expenditure Patterns

Table 2 presents an analysis of the energy expenditure patterns among households in the community. The data highlights the types of energy sources used and their associated costs, shedding light on the financial burden of energy access. Table 1 provides a detailed breakdown of energy expenditure across different energy types, offering insights into the diversity of energy sources used and their associated costs. On average, households spend ZAR 248 (approximately USD 13) monthly on energy, with significant variation (standard deviation of ZAR 160, or USD 8.40), reflecting differing energy needs and access. The highest expenditure is on liquefied gas, with a mean of ZAR 104 (approximately USD 5.45), indicating its importance as a primary energy source for some households. This is followed by paraffin (ZAR 50 or USD 2.62) and wood (ZAR 49 or USD 2.57), suggesting that traditional and transitional fuels still play a role in meeting energy needs.

Table 2. Household energy expenditure breakdown (ZAR and USD).

Variable	Mean (ZAR)	Mean (USD)	Std. Dev
Wood Expenditure	48.50	2.57	21.70
Paraffin Expenditure	50.47	2.67	49.86
Liquefied Gas Expenditure	104.15	5.50	107.39
Candles Expenditure	34.42	1.87	21.57
Generator Expenditure	10.23	0.54	33.84
Total Energy Expenditure	247.75	13.09	160.49
Per Capita Energy Expenditure	92.40	4.88	78.17

Note: Conversion assumes an exchange rate of 1 USD ≈ 18.9 ZAR (prevailing rate at time of writing this article). Source: Authors' computation, 2025.

The low average expenditure on generators (ZAR 10 or USD 0.52) suggests that few households rely on this source, which is likely due to its high operating costs. On a per capita basis, households spend an average of ZAR 92 (approximately USD 4.82) on energy, with expenditures ranging from ZAR 10 (USD 0.52) to ZAR 316 (USD 16.54). These findings highlight the varying degrees of energy access and affordability within the community, which are critical for understanding and addressing energy poverty.

3.2. Energy Poverty Prevalence

Table 3 presents the results indicating the distribution of households based on their energy poverty status, providing a foundational understanding of the extent of energy poverty. This classification forms the basis for the subsequent analysis, which applies a probit regression model to examine the factors contributing to energy poverty in the community.

Table 3. Energy poverty statistics.

Energy Poverty	Frequency	Percentage
Energy Poor	20	37.7%
Not Energy Poor	33	62.3%
Total	53	100%

Source: Authors' computation, 2025.

The data showed that 37.7% of households were experiencing energy poverty. This included those who were severely or moderately energy poor. These households not only lacked access to modern energy sources but also faced other challenges like low or unstable income, large household sizes, and a heavy reliance on traditional fuels such as firewood. These factors made it harder for them to meet their basic energy needs.

On the other hand, 62.3% of households (33 in total) were not classified as energy poor. This finding reflects that these households met their basic energy needs through consistent access to alternative sources such as paraffin and LPG. However, this does not mean they enjoy full energy security; instead, it indicates that they have managed to cope within the constraints of an off-grid environment, often through relatively higher per capita income levels, diversified income sources, or sustained support from social grants. Their ability to afford energy alternatives enables them to avoid severe deprivation, but they remain exposed to the limitations of using less efficient, less sustainable, and often more expensive energy sources. Thus, while these households are not suffering from the worst forms of energy poverty, they still lack access to modern and reliable energy systems. Overall, being classified as not energy poor does not mean households are fully energy secure. Rather, it is an indication that some households are managing to get by within the constraints of the limited and unreliable energy options available to them.

3.3. Factors Contributing to Energy Poverty: Probit and Marginal Effects

This section presents the results of the probit regression model, which identifies the key factors contributing to energy poverty in the Upper Blinkwater community. The model assesses how various socioeconomic and demographic characteristics influence the likelihood of households experiencing energy poverty. The probit coefficients indicate the direction and significance of each predictor's relationship with energy poverty, while the AMEs provide the marginal impact on the probability of a household being energy poor, offering more intuitive interpretation and serving as a robust check of the model.

3.3.1. Factors Influencing Energy Poverty: Probit Regression

Table 4 presents the coefficients, standard errors, and significance levels for the probit model examining the factors influencing energy poverty. The analysis reveals some statistically significant relationships between various socioeconomic factors and the likelihood of experiencing energy poverty.

