

Article

Household Energy Access, Energy Poverty, and Energy Stacking in the Context of South Africa's Energy Transition

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Abstract

Energy poverty remains a persistent challenge in South Africa, despite relatively high levels of electricity access in urban townships. This study investigates household energy consumption patterns, energy-related challenges, and community perceptions of renewable energy in South Africa. In this study, a quantitative research design was employed, using a structured questionnaire administered to households selected from both electrified and non-electrified areas. The data were analyzed using descriptive statistics and inferential analysis with the Statistical Package for the Social Sciences (SPSS Version 30). The findings demonstrated that although electricity is widely used for basic services such as cooking and lighting, many households continue to rely on multiple fuels to meet their daily energy needs. This practice of energy stacking reflects ongoing concerns about affordability, reliability, and safety, and highlights that access to electricity alone does not guarantee energy security. Households also report significant financial pressure from energy costs, as well as health and fire risks associated with the use of unsafe alternative fuels. While awareness of renewable energy is present within the community, knowledge levels are uneven and not strongly associated with demographic factors, suggesting the need for more inclusive and targeted engagement strategies. Overall, the study demonstrates that energy poverty in urban South African townships extends beyond physical grid connection and is shaped by complex socio-economic and safety considerations. By foregrounding community perspectives, this research contributes to the international literature on multidimensional energy poverty and supports the design of integrated, people-centered interventions that advance affordable, reliable, and clean energy transitions in the Global South.

Keywords: renewable energy; energy transition; sustainable energy; energy poverty; energy access; South Africa



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1. Introduction

South Africa's electricity generation system remains overwhelmingly dependent on coal, with coal-fired power plants contributing approximately 83.5% of the national energy mix [1–3]. This heavy reliance on coal has shaped the country's energy landscape for decades, providing relatively low-cost electricity while simultaneously creating significant environmental, economic, and social challenges. An aging power infrastructure, frequent plant breakdowns, and escalating operational costs have reduced system reliability, leaving the national grid increasingly vulnerable. In Gauteng province, South Africa's economic hub, electrification levels remain uneven, with approximately 82% of households connected

to the grid [4,5]. Despite relatively high electrification rates compared to other regions, access alone has not translated into energy security or affordability for all households.

Rapid population growth, sustained urbanization, increased industrial activity, and limited investment in new electricity generation capacity have placed persistent pressure on the national grid. These pressures have contributed to recurrent load shedding since 2007, a defining feature of South Africa's electricity crisis. Load shedding has disrupted economic productivity, public services, and household livelihoods, particularly affecting low-income and vulnerable communities that lack alternative energy options [2–5]. As electricity tariffs continue to rise, energy insecurity has intensified, deepening existing socio-economic inequalities and undermining progress toward universal access to modern energy services.

Against this background, important questions remain about how households in urban South African townships experience energy access in their daily lives. While electrification rates are relatively high in many urban areas, less is known about how affordability constraints, housing conditions, and reliability concerns shape real household energy choices and perceptions of alternative energy options.

This study, therefore, asks: How do households in an urban South African township experience energy use, energy-related challenges, and renewable energy awareness in the context of persistent energy poverty? To address this overarching question, the study explores:

- (1) The main household energy sources and patterns of fuel stacking.
- (2) The economic, safety, and reliability challenges influencing energy decisions.
- (3) Community awareness and perceptions of renewable energy technologies, including whether demographic factors are associated with differences in knowledge. These questions are directly aligned with the statistical analyses and hypothesis testing presented later in the paper.

This study focuses on Gauteng, South Africa's economic hub, where rapid urbanization, strained infrastructure, and persistent inequality create complex dynamics of energy access. Although electrification rates in Gauteng are relatively high compared to other provinces, many low-income urban communities continue to experience affordability constraints, unreliable supply, and reliance on multiple fuels. The empirical investigation is centered on Soshanguve, a large township situated approximately 30 km north of Pretoria in Gauteng, just east of Mabopane. As part of the City of Tshwane Metropolitan Municipality, Soshanguve represents a socially and economically diverse urban settlement where formal electrification coexists with income insecurity, informal housing expansion, and energy stacking practices. Its characteristics make it a suitable case study for examining the multidimensional nature of energy poverty in an urban South African context.

Although the empirical focus is on Soshanguve, the findings have wider international relevance. Across many countries in Africa, Asia, and Latin America, households are formally connected to electricity grids yet continue to experience energy insecurity due to high costs, unreliable supply, and dependence on unsafe alternative fuels. Energy stacking, affordability stress, and uneven awareness of renewable energy technologies are therefore not uniquely South African challenges but central features of urban energy poverty in the Global South. By examining these dynamics at the community level, this study contributes to international debates on multidimensional energy poverty, just energy transitions, and the design of inclusive, people-centered clean energy policies.

Energy poverty remains a critical and multidimensional challenge across both rural and urban settings in South Africa. Approximately 13.85% of the population still lacks access to electricity, with many households relying on traditional and transitional fuels such as firewood, coal, paraffin, and candles for cooking, lighting, and space heating [6–8].

Even in households connected to the grid, electricity access does not necessarily equate to consistent or sufficient energy use. Household income levels strongly influence energy choices, often resulting in the continued use of multiple fuels alongside electricity, a phenomenon commonly referred to as fuel stacking [9]. This practice reflects affordability constraints, reliability concerns, and cultural preferences.

