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South Africa's Energy Landscape Amidst the Crisis: Unpacking Energy Sources and Drivers with 2022 Statistics South Africa Census Data

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Abstract: This paper examines patterns and drivers of energy choices for cooking and lighting in South Africa using the Statistics South African (StatSA, 2022) Census data at district municipality (districts) levels. Employing spatial and regression analysis, the findings show that electricity is the main source of energy for cooking across South Africa. However, there is a large swathe of the country covering districts, such as Vhembe and Mopani in Limpopo, eastern Mpumalanga, KwaZulu-Natal, and northern Eastern Cape provinces, where wood is the predominantly used energy type for cooking. There is almost uniform use of gas for cooking across the country. Electricity is the main energy source for lighting in South Africa. It is followed by candles, likely explained by loadshedding, and surprisingly solar energy a distant third. In terms of drivers, dwelling types play statistically significant role in what energy type to use for cooking and lighting, albeit differently. In terms of lighting, formal dwelling is positively related to the choice of electricity and informal dwelling is related to the choice of electricity (negatively) and candles (positively) for lighting. The level of higher education, household size, and the dependency ratio have varied statistically significant roles in the choice of either energy type for cooking or lighting by formal, informal, and traditional dwellers. Relevant policy prescriptions that are needed to engender the country towards sustainable energy use, diversification of energy types from electricity to other renewable energy sources, such as solar, and reduction in over-dependency on the biomass energy sources, such as paraffin and wood, especially in rural and poor districts, are proposed.

Keywords Households; Energy sources; Statistics South Africa census 2022; South Africa

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1. Introduction

South Africa, as one of the most developed nations in the African continent, is the largest consumer of energy. With much of its energy from coal, South Africa ranks as the 7th largest global coal producer (International Energy Agency's Energy Atlas, IEA, 2020; Jain and Jain, 2017). Despite South Africa's vast potential for biomass, wind, and solar energy, the country relies on coal for its fuel source due to its cost-effectiveness. This overreliance on coal (up to 80%) is also straining existing coal power stations, and presents environmental challenges, making the development of renewable energy sources crucial for the country (CSIR, 2023). To move towards successful renewable energy development in the country, several challenges, including technical, financial, policy, and environmental issues, must be addressed (Sarkodie and Adams, 2020).

Oyuke, Penar and Howard (2016) succinctly put forward the case for access to electricity. They argue that access to electricity is fundamental to opportunities in today's world. Quoting the former United States' President Obama, Oyuke, Penar and Howard (2016) add that "It is the light that children study by; the energy that allows an idea to be transformed into reality. It is the lifeline for families to meet their vital needs" (U.S. Agency for International Development, 2013). Moreover, the Sustainable Development Goal number seven (SDG 7) emphasizes the need for access to modern, reliable, affordable and sustainable energy sources as vital for economic development, poverty eradication and reducing inequalities, through improvement in health and wellbeing, food

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production, water supply, education and climate change mitigation (United Nation, 2023; Nerini *et al*., 2018; Moreno-Dobson, 2006; Brenneman and Michel, 2002; Banerjee *et al*., 2021).

Given the importance of the residential sector in terms of energy consumption, an extensive understanding of households' energy consumption patterns and choices is vital (Bohlmann *et al*., 2018). While literature on energy consumption in South Africa is vast (e.g., works by de Wet and Blignaut, 2001; Ziramba, 2008; Inglesi, 2009; Inglesi-Lotz and Blignaut, 2011; Inglesi and Pouris, 2010; Inglesi-Lotz, 2011; Makonese *et al*., 2016, and others, incorporating the industrial and residential sector), Bohlmann *et al*., (2018) decry the insufficient literature on the patterns, evolution and characteristics of energy use in South Africa focusing on the residential sector. As such, the main goal of this paper is to unpack energy type sources, choices, and their drivers in South African households using StatSA's (2022) Census data. Several authors acknowledge that household energy consumption is driven by household characteristics, such as income levels, energy prices, energy access, weather, household size and appliances and its energy efficiency, thus making the importance of understanding such relationships paramount (see Bohmann *et al*., 2018). Similarly, amidst the ongoing energy crisis in the country, the paper is timely as it will provide a deeper understanding of the energy characteristics across the country, which is essential in determining appropriate policies and steps required to be undertaken for future energy access across different regions in South Africa.