Table 4. Probit regression results for determinants of energy poverty.

Energy Poverty	Coefficient	Std.Err.	z	$p > \|z\|$
Constant	−10.8036	4.259146	−2.54	0.011 **
Gender	−1.2911	0.7928501	−1.63	0.103
Age	−0.0122	0.0264529	−0.46	0.644
Household size	−0.5417	0.2238437	−2.42	0.016 **
No formal education	0.4537	0.8850453	0.51	0.608
Formal education	1.9484	1.462247	1.33	0.183
Employment status	−0.0792	0.9558246	−0.08	0.934
Mud-cement housing	−0.0379	0.8858909	−0.04	0.966
Brick housing	−1.1397	0.8987651	−1.27	0.205
Log of social grant amount	2.0242	0.7533575	2.69	0.007 ***
Index of non-productive assets	0.0787	0.2086874	0.38	0.706

** $p < 0.05$, *** $p < 0.01$. Source: Authors' computation, 2025.

The coefficient for gender is negative (−1.29) and statistically significant at the 10% level (*p*-value = 0.103). This indicates that male-headed households are less likely to experience energy poverty compared to female-headed households. While this relationship is marginally significant, it suggests that male-headed households might have better access to resources, income, and fewer caregiving responsibilities, which could contribute to their reduced likelihood of experiencing energy poverty.

The coefficient for age is negative (−0.012) but not statistically significant (*p*-value = 0.644). This suggests that age does not have a meaningful impact on the likelihood of experiencing energy poverty in this context, as the result is not significant.

Household size has a negative coefficient (−0.542) and is statistically significant (*p*-value = 0.016). Larger households are less likely to experience energy poverty, potentially because the pooling of resources or shared responsibilities in larger households could help mitigate energy-related challenges.

The coefficients for the two education categories show mixed results. The first category (1) has a positive coefficient (0.454) but is not statistically significant (*p*-value = 0.608). The second category (2) has a larger positive coefficient (1.948) but is also not significant at the 5% level (*p*-value = 0.183). This suggests that while education may influence expectations regarding energy access, it does not appear to significantly impact the likelihood of experiencing energy poverty in this study.

The coefficient for employment status is negative (−0.079) but not statistically significant (p-value = 0.934). This implies that employment alone does not have a significant effect on the likelihood of energy poverty in this sample, possibly due to limited employment opportunities or low wages in the community.

The coefficients for housing types (mud-cement and brick) do not show significant effects. The coefficient for mud-cement housing is −0.038 (p-value = 0.966), and for brick housing, it is −1.14 (p-value = 0.205). These results suggest that housing type, in this context, does not significantly affect the likelihood of energy poverty, although better-quality housing may reflect better socioeconomic standing.

The coefficient for the log of social grant amount is positive (2.024) and statistically significant (p-value = 0.007). This finding indicates that higher social grant amounts are associated with an increased likelihood of experiencing energy poverty. While social grants provide important financial support, they may not be sufficient to cover the energy needs of households, highlighting the limitations of this form of assistance in alleviating energy poverty.

The coefficient for the index of non-productive assets is positive (0.079) but not statistically significant (p-value = 0.706). This suggests that owning non-productive assets does not significantly influence the likelihood of energy poverty, possibly because these assets do not generate income or provide direct benefits for addressing energy needs.

3.3.2. Average Marginal Effects (AMEs) from Probit Model

Table 5 presents the average marginal effects (AMEs) for each variable in the probit model. The AMEs provide a clearer interpretation of how the explanatory variables affect the likelihood of being energy poor, providing insights into how a one-unit change in each explanatory variable affects the probability of experiencing energy poverty.

Table 5. Average marginal effects (AMEs) from probit model.