A significant proportion of low-income households reside in government-provided housing or informal settlements constructed primarily from corrugated iron sheets and other low-quality materials. These dwellings typically exhibit poor thermal performance, resulting in excessive heat loss in winter and excessive heat gain in summer. As a result, households experience discomfort and increased energy demand for space heating and cooling, further exacerbating financial strain. The interaction between poor housing quality and limited energy access highlights the structural nature of energy poverty and its close link to broader issues of housing, urban planning, and social inequality.

Energy poverty is generally defined as the lack of access to affordable, reliable, and modern energy services necessary for basic household needs and socio-economic development [6–10]. At the global level, nearly 3 billion people lack access to clean, modern energy for cooking and heating, while approximately 13% of the world's population lacks access to electricity. Sub-Saharan Africa and South Asia bear a disproportionate share of this burden, with energy poverty reinforcing cycles of poverty, poor health outcomes, and limited educational and economic opportunities [10,11]. These global trends underscore the relevance of energy poverty as a development challenge with strong local manifestations in South Africa.

Various methodological approaches are used to measure and assess energy poverty. The expenditure-based approach classifies households as energy-poor when they spend more than 10% of their income on energy services, reflecting the financial burden of energy costs [6,12]. The subjective approach relies on household self-assessments of whether their energy needs for cooking, lighting, and heating are adequately met. In contrast, the thermal inefficiency approach focuses on indoor thermal comfort, using temperature measurements and building characteristics to evaluate energy deprivation [6,13,14]. Each approach captures distinct dimensions of energy poverty, underscoring its complex, context-specific nature.

Energy poverty disproportionately affects women and children, who are typically responsible for household energy provision, cooking, and fuel collection. Prolonged exposure to indoor air pollution from solid fuels is associated with respiratory diseases, eye irritation, and cardiovascular conditions, while the physical demands of fuel collection contribute to musculoskeletal injuries and fatigue [15,16]. Women also face increased risks related to reproductive health and time poverty, as energy-related tasks reduce opportunities for education and income-generating activities. In South Africa, approximately 43% of households are classified as energy-poor based on expenditure thresholds, illustrating the scale and persistence of the problem [17]. The widespread reliance on multiple fuels further reflects households' coping strategies in response to unreliable and unaffordable energy supply [17–20].

Given rising energy demand, declining coal quality, aging infrastructure, and increasing climate-related risks, South Africa faces growing pressure to accelerate its transition to sustainable, low-carbon energy systems [18–22]. Renewable energy technologies offer significant potential to improve energy access, enhance grid resilience, and reduce environmental impacts. However, their widespread adoption remains constrained by high upfront costs, limited technical capacity, skills shortages, policy uncertainty, and challenges with social acceptance, particularly at the household and community levels [23–25].

Across Africa, the need to expand energy access while reducing environmental impacts has placed energy transitions high on national and regional policy agendas. Many countries face the dual challenge of addressing persistent energy poverty and building low-carbon energy systems in line with global climate commitments. Renewable energy technologies, particularly solar and wind, have emerged as key components of this transition due to their potential to extend access, diversify supply, and improve system resilience. Despite rapid growth in installed renewable capacity in some African countries, significant barriers remain at both system and household levels. High upfront costs, limited access to finance, weak technical capacity, and policy and regulatory uncertainties can slow the deployment of renewable energy solutions. At the community level, adoption may also be constrained by limited awareness, lack of trust in new technologies, and competing immediate needs related to food, housing, and employment [26,27].

South Africa presents a particularly complex case within the African energy transition landscape. The country's electricity system is heavily dependent on coal, making decarbonization both urgent and politically sensitive due to employment and economic concerns in coal-dependent regions. At the same time, South Africa has made notable progress in utility-scale renewable energy procurement and has committed to a just energy transition that balances climate goals with social protection and economic inclusion [1,2].

However, much of the national transition discourse has focused on large-scale energy generation and grid reform, with less attention given to how low-income urban households experience and engage with energy transitions. Household-level adoption, awareness, and perceptions of renewable energy remain underexplored, particularly in townships and informal settlements where affordability constraints and infrastructural limitations are most pronounced. Understanding these local perspectives is essential for ensuring that energy transitions are not only technically successful but also socially inclusive and responsive to the needs of vulnerable communities.

Electricity access in Sub-Saharan Africa remains structurally uneven despite sustained electrification efforts. According to recent regional analyses, overall electricity access in Sub-Saharan Africa remains below 55%, with rural access rates significantly lower than urban levels [28]. Off-grid communities account for a substantial share of the access deficit, particularly in peri-urban and informal settlements where grid expansion is technically feasible but economically constrained. The article "Electrification Planning for Off-Grid Communities in Sub-Saharan Africa" highlights that decentralized renewable systems are increasingly promoted to close these gaps, yet investment limitations, weak institutional coordination, and affordability barriers continue to hinder large-scale deployment [29].

Beyond physical access, energy insecurity remains a multidimensional challenge. Using global panel data, Le and Park (2021) [30] demonstrate that energy insecurity is driven not only by infrastructure deficits but also by income volatility, energy price instability, and governance constraints. In Sub-Saharan Africa, households frequently engage in fuel stacking as a coping mechanism in response to unreliable supply and cost pressures.