The remainder of the paper is structured as follows: Section 2 reviews related literature, including theories of energy choices, an overview of energy sources in South Africa, the significance of energy to economic growth and households, government policy towards the renewable energy mix in South Africa, and socio-economic factors affecting residential energy choices. Section 3 describes the data and methods employed in the paper. Section 4 dwells on the results and related discussions, while the last section concludes the paper.

2. Literature Review

2.1. Theoretical Background

The literature on household's choice for lighting and cooking energy source is divided into two channels: the energy ladder and fuel stacking hypotheses. The energy ladder hypothesis ascribes the differences in energy use patterns between households to variations in income status (van der Kroon *et al*., 2013). This explains the transition in cooking energy source from traditional biomass to modern sources along an imaginary ladder with improvement in the welfare (income) of households (Rajmohan *et al*., 2007). Hosier and Dowd (1987) suggest that households face a vector of energy choices ranked in a schematic way in order of increasing technological innovation. The hypothesis views energy demand in three stages. The initial stage is emphasizing universal dependence on biomass. The second stage entails fuel switching whereby households switch from biomass to transition fuels such as kerosine, coal and charcoal in response to the growth of income and other socioeconomic factors such as deforestation and urbanisation. The final stage of the ladder marks the switching to the use of modern energy such as liquified petroleum gas and electricity for cooking (Heltberg, 2004). Other studies such as Hosier and Down (1987), Leach (1992), Sathaye and Tayle (1991), Smith *et al*., (1994), Reddy and Reddy (1994) provide evidence in support of these hypotheses. Nevertheless, criticism is often posed against the energy ladder hypothesis, in that it is too simple, and tends to assume away the existence of inter-fuel substations among households (Heltberg, 2004; Akpalu *et al*., 2011).

The energy stacking hypothesis on the other hand posits that energy transition among households does not necessarily imply a stepwise movement from one fuel to another. Instead, households utilize various fuel sources (van der Kroon, 2013; Heltberg, 2004; Leach, 1992; Masera *et al*., 2000). Therefore, households rather have a portfolio of high and low-cost energy type constrained by dwelling types, income, household size and other preferences. Energy choice depends mainly on the abovementioned factors and unreliable availability of modern energy sources.

2.2. Overview of Energy Sources in South Africa

South Africa is the largest consumer of energy in Africa (International Energy Agency's Energy Atlas, IEA, 2020; Jain and Jain, 2017). In 2022, according to the Council for Scientific and Industrial Research (CSIR, 2023), South Africa produced 233 Terawatt-hour (TWh) from varied utility-scale generation technologies. These technologies include coal, nuclear, hydro, solar photovoltaics (PV), onshore wind, concentrated solar power (CSP), pumped storage and diesel-fuelled open cycle gas turbines. However, the country's energy production has been declining in the last decade – for instance, in 2010 energy production was 249 TWh. In terms of energy mix, coal remains the dominant energy source in South Africa, contributing 80% of the country's electricity generation (CSIR, 2023; Akinbami *et al*., 2021). Despite recent investments toward renewable energy technologies, the contribution of renewable energy technologies, that is, wind, solar PV and CSP, is a paltry 13.7% (without hydro its contribution is 7.3%) of the total energy mix. Nuclear and diesel energy contributed 4.6% and 1.6%, respectively (CSIR, 2023).

Unfortunately, this heavy reliance on coal has positioned South Africa among the top 10 greenhouse gas emitters globally (Bekun, 2019; Cohen *et al*., 2018). Initially, the rapid surge in electricity generation in South Africa in the period between the 1890s and the early 1900s was primarily a response to the increasing demand from power mining machinery and to provide municipal lighting. However, the continued extensive use of coal for power generation has resulted in high carbon dioxide (CO2) emissions. South Africa is not only the largest CO2 emitter in Africa, accounting for over 34% of the continent's total CO2 emissions, but it also ranks as the largest greenhouse gas emitter in Africa and the 14th largest CO2 emitter globally (Akinbami *et al*., 2021).