Energy Poverty	AME (dy/dx)	Std.Err.	z	$p > \lvert z \rvert$
Gender (Male = 1)	−0.3030	0.1648	−1.84	0.066 ***
Age	−0.0028	0.0061	−0.46	0.643
Household size	−0.1271	0.0366	−3.47	0.001 *
No formal education	0.0988	0.1806	0.55	0.584
Formal education	0.4152	0.2371	1.75	0.080 ***
Employment status	−0.0185	0.2241	−0.08	0.934
Mud-cement housing	−0.0077	0.1799	−0.04	0.966
Brick housing	−0.2461	0.1603	−1.53	0.125
Log of social grant amount	0.4750	0.1153	4.12	0.000 *
Index of non-productive assets	0.0184	0.0486	0.38	0.704

* $p < 0.1$, *** $p < 0.01$. Note: dy/dx for factor levels is the discrete change from base level. AMEs are calculated post-probit estimation. Coefficients reflect latent index function, while AMEs indicate marginal impact on probability of energy poverty. Source: Author's computation, 2025.

For gender, the AME is −0.303, indicating that male-headed households are 30.3% less likely to experience energy poverty compared to female-headed households. This result is statistically significant at the 10% level (p-value = 0.066), which supports the finding from the probit model that male-headed households are less likely to be energy poor. This relationship may reflect socioeconomic factors such as greater access to resources, income, and fewer caregiving responsibilities in male-headed households, which could enable them to afford energy.

The AME for age is −0.0028, suggesting that age does not significantly affect the probability of experiencing energy poverty. With a high *p*-value of 0.643, this result aligns with the probit coefficient, which was not statistically significant. This result suggests that older household heads may have more stable income sources, such as pensions, which could enhance their financial resilience and ability to prioritize energy needs.

For household size, the AME is −0.1271, meaning that each additional household member reduces the likelihood of experiencing energy poverty by 12.71%. This finding is statistically significant (*p*-value = 0.001) and supports the probit coefficient, which indicated that larger households are less likely to experience energy poverty. This may reflect the benefits of collective resource pooling or labor sharing in larger households, which could help reduce reliance on costly energy sources.

The AMEs for education are positive but not statistically significant. For non-formal education, the AME is 0.0988 (p = 0.584), and for formal education, it is 0.4152 (p = 0.080). These results suggest that while education may play a role in shaping energy poverty outcomes, its effect is not statistically significant in this study. Interestingly, formal education is associated with a higher likelihood of experiencing energy poverty. This could reflect the fact that more educated household heads tend to have higher expectations for modern energy services. When these expectations are unmet due to the limitations of the off-grid environment, it could lead to a stronger sense of energy deprivation.

The AME for employment status is −0.0185, indicating that employment status has minimal impact on the likelihood of experiencing energy poverty. This is consistent with the probit result, where employment status was found to be statistically insignificant.

The AMEs for housing types (mud-cement and brick) are both statistically insignificant. The AME for mud-cement housing is −0.0077 (*p*-value = 0.966), and for brick housing, it is −0.2461 (*p*-value = 0.125). These results suggest that housing type does not have a significant impact on energy poverty in this community, with households in brick houses showing a lower probability of experiencing energy poverty compared to those in mud houses. This implies that better-quality housing may reflect a better socioeconomic position, enabling these households to access more affordable or alternative energy sources.

The AME for social grant amount is 0.475, indicating that an increase in social grant income by one South African Rand increases the probability of being energy poor by 47.5%. This result is highly significant (*p*-value = 0.000) and highlights the potential limitations of social grants in addressing energy poverty. While social grants provide essential support, this finding suggests that reliance on them may not be sufficient to overcome energy poverty, likely due to their relatively low value.

The index of non-productive assets showed a positive but statistically insignificant association with energy poverty (AME = 0.066, *p*-value = 0.704). This finding suggests that households valuing non-productive assets may have fewer resources to invest in energy access, which could increase the likelihood of experiencing energy.

Overall, the marginal effects confirm the robustness of the model by showing consistency in the direction and statistical significance of key variables.