Demand-side pressures further complicate the transition. Electricity demand in Sub-Saharan Africa is projected to grow faster than the global average, driven by urbanization and demographic expansion [31]. However, renewable energy deployment faces structural barriers, including high capital costs, grid instability, and regulatory uncertainty. Lemaire et al (2026) [31] estimate that without significant policy reform and financial mobilization, the renewable expansion required to meet sustainable development targets will fall short of projected demand growth. Table 1 summarizes electricity access rates, demand growth trends, off-grid deficits, and energy insecurity indicators in Sub-Saharan Africa.

While prior studies in South Africa have examined energy poverty, fuel stacking, and household energy use, this study provides new empirical insights by combining data

from both electrified and non-electrified households in Soshanguve, highlighting how affordability, housing conditions, and social perceptions shape energy choices. In addition, the study contextualizes household-level energy insecurity within South Africa’s broader energy transition, providing policy-relevant evidence for the design of socially inclusive renewable energy interventions. By linking micro-level patterns of energy use to the challenges of a low-carbon transition, this research contributes to both the national and international discourse on equitable energy access and sustainable energy transitions.

Table 1. Electricity access, demand growth, and energy insecurity trends in Sub-Saharan Africa.

Indicator	Sub-Saharan Africa	Urban Sub-Saharan Africa	Rural Sub-Saharan Africa	Reference
Electricity Access Rate (%)	~55%	~78%	~34%	[28]
Population Without Access (millions)	>550 million	—	Majority rural	[29]
Annual Electricity Demand Growth (%)	4–6%	Higher in urban centers	—	[31]
Share of Households Using Multiple Fuels (%)	>60% in low-income areas	Common	Common	[30]
Key Drivers of Energy Insecurity	Income volatility, price shocks, governance gaps	—	—	[30]
Main Barriers to Renewable Expansion	Financing gaps, grid constraints, policy risk	—	—	[31]

2. Methodology

Descriptive analysis is a statistical approach used to summarize and objectively describe the characteristics, distribution, and patterns within a dataset, allowing for an initial understanding of the nature and scale of the variables under investigation [32]. In this study, descriptive analysis was applied to provide an overview of respondents’ socio-demographic characteristics and to contextualize household energy-related information prior to inferential analysis. The analysis was conducted using frequency distributions, custom tables, means, and standard deviations. These statistical measures were used to summarize key variables, including respondents’ age, highest level of education attained, and primary source of income. The use of descriptive statistics enabled the identification of dominant trends and variations across the sampled population, supporting subsequent comparative and inferential analyses. The methodological workflow of the study is shown in Figure 1.

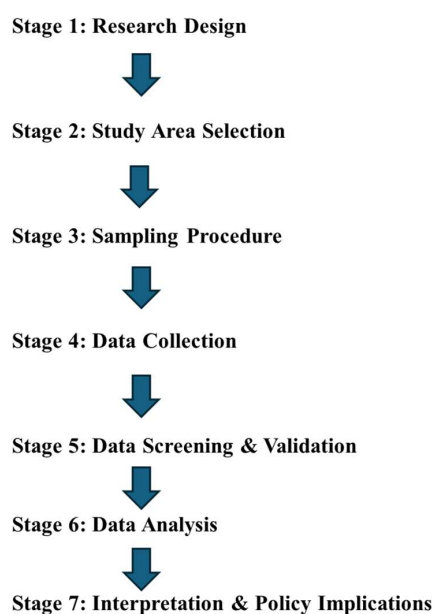


Figure 1. Methodological workflow of the study.

A total of 140 questionnaires were distributed within the study area. Of these, 121 questionnaires were returned, resulting in a response rate of 86.4%. Following data screening and validation, 115 questionnaires were deemed suitable for analysis, corresponding to a valid response rate of 95% (Table 2). The remaining questionnaires were excluded due to incomplete responses and missing data that could compromise the reliability of the analysis. The final dataset was considered adequate for descriptive and inferential statistical analysis, providing a robust basis for examining household characteristics, energy consumption patterns, and factors influencing energy choices within the community.

Table 2. Summary of questionnaire distribution and validation.

Description	Number	Percentage (%)
Questionnaires Distributed	140	100
Questionnaires Returned	121	86.4
Validated Questionnaires	115	95.0 (of returned)
Discarded Questionnaires	6	5.0 (of returned)
Overall Valid Response Rate	115	82.1 (of distributed)

To ensure data reliability and analytical consistency, a structured validation procedure was implemented prior to statistical analysis. Questionnaires were included in the final dataset only if they met the following criteria:

- i. Completeness threshold: At least 90% of key survey sections (demographics, energy use, expenditure, and renewable energy perception) were completed.
- ii. Eligibility requirement: The respondent had to be 18 years or older and a permanent household member.
- iii. Logical consistency check: Responses were screened for contradictory answers (e.g., indicating no electricity access while reporting exclusive electricity use for all energy services).
- iv. Duplicate removal: Only one questionnaire per household was accepted.
- v. Missing critical variables: Surveys missing essential variables required for hypothesis testing (age category or renewable energy knowledge) were excluded.

Based on these criteria, six questionnaires were discarded due to incomplete responses and missing critical variables, resulting in a final validated sample of 115 responses.

In this study, the term available energy resources refers to energy sources that are physically accessible and practically usable by households within the study. Within the household context of Soshanguve, renewable energy primarily refers to small-scale solar photovoltaic (PV) systems and solar water heating technologies, as these are the most practically deployable renewable technologies at the residential level.