While energy is undeniably an important ingredient for economic growth, South Africa finds itself gripped by a prolonged energy crisis. Chronical underinvestment in the electricity sector has led to escalating power prices and a shortage of capacity during peak demand periods, resulting in demand rationing and blackouts, which have had severe economic implications (Pollet *et al*., 2015). The rising energy demand has started to overwhelm the existing power generating plants in South Africa and likely to affect the welfare of many South Africans (Inglesi-Lotz, 2011). In 2022, South Africa witnessed the worst loadshedding compared to the previous year's amounting to an outage duration of 3,773 hours or 11,529 GWh energy shed (CSIR, 2023). The major energy shortages, from unplanned outages, energy shortages, blackouts, high energy tariffs, follow mainly from many years of underinvestment in power infrastructure and energy poverty in low-income households (Pollet, *et al*., 2015). The poor performance and high maintenance of costs of Eskom's (Eskom presently stands as South Africa's largest power entity, responsible for about 96% of the country's electricity generation, operating 14 coal-fired power stations primarily clustered in the Mpumalanga province) coal fleet, and a lack of progress in adding new generation capacity to the national grid will most likely ensure the continuation of the country's energy crises in the foreseeable future (Greenpeace, 2023).

In South Africa, the percentage of households with access to electricity have increased to 86.15%, but a large share of households is still without electricity or cannot afford to use sufficient energy to meet their needs (Department of Energy, 2018). According to the StatsSA (2022) Census data, 64.9% of South African households use electricity for cooking, 25.7% use gas (Mostly standard LPG - Liquefied Petroleum Gas) for cooking, while the rest use paraffin (2.7%) and wood (6.1%) for cooking. In the case of energy for lighting, approximately 94.7 % of households use electricity for lighting, whereas 0.3% and 0.9% use gas and paraffin, respectively. Approximately 3.2% and 0.7% use candles and solar, respectively (StatsSA, 2022).

According to the General Household Survey (GHS), in 2021, about 11% of South African households did not have access to electricity, and some of this 11% with no electricity accessing electricity through informal or illegal connections (StatsSA, 2021). Almost three quarters (73.1%) of the 3.6% without formal access to electricity, were connected through informal sources, such as sharing connection with neighbouring households to whom they pay to, while 11.7% accessed through illegal connections (GHS, 2012). Eberhard et al. (2014) approximate South Africa's electricity demand to grow by 5.4% annually. Sarkodie and Adams (2020) suggest that of the 634 million people without electricity in Sub-Saharan Africa (SSA), eight million are in South Africa.

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In South Africa, the literature on energy consumption is vast. Decrying the limited research focusing on residential consumption in South Africa, Bohlmann *et al*., (2018) analysed the South African residential sectors' energy characteristics, such as energy use profile, geographical distribution, and demographic characteristics. They highlight how the residential sector is one of the largest with regards to electricity consumption in South Africa, with their 2014 estimates showing that the sector consumes 23% of total energy consumption in the country. They conclude that, despite the provision of 50kWh of free electricity per month to poorer households connected to the national grid aimed at alleviating energy poverty, many lower income households still make use of other energy sources (up to 70%), such as wood and paraffin, to meet their basic energy requirements.