4. Discussion

The analysis above reveals a notable gender disparity in energy poverty, with male-headed households being less susceptible to energy poverty than female-headed households. This is consistent with previous research indicating that gender plays a crucial role in determining household energy access and security (Ngarava et al., 2022). Female-headed households often face challenges that worsen their vulnerability to energy poverty. These households often live on lower income levels and are more likely to be dependent on informal employment or social grants, limiting their ability to invest in modern energy solutions (Clancy et al., 2003). Moreover, the caregiving responsibilities placed on women further constrain their financial and time resources, making it more difficult to explore alternative or more reliable energy sources. This aligns with the broader literature on gendered poverty dynamics, which emphasizes that female-headed households often experience multiple layers of economic and social exclusion (Mofokeng, 2021; Percept Actuaries & Consultants, 2023). Despite evidence suggesting that women are generally more mindful in household energy use, which often lead to greater efficiencies and savings, findings from this study indicate that this alone is insufficient to overcome the broader socioeconomic disadvantages they face, particularly in rural and low-income settings. Furthermore, the intersectionality of gender and race in South Africa cannot be overlooked. Some studies (Ngarava et al., 2022; OXFAM South Africa, 2024) suggest that Black South African women, in particular, face compounded disadvantages due to historical inequalities that have limited their access to economic opportunities and modern energy infrastructure. As a result, female-headed households are more likely to experience severe energy poverty, reinforcing cycles of economic hardship and social marginalization.

It is also suggested from the results that larger households are less likely to experience energy poverty, which opposes previous studies that have confirmed household size is positively correlated with energy poverty (Chen & Feng, 2022; Sovacool, 2012). Typically, large households tend to require more energy for their regular activities such as cooking, heating, and lighting, and therefore are more vulnerable to energy poverty, as they have higher consumption needs. But the evidence of this study suggests that larger households can have an advantage in gaining access to energy resources through labor pooling and income sharing. This is particularly so when considering the dual nature of energy access in Upper Blinkwater, where households both use freely available firewood and buy energy sources such as paraffin and gas. For example, in the case where firewood is still the primary source of energy, merely because it is readily available and does not necessarily mean direct cash expenditure, larger households have an advantage as they share the responsibility of gathering firewood among the many household members, ensuring continuous and consistent energy without overburdening any single person. In contrast, in those households where energy sources such as paraffin and LPG are used, the dynamics of energy poverty shift from labor to income pooling, and the households have a diversified income flow, whereby more members of the household contribute economically towards energy expenditure, which allows for more stable and consistent energy supply. On the other hand, while larger households have higher total energy needs, their per capita energy use is lower due to scale economies in energy use (Pachauri et al., 2004). For example, lighting and cooking energy can be shared among more individuals without a proportional increase in cost, making energy consumption more efficient. This suggests that while absolute energy demand may increase with household size, affordability and access may not necessarily decline if financial contributions are distributed across multiple earners.

The findings also suggest that while education may widely be regarded as a catalyst for improved livelihoods in terms of increased income-generating activities, enabling access to cleaner energy sources (Nussbaumer, 2012; Sovacool & Griffiths, 2020), its impact in rural, off-grid communities appears to be limited by infrastructural constraints. Based on the results, although educated household heads may be well aware of new energy services and their benefits, they remain trapped in energy poverty. While their skills could help them secure formal employment and increase disposable income for modern energy sources, persistent challenges, including unreliable energy infrastructure, a lack of job opportunities, and financial constraints, prevent them from investing in alternative energy solutions such as solar home systems or generators. This suggests that education alone may not guarantee improved access to energy unless accompanied by adequate infrastructure. This finding contradicts the 'energy ladder hypothesis', which posits that households with higher income or education levels are more likely to transition to cleaner fuels (Ramaswamy et al., 2024). However, where enabling infrastructure is not available, the educated will sense the constraints of their surroundings more acutely than their less educated counterparts. It gives support to the argument of Pachauri et al. (2013) that not only does access to modern energy services require demand-side preparedness but also supply-side infrastructure to mitigate energy poverty.

Research has also shown that economic affordability significantly influences the ability of a household to transition from unclean energy sources such as firewood and paraffin to clean energy sources such as electricity and liquefied petroleum gas (LPG) (Ramaswamy et al., 2024). It is then not surprising that social grant recipients in Upper Blinkwater are the most affected by energy poverty. In a community where formal employment opportunities are virtually nonexistent, many households depend on social grants as their primary or even sole source of income. Rather than lifting households out of poverty, social grants merely provide a basic level of subsistence, but not sufficient to maintain modern energy services. The research results depict a positive correlation between social grants and energy poverty, with evidence that as more people receive social grants, more people suffer from energy poverty. This trend reflects the structural economic challenges facing rural communities, where growing reliance on social support indicates deepening poverty rather than economic progress. Moreover, social grants are often insufficient to cover the high costs of cleaner energy sources, making households that already operate within tight financial constraints find it increasingly difficult to transition to cleaner energy options. Not only does this perpetuate energy poverty, but it also exacerbates broader social and economic vulnerabilities.