2.1. Study District

Soshanguve, a large peri-urban township within the City of Tshwane Metropolitan Municipality in Gauteng Province, South Africa, was selected as the case study for this research (Figure 2). Established in 1974 and located approximately 25 km north of Pretoria, Soshanguve derives its name from the initials of the Sotho, Shangaan, Nguni, and Venda ethnic groups, reflecting the township's ethnically diverse population and historical role as a settlement area during the apartheid era [33]. Today, Soshanguve is a complex socio-economic environment shaped by rapid urbanization, migration, and uneven development.

The township is spatially organized into a series of blocks and extensions, which vary considerably in terms of infrastructure provision, housing quality, and access to basic services. Older blocks are relatively well developed and are generally characterized by formal housing, paved roads, and access to electricity, water, and sanitation services.

In contrast, newer extensions are predominantly composed of informal dwellings and government-subsidized Reconstruction and Development Program (RDP) houses. These areas often experience service delivery backlogs, overcrowding, and limited access to reliable electricity, conditions that contribute to energy insecurity and reliance on alternative energy sources.

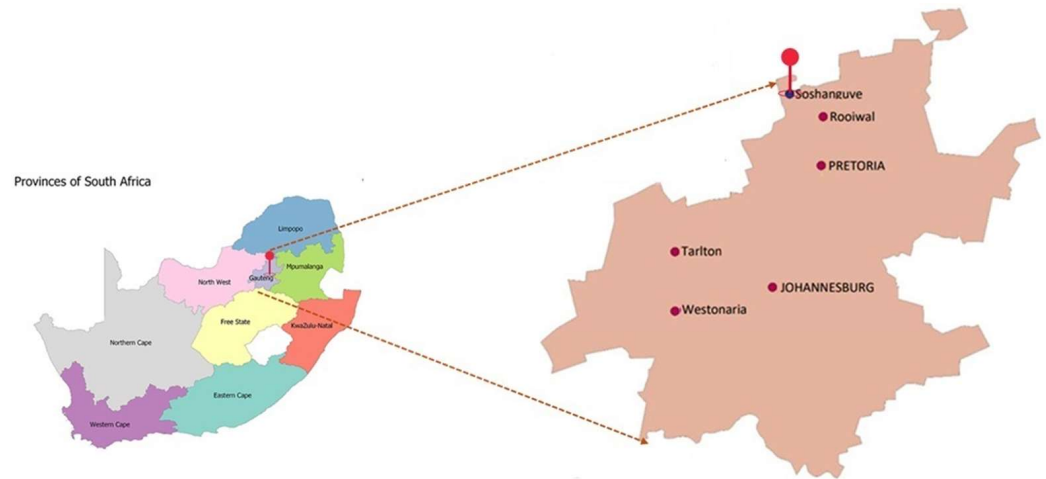


Figure 2. Map of South Africa, showing Gauteng province and the location of Soshanguve.

According to the 2011 national census, Soshanguve had an estimated population of 403,162 residents, making it one of the largest townships in South Africa. A significant proportion of the population falls within the economically active age group of 15–64 years, accounting for approximately 69.4% of the total population. Despite this relatively high working-age population, unemployment and underemployment remain persistent challenges, with many households experiencing irregular incomes and economic vulnerability. These socio-economic conditions directly influence household energy consumption patterns, affordability, and fuel choices. The diversity of housing types, income levels, and access to infrastructure within Soshanguve makes it a suitable and representative case study for examining household energy use and energy poverty in urban and peri-urban contexts. The township provides a valuable setting for assessing how socio-economic factors, housing characteristics, and levels of energy awareness shape household energy decisions and the potential adoption of renewable energy technologies [34].

2.2. Data Collection

This study adopted a quantitative and descriptive research design, supported by a limited qualitative component, to provide deeper insight into household energy experiences and decision-making processes. The quantitative approach captured measurable patterns in energy access, consumption, expenditure, and fuel choices across households, while the qualitative elements allowed respondents to elaborate on contextual factors that could not be fully explored through structured questions alone. This mixed approach strengthened the interpretation of the findings by combining statistical description with explanatory insights.

A random sampling technique was employed to select households within the study area, ensuring representation from both electrified and non-electrified households. The study area was first divided into residential sections to ensure spatial coverage across the township. Within each section, households were selected using a systematic random sampling method, where households were approached at regular intervals along selected streets for participation. If a selected household was unavailable or declined to participate, the next household was approached to maintain the sampling interval and achieve the

desired sample size. This approach reduced the likelihood of clustering responses within a single area and helped capture variation in housing conditions, service access, and socio-economic characteristics across the community.

This approach allowed for meaningful comparison of energy consumption patterns across different access levels. Participation in the study was restricted to individuals aged 18 years and above, with one respondent per household to avoid duplicate responses and ensure consistency in household-level data.

Data were collected through a structured household survey administered in person within the study area using a Computer Assisted Personal Interview (CAPI) approach. Trained field assistants visited selected households and conducted face-to-face interviews with adult household members. Although the questionnaire was hosted on Google Forms, the platform served solely as a digital data-capture tool within the CAPI framework rather than an online self-administered survey. Fieldworkers used mobile devices to record responses during interviews, ensuring that participants who lacked internet access, digital literacy, or personal devices were not excluded from the study. This in-person, interviewer-assisted approach helped improve response quality and inclusiveness, particularly among low-income and vulnerable households that might otherwise be underrepresented in purely online surveys. The use of an electronic platform also ensured data security and streamlined data management for subsequent analysis.