2.3. The Significance of Energy to Economic Growth and Households

Numerous studies have explored the impact of energy and electricity provision on economic growth (Shahbaz *et al*., 2013; Adams *et al*., 2016; Bonan *et al*., 2017). Access to electricity is essential for achieving sustained economic growth, advancement of employment opportunities, health, educational outcomes, the overall quality of public services, improved living standards, and an enhanced quality of life (World Bank, 2017, 2018; Moreno-Dobson, 2006; Brenneman and Michel, 2002). Consensus among scholars and analysts is that access to electricity is fundamental in meeting societal needs, promoting economic growth, and facilitating human development. Energy is strongly linked with all SDGs, encompassing health, food security, poverty alleviation, and climate change (World Bank, 2017; Banerjee *et al*., 2021). Savacool (2014) asserts that deprivation of energy access often leads to morbidity, political instability and even environmental degradation. Dinkelman (2011) and Bensch *et al*., (2020) studied the effect of rural electrification on employment in South Africa and concluded that electricity access increased hours of work for both male and female, reduced female wages and raised male earnings.

The electrification of underserved communities has yielded various additional benefits, including evening adult education in schools and the enhancement of educational facilities using equipment like photocopiers and computers. Increased rural electrification is closely tied to higher literacy rates among the youth due to improvements in both school and home-based learning environments (Trotter 2016; Banerjee *et al*., 2021). Access to electricity promotes education and gender equality, while reducing production and transaction costs through better access to transportation networks. Additionally, the presence of electric street lighting has been correlated with reduced crime rates (Sardokie and Adams, 2020). Furthermore, the advantages of electricity access are closely associated with increased productivity and opportunities, which, in turn, reduce transaction costs, ultimately fostering economic development (Calderon and Serven, 2004; Zhang Fan and Zhan, 2002; Rao and Pachauri, 2017).

In rural communities, access to electricity can lead to additional income-generating activities, both in agriculture and other sectors. A study conducted by Kooijman-van Dijk and Clancy (2010) revealed that 25% of households with access to electricity ran home-based businesses, as opposed to 15% of households without electricity. However, it is crucial to acknowledge that when examining the relationship between electricity access and income inequality, the context and the level of development must be considered. This is imperative because access to energy does not guarantee automatic growth and development. The overall context and environment must be conducive to growth and development (Kanagawa and Nakata, 2008; Khandker *et al*., 2013).

Sardokie and Adams (2020) explored the interplay between electricity access, the control of corruption, and income inequality in South Africa. The study identified a positive correlation between rising income levels and increased access to electricity. Furthermore, the study demonstrated that income inequality positively affects access to electricity, suggesting that income distribution disparities do not hinder electricity access in South Africa. Conversely, there was a negative relationship between access to electricity and corruption, signalling a deficiency in good governance and institutional quality. While economic growth is crucial for realizing universal electricity access, the study underscores the critical importance of good governance and institutional quality in ensuring the availability, accessibility, and affordability of energy security.

Conversely, the lack of adequate of energy can be detrimental to national economic development, for example, through increased running costs as well as reduced productivity and profitability. Insufficient energy can also lead to political instability, disruption in the quality of life, damage to the environment, and declining livelihoods (Greenpeace, 2003). The lack of access to guaranteed power has been identified by the South African government as one of the key barriers to economic growth (Pollet *et al*., 2015). Andresen *et al*., (2013) estimated the total effect of power outages on economic growth in SSA over the period 1995–2007. They conclude that the lack of reliable energy infrastructure contributes to approximately 2-percentage point loss of Gross Domestic Product (GDP). In the continuing energy outages in South Africa, the South African Property Owners Association (SAPOA, 2023) has noted that firms are compelled to invest in either diesel generators, solar, or both making such firms to incur huge operational costs and unable to operate optimally.

2.4. Government Policy towards Renewable Energy Mix in South Africa

Among Africa's largest economies, namely Nigeria, South Africa, and Egypt, South Africa has developed the most comprehensive renewable energy plan (Akinbami *et al*., 2021). To transition towards renewable energy sources, South Africa introduced a white paper in 2003, outlining a plan to generate 10 TWh of electricity from sources such as biomass, wind, solar, and small-scale hydro. Subsequently, in May 2011, an integrated resource plan was enacted, setting a new goal of adding 17,800 MW of renewable energy to the energy mix by 2030 (Akinbami *et al*., 2021). The establishment of the Renewable Energy Independent Power Producer's Programme (REIPPP) in 2011 marked an ambitious initiative for promoting renewable energy generation in South Africa, focusing on three core objectives namely; reducing CO2 emissions, enhancing generating capacity, and fostering economic development. The REIPPP program has successfully diversified energy generation by involving over 60 power producers, leading to a steady increase in South Africa's renewable energy capacity. Still the country relies more on coal (about 80%), while the renewable energy mix provides the balance (CSIR, 2023). South Africa is also home to Africa's only nuclear power plant.