Overall, the findings strongly suggest that energy poverty in Upper Blinkwater is not merely a result of individual household choices but is deeply rooted in economic and infrastructural limitations. The persistent reliance on social grants, lack of employment opportunities, and energy infrastructure points to the fact that, without targeted interventions, energy poverty will continue and deepen socioeconomic inequalities.

While these findings offer important insights into the structural drivers of energy poverty in Upper Blinkwater, it is equally important to acknowledge the limitations of the study that may influence the interpretation and generalizability of the results. Upper Blinkwater represents a unique case with a relatively small population, which may constrain the generalizability of the results beyond this rural community. Although the methods employed were carefully designed to maximize the robustness and validity of the findings, ensuring that the conclusions drawn are both reliable and meaningful for understanding energy poverty in this context, the findings should be interpreted with caution when applied to settings with different socioeconomic or geographic characteristics. In addition, the study primarily focused on observable household-level variables, while other unobserved factors such as cultural practices, energy-use habits, and intra-household decision-making may also play a significant role in shaping energy poverty. Future research may also benefit from incorporating a qualitative approach to exploring these dimensions in greater depth, further validation using alternative modeling techniques could enhance the reliability of the conclusions. Future studies should consider expanding the sample, employing longitudinal data, and integrating qualitative insights for a more comprehensive understanding of energy poverty dynamics.

5. Conclusions

This study examined the factors contributing to energy poverty in the remote rural village of Upper Blinkwater. The findings reveal many of the households in this community were managing to cope with the limited and often unreliable energy options available to them. The findings showed that female-headed, younger-headed, educated, and social grant-dependent households were the most vulnerable to energy poverty. These disparities identify that access to energy is not just a technological issue but is strongly linked to social, economic, and demographic determinants. The findings point to the need for a more refined understanding of energy poverty, one that extends beyond the supply of infrastructure to address the broader systemic problems underpinning energy access. That energy poverty is so prevalent among female-headed households, for instance, suggests that gender is an important determinant of household energy insecurity. Female-headed households in rural regions are likely to face greater economic handicaps, including lower income-earning opportunities and a higher reliance on social grants, which diminishes their ability to afford cleaner sources of energy. Similarly, younger-headed households' exposure might be attributable to lower financial securities and less asset accumulation, which again limits their energy choices. In the same vein, social grant dependency is positively associated with energy poverty highlights the failure of income transfers to address structural barriers such as high fuel costs, lack of infrastructure, and economic stagnation. These findings underscore the importance of multidimensional and inclusive policy approaches that go beyond technological access to address the root causes of socioeconomic inequality.

Addressing energy poverty in Upper Blinkwater and comparable areas therefore requires a multifaceted approach that exceeds purely monetary interventions. Interventions need to be gender-responsive, with the aim of improving women and female-headed households' access to economic resources and alternative livelihood opportunities. It is not sufficient to simply scale up social safety nets energy affordability programs targeting those most vulnerable, investment in decentralized energy solutions, and policy stimulating local economic development are required. An integrated solution that incorporates social, economic, and infrastructural elements will be the answer to breaking the energy poverty cycle and encouraging sustainable development in rural South Africa. Although this study focuses on the Upper Blinkwater community, its findings have broader relevance for understanding energy poverty in other remote, off-grid areas that face shared challenges, including limited income opportunities, inadequate infrastructure, dependence on social grants, and gender-based disparities in household decision-making and access to resources. The insights presented here not only deepen the localized understanding of energy poverty dynamics but also contribute to global efforts aimed at designing targeted interventions for marginalized, energy-deprived populations.

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Abbreviations

The following abbreviations are used in this manuscript:

AME	Average marginal effects
FBE	Free basic electricity
LPG	Liquified petroleum gas
MEPI	Multidimensional Energy Poverty Index
NIDS	National Income Dynamics Survey
SDGs	Sustainable Development Goals
STATA	Statistics and Data Statistical Software
USD	United States Dollar
ZAR	Zuid-Afrikaanse Rand (South African Rand)

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