2.3. Data Analysis

Data collected from the complete questionnaires were coded, entered, and analyzed using the Statistical Package for the Social Sciences (SPSS). SPSS was selected due to its wide application in social science research, survey-based studies, market research, government analysis, and educational research, as well as its reliability in handling structured questionnaire data. The software is particularly suited for managing large datasets and performing both descriptive and inferential statistical analyses in a systematic and transparent manner [35].

Prior to analysis, the dataset was screened for completeness, consistency, and potential entry errors. Descriptive statistical techniques, including frequencies, percentages, means, and cross-tabulations, were employed to summarize household demographic characteristics, energy access levels, fuel choices, and expenditure patterns. These analyses provided an overview of energy consumption behavior across electrified and non-electrified households. Where appropriate, comparative analyses were conducted to examine differences in energy use and energy-related challenges between household groups. SPSS was also used to generate tables and graphical representations, such as bar charts and pie charts, to support the clear presentation and interpretation of results. The combined use of numerical outputs and visual tools enhanced the clarity of the findings and facilitated meaningful discussion in relation to the study objectives.

2.4. Hypothesis Test

The research hypothesis tested in this study was formulated to examine whether there is a relationship between respondents' age and their level of knowledge and perceptions of renewable energy within the community. Specifically, the hypothesis sought to determine whether differences in knowledge and perceptions of renewable energy vary significantly across age groups. This hypothesis was developed in line with the study's objective of understanding socio-demographic influences on energy awareness and adoption [34].

The chi-square (χ^2) test of independence was employed to test this hypothesis and to assess whether a statistically significant association exists between age categories and levels of renewable energy knowledge. The chi-square test is appropriate for analyzing

relationships between categorical variables and is widely used in social and energy-related research involving survey data [36,37]. By comparing observed frequencies with expected frequencies under the assumption of independence, the test enables the identification of meaningful associations between variables.

In this study, age was categorized into predefined groups, while renewable energy knowledge was measured using categorical response options derived from the questionnaire. A significance level of 0.05 was adopted for hypothesis testing. The results of the chi-square analysis provide insight into how age-related differences may influence awareness and perception of renewable energy technologies within the community. The formula for calculating the chi-square is given in Equation (1).

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

Null Hypothesis (H₀). *There is no significant relationship between age and perception (or level of knowledge) of renewable energy in the community.*

Alternative Hypothesis (H₁). *There is a significant relationship between age and perception (or level of knowledge) of renewable energy in the community.*

2.5. Demographics of Participants

The demographic characteristics of the respondents are presented in Table 3. The results indicate that the Soshanguve community sample is predominantly composed of young adults, a trend consistent with earlier demographic studies of the area [38]. Approximately 49.60% of respondents fall within the 18–39 age group, reflecting a relatively youthful population. In contrast, respondents aged 50 and above account for 13.90% of the sample. This age distribution suggests a community with a large, economically active population, with important implications for energy demand, consumption patterns, and openness to new energy technologies.

Table 3. Age of participants.

Age Population	Frequency	Percentage
18–29	14	12.20%
30–39	43	37.40%
40–49	42	36.50%
50+	16	13.90%

Table 4 presents the primary sources of income among the respondents. The findings show that most participants (59.10%) are formally employed and earn regular salaries, indicating some degree of income stability within the sample. This is followed by 20.90% of respondents who rely on government social grants as their main source of income, highlighting the presence of economically vulnerable households in the community. Self-employed individuals account for 7.80% of the respondents, while pensioners account for 2.60% of the sample. The “Other” sources of income category accounts for 9.60% of respondents and includes income from child maintenance, part-time employment, informal work, and alimony. The diversity of income sources observed reflects varying levels of economic security and directly influences household energy choices, affordability, and the ability to adopt alternative or renewable energy solutions. These socio-economic characteristics provide important context for interpreting subsequent analyses of energy consumption patterns and perceptions of renewable energy within the community.

Table 4. Source of income of the respondent.

Source of Income	Frequency (<i>n</i>)	Percentage (%)
Employed (Salary/Wages)	68	59.10
Social grant	24	20.90
Self-employed	9	7.80
Pension	3	2.60
Other, please specify	11	9.60

3. Results and Discussion

3.1. Household Energy Use Patterns

3.1.1. Cooking

The results for household energy usage for cooking are shown in Table 5. Cooking accounts for about 90% of total household energy use in many developing countries and is strongly influenced by local food practices [39–41]. The results indicate that electricity is the most used cooking energy source, with 69.60% of respondents reporting its use, while 30.40% indicated that they do not use electricity for cooking. This suggests a relatively high level of access to grid-based cooking energy among the sampled households. LPG is the second most frequently used cooking fuel, with 40.90% of respondents reporting its use. However, a larger proportion (59.10%) reported not using LPG, suggesting that while LPG plays an important complementary role, it is not yet a dominant cooking fuel for most households. The use of paraffin remains present but limited, with 26.10% of respondents indicating usage, while 73.90% reported not using paraffin for cooking. This may reflect a gradual shift away from paraffin due to concerns about safety, cost, or health. The adoption of solar energy systems for cooking is extremely low, with only 0.90% of respondents reporting usage. This highlights the limited penetration of solar-based cooking technologies within the study area. Traditional biomass fuels, such as firewood, straw, or charcoal, are used by 8.70% of respondents, while the majority (91.30%) reported not relying on these sources. Similarly, other cooking energy sources were reported by only 3.50% of respondents, indicating minimal dependence on alternative or informal energy options. Overall, the findings suggest that while electricity dominates as the primary cooking energy source, households continue to rely on multiple fuels, with LPG serving as a key supplementary option. This pattern is consistent with previous South African studies, which show that electrification does not automatically lead to exclusive reliance on electricity for cooking, particularly in low-income urban areas where affordability and supply reliability remain concerns. Similar trends have been reported across the Global South, including in Sub-Saharan Africa and parts of South Asia, where households adopt a fuel stacking strategy rather than progressing linearly up the traditional energy ladder [42,43]. Compared with rural-focused studies that report greater reliance on biomass fuels, the relatively low use of firewood and charcoal in this study reflects the more urbanized setting, where grid access levels are higher but economic constraints still limit a full transition to clean, modern energy. The persistence of paraffin use, despite its known safety and health risks, also aligns with findings from other developing country contexts where transitional fuels remain important coping mechanisms. These similarities position the study within broader international evidence showing that the energy transition at the household level is shaped less by simple access and more by affordability, reliability, and perceived risk [39–43].

Table 5. Energy sources used for cooking.

Energy Source for Cooking	No	Yes	Percentage
Electricity	30.40%	69.60%	100.00%
Liquefied Petroleum Gas (LPG)	59.10%	40.90%	100.00%
Paraffin	73.90%	26.10%	100.00%
Solar system	99.10%	0.90%	100.00%
Firewood, straw, or Charcoal	91.30%	8.70%	100.00%
Other sources	96.50%	3.50%	100.00%

Note: Percentages may exceed 100% because respondents were permitted to select multiple energy sources.

3.1.2. Household Energy Sources for Lighting

As shown in Table 6, the findings indicate that electricity is the dominant lighting source, with 85.20% of respondents reporting its use, while 14.80% reported not relying on electricity for lighting. This suggests relatively high access to grid-based lighting among the households surveyed. In contrast, the use of LPG, firewood, straw, or charcoal for lighting is negligible, with only 0.90% of respondents reporting use for each of these sources. Similarly, paraffin is used by a very small proportion of households (3.50%), indicating a reduced reliance on traditional or hazardous fuels for lighting. The adoption of solar lighting systems remains limited, with 4.30% of respondents reporting use. Although still low, this suggests emerging interest in decentralized renewable lighting solutions, potentially as backup or supplementary sources. A notable finding is the continued reliance on non-grid and transitional lighting options. Rechargeable lights are used by 22.60% of respondents, while candles are used by 33%. The relatively high use of candles, despite widespread access to electricity, may reflect affordability issues or the frequency and reliability of power outages. Similarly, other lighting sources were reported by 21.7% of respondents, further indicating energy stacking behavior among households. Overall, the results reveal a pattern of energy diversification, with electricity serving as the primary lighting source and being supplemented by alternative technologies such as rechargeable lights and candles. This highlights ongoing challenges in achieving reliable, affordable, and uninterrupted energy access, even in contexts with high levels of electrification. This finding aligns with previous South African studies showing that even in electrified urban settlements, households maintain backup lighting options due to load shedding, rising electricity costs, and concerns about supply reliability [42,44].

Table 6. Percentage breakdown of different energy sources used for lighting.

Source	No	Yes	Percentage
Electricity	14.80%	85.20%	100.00%
Liquefied Petroleum Gas (LPG)	99.10%	0.90%	100.00%
Paraffin	96.50%	3.50%	100.00%
Solar system	95.70%	4.30%	100.00%
Firewood, straw, or Charcoal	99.10%	0.90%	100.00%
Rechargeable lights	77.40%	22.60%	100.00%
Candle	67.00%	33.00%	100.00%
Other sources	78.30%	21.70%	100.00%

Note: Percentages may exceed 100% because respondents were permitted to select multiple lighting sources.

3.2. Household Energy Cost

Results, as shown in Figure 3, indicated that 44.30% of participants spend 600 South African Rands (R600) or more on energy expenditure per month, while 37.40% spend between R0 and R150, and 18.30% spend between R150 and R500 per month. Availability

and affordability are paramount criteria influencing community members' selection of energy fuels.

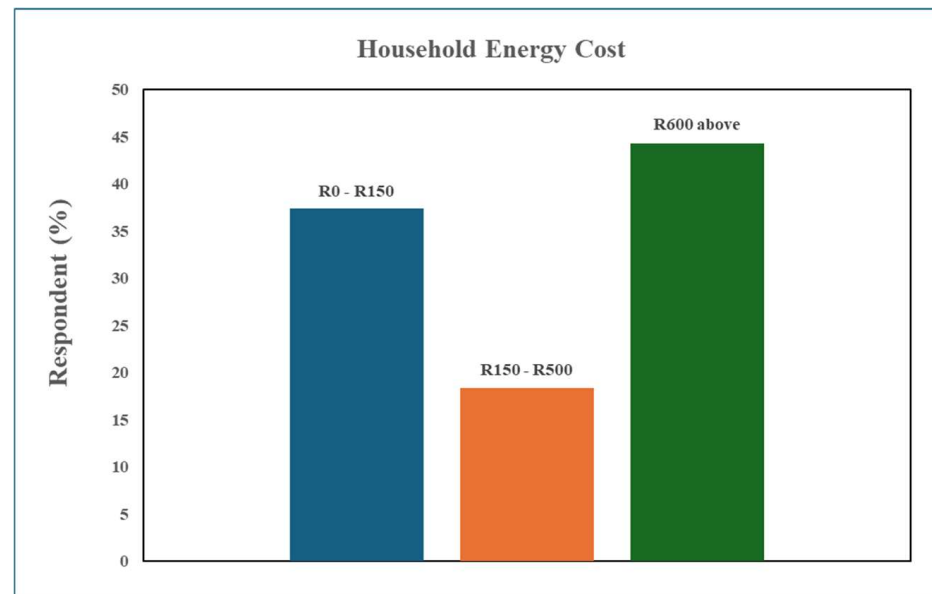


Figure 3. Respondent household energy cost.

The results presented in Figure 3 show clear variation in monthly household energy expenditure among respondents. A substantial proportion of participants (44.30%) reported spending R600 or more per month on energy, indicating a significant financial burden for many households. Households reporting monthly energy spending of R600 or more may be allocating a substantial portion of their income to energy, particularly compared to the median monthly household income of around R8000 or to typical social grants such as the child support grant (~R560) or the older persons/disability grant (~R2180). This indicates that energy costs can exceed the income some households receive from a single grant, creating a significant financial burden and limiting their ability to meet other essential needs. These findings show that energy poverty in this context is not only about physical access to electricity but also about the ability to afford safe and reliable energy services. Without targeted measures such as lifeline tariffs, subsidies, or support for low-cost renewable options, the transition to cleaner energy risks deepening existing socio-economic inequalities rather than promoting equitable access. In contrast, 37.40% of respondents reported monthly energy expenditure ranging from R0 to R150, while 18.30% reported expenditure between R150 and R500. This distribution highlights pronounced disparities in household energy spending within the community. High energy expenditure among a large segment of respondents suggests that energy costs constitute a considerable share of household income, particularly for low- and middle-income households. Conversely, lower reported expenditure may reflect limited energy access, reliance on alternative fuels, or constrained energy use due to affordability challenges. These patterns are consistent with the presence of energy poverty and fuel stacking behavior within the community. The findings further indicate that availability and affordability are the primary factors influencing community members' selection of energy fuels. Households tend to prioritize energy sources that are readily accessible and financially manageable, often at the expense of efficiency or environmental considerations. This underscores the need for energy interventions that not only expand access but also address affordability, promoting sustainable and equitable energy use [45].

3.3. Household Challenges Related to Energy Access

Table 7 presents respondents' perceptions of key household challenges related to energy access, rated on a five-point Likert scale from Strongly Disagree to Strongly Agree. Regarding the affordability of monthly household energy costs, responses were mixed. While 40.90% of respondents (Agree = 23.50%; Strongly Agree = 17.40%) indicated that they can afford their energy costs, a substantial proportion (43.50%) expressed disagreement (Disagree = 29.60%; Strongly Disagree = 13.90%). This suggests that energy affordability remains a significant concern for many households, reflecting uneven economic capacity to sustain regular energy expenditures. Regarding the adequacy of alternative energy sources, more than half of the respondents (53.90%) agreed that alternative energy options are insufficient to meet household energy requirements. Only 33% disagreed or strongly disagreed with this statement, while 13% remained neutral. This finding highlights limitations in the reliability, capacity, or accessibility of household-level alternative energy solutions. Concerns about the health impacts of available energy sources were also prominent. Nearly half of the respondents (47.80%) agreed or strongly agreed that household energy sources have a negative impact on household members' health. In contrast, 43.50% disagreed or strongly disagreed, indicating a divided perception, though with a slight tendency to recognize health-related risks associated with energy use. Perceptions of fire risk due to unsafe energy sources were particularly strong. A clear majority of respondents (61.80%) agreed or strongly agreed that unsafe energy sources pose a danger of house fires. Only 30.50% disagreed or strongly disagreed with this concern, while a small proportion (7.80%) were neutral. This highlights safety as a significant concern in household energy access and use. These findings underscore the ongoing prevalence of energy insecurity and fuel stacking practices, reinforcing the need for policies that enhance access to affordable, reliable, and safe household energy. The affordability concerns reported by many respondents are consistent with South African studies showing that rising electricity tariffs and unstable incomes limit households' ability to rely exclusively on grid electricity, even in urban areas with formal connections [39–41].

Table 7. Respondent household challenges related to energy access.

Household Challenges	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I can afford the monthly household energy costs	13.90%	29.60%	15.70%	23.50%	17.40%
Alternative energy sources are not sufficient for household requirements	16.50%	16.50%	13.00%	33.00%	20.90%
The health of household members is affected by the available energy source	23.50%	20.00%	8.70%	40.00%	7.80%
The danger of house fires due to unsafe energy sources	20.90%	9.60%	7.80%	43.50%	18.30%

3.4. Test of Hypotheses, Using Chi-Square (*p*-Value)

The results examining the relationship between age and perceptions of renewable energy knowledge within the community are presented in Table 8. The chi-square analysis produced a *p*-value of 0.114, which is higher than the adopted significance level of 0.05. This indicates that the observed differences in renewable energy knowledge across age groups are not statistically significant. Consequently, the null hypothesis is not rejected, suggesting that age does not have a significant influence on respondents' knowledge or perceptions of renewable energy within the study area. In addition to statistical significance, effect size was assessed using Cramér's *V* to evaluate the strength of the association. The obtained Cramér's *V* value of 0.229 indicates a weak association between age and renewable energy knowledge. While minor variations in awareness levels across age categories may exist,

these differences are insufficient to suggest a meaningful or systematic age-related pattern within the community.

Table 8. Cross-tabulation results for knowledge of renewable energy and age.

Knowledge of Renewable Energy Systems and Age					
Renewable Energy Systems	Age Categorically (Years)				Total
	18–29	30–39	40–49	50 Years & Above	
Not at all familiar	5 (41.70%)	2 (16.70%)	3 (25%)	2 (16.70%)	12
Slightly familiar	0	4 (28.60%)	5 (65.70%)	5 (65.70%)	14
Somewhat familiar	3 (13.60%)	10 (45.50%)	5 (22.70%)	4 (18.20%)	22
Moderately familiar	4 (13.80%)	16 (55.20%)	4 (13.80%)	5 (17.20%)	29
Extremely familiar	7 (18.40%)	18 (47.40%)	10 (37%)	3 (7.90%)	38
<i>p</i> -value (Cramer’s V value)			0.114 (0.229)		<i>n</i> = 115

Overall, the findings suggest that knowledge of renewable energy is relatively consistent across age groups in Soshanguve. This suggests that awareness and information gaps related to renewable energy may be influenced more by factors such as education level, income, or access to information than by age alone. These results provide important insight for the design of community-level renewable energy awareness and education initiatives, which may not need to be age-specific to be effective.

3.5. Implications for Energy Transition

The findings have clear implications for South Africa’s energy transition. Policies that focus solely on grid expansion or renewable technology deployment risk overlooking the socio-economic barriers that constrain household energy use. Without measures to address affordability, households may continue to rely on multiple fuels or unsafe alternatives, thereby reducing the effectiveness of low-carbon energy strategies. This underscores the importance of integrating social equity into energy transition planning. Targeted subsidies, lifeline tariffs, energy-efficient housing interventions, and decentralized renewable energy systems could help ensure that the shift to cleaner energy does not exacerbate existing inequalities.

3.6. International Relevance

Although the study is geographically focused, the results have broader international significance. Similar energy poverty patterns are observed in low-income urban communities across countries such as India, Brazil, and Kenya, where households use multiple fuels to cope with high energy costs or unreliable supply. The study contributes to the global discourse on inclusive energy transitions by highlighting how household-level constraints can limit the uptake of renewable energy technologies and the effectiveness of decarbonization policies. Lessons from this research can inform energy access programs in other regions, particularly where rapid urbanization, socio-economic inequality, and legacy fossil-fuel dependency intersect.

3.7. Theoretical Implications

The study’s findings reinforce and extend existing theoretical frameworks on energy poverty and socio-technical transitions. Consistent with energy poverty theory, household energy choices are shaped by both economic and structural factors, including income, housing quality, and access to services. The prevalence of fuel stacking underscores the limitations of assuming linear relationships among energy access, awareness, and behavior,

underscoring the need for frameworks that account for knowledge, attitude, and practice gaps in energy use. Additionally, situating household experiences within broader energy transition dynamics illustrates the interplay between micro-level decisions and macro-level policy objectives, contributing to the literature on socially inclusive transitions.

4. Conclusions

This study examined household energy use patterns, energy-related challenges, and perceptions of renewable energy within the Soshanguve community, with the aim of informing more inclusive and sustainable energy strategies. The findings indicate that electricity is the dominant energy source for both cooking and lighting, suggesting relatively high levels of grid access among the surveyed households. However, the continued use of LPG, paraffin, candles, rechargeable lights, and, to a lesser extent, biomass fuels highlights the persistence of energy stacking practices. This suggests that access alone does not guarantee reliable, affordable, or sufficient energy services, particularly in a context characterized by frequent power outages and rising energy costs. Household energy expenditure remains a significant burden for many respondents, with a substantial proportion spending R600 or more per month on energy. Perceptions of affordability were divided, reflecting underlying income inequalities and uneven economic resilience. Concerns related to the inadequacy of alternative energy sources, health impacts, and the risk of house fires further underscore the multidimensional nature of energy poverty within the community. These challenges are closely linked to the quality of housing, fuel safety, and the limited penetration of clean and reliable renewable energy technologies at the household level. The hypothesis testing results indicate no statistically significant relationship between age and knowledge or perception of renewable energy systems. This suggests that awareness of renewable energy cuts across age groups and may be shaped more by shared community experiences, exposure, and access rather than demographic factors alone. Nevertheless, the generally weak association and varied levels of familiarity point to the need for broader, community-wide education and engagement initiatives. Overall, the study highlights that while progress has been made in expanding electricity access, energy insecurity persists in more subtle forms related to affordability, reliability, safety, and sustainability. Addressing these challenges requires integrated policy interventions that promote affordable clean cooking and lighting technologies, improve energy reliability, and strengthen community awareness and capacity around renewable energy solutions. Such approaches are crucial for supporting South Africa's energy transition while ensuring it is socially inclusive and responsive to the realities of low-income households.

Despite its contributions, the study has several limitations. First, household income was not collected, so we relied on regional and national statistics to contextualize energy expenditures. Second, the study focuses on a single township, limiting generalization to other communities or regions. Third, the cross-sectional design captures a snapshot in time, preventing the assessment of temporal changes in energy use or the adoption of renewable technologies. Future research should consider longitudinal designs, comparative studies across multiple townships or countries, and interventions to address affordability and promote renewable energy adoption. Such studies could provide more robust evidence for policy design and help guide just and inclusive energy transitions globally.

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