The development of renewable energy sources in South Africa holds the potential to significantly reduce the heavy reliance on coal, which is both finite and environmentally unfriendly. Furthermore, the growth of the renewable energy sector in the country can create new job opportunities, thereby bolstering the South African economy. Due to its geographical location and population, South Africa has the potential to adopt various renewable energy sources, including biomass, wind, and solar energy. While biomass energy constitutes a notable portion of Africa's energy use, it is primarily employed for non-commercial purposes, such as cooking and heating through the burning of wood, tree branches, charcoal, and animal waste (Maji *et al*., 2019). The South African Renewable Energy Data and Information Service documented that more than 100 GWh of energy was produced from biomass in 2016, although no data have been recorded since then (as reported in Akinbami *et al*., 2021). Integrating biofuels into South Africa's energy sector offers an opportunity to diversify the fuel sources for electricity generation and reduce the nation's reliance on imported crude oil for transportation. Corncobs (agricultural remains from corn) are a potential substitute for coal or co-firing in coal plants for power generation. While most corncobs have been utilized for cooking and heating in rural areas, industrial use of this agricultural waste for energy generation in South Africa remains underutilized. Various policies, such as the Biofuel Industrial Strategy (BIS), have been adopted in South Africa to promote the use of biofuels and create jobs in rural areas.

The delay in implementing the BIS because of government inaction and the setting up a modest 2% target for biofuel integration into the energy mix are among the difficulties facing the development of South Africa's biofuel industry (as cited Akinbami *et al*., 2021). Moreover, the absence of committees or task forces to monitor and drive the industry towards these goals, as well as the lack of subsidies and governmental support, hinders the growth of this renewable energy resource.

Balmer (2007) asserts that even though the South African energy policy is progressive and even encompasses the Millennium Development Goals (MDG's), the government is still marginally pursuing the implementation of pro-poor energy policies and that there are insufficient resources allocated to redress energy poverty in South Africa. For example, he argues that policies designed to address access to electricity, such as subsidies, tend to be ineffective because households without electricity tends to be typically located in rural areas therefore miss on the benefits of such policies. Thom (2000) points out that the South African electrification program has been executed as a blanket program and failed to account for the fact that some traditional households are still not able to afford to purchase electricity beyond the quota allotted. Therefore, many rural and traditional households still depend on other sources of energy to meet their basic energy needs. Moreover, there is insufficient policy implementation to address energy poverty in the non-grid consumers. Bohlmann *et al*., (2018) argue that a firm grasp of energy sector consumption patterns is vital in forecasting the challenges and opportunities on the future design and implementation of energy policy.

2.5. Socio-Economic Factors Affecting Residential Energy Choices in South Africa

South African households depend on multiple energy sources to meet their daily energy needs. Broadly with a high access to electricity in the country, the type of energy dependent upon tends to differ depending on whether the household has electricity connection or not. Available evidence shows that households with electricity connection rely on electricity for lighting, cooking and heating; however, other sources such as candles, firewood, paraffin and gas are also used (see Bohlmann *et al*., 2018). In the absence of electricity connection, households rely primarily on candles, firewood, and paraffin, with a small share of households reporting the use of coal or gas (Barnes and Toman, 2006; Bohlmann *et al*., 2018). In the choice of which energy type to use, several factors, including income, household size, location, energy prices and energy access are responsible (Bohmann *et al*., 2018; Sarkodie and Adams, 2020).

Income is a critical determinant of what energy type a household choose for cooking, lighting, and heating. Sugrue (2005) and Lloyd (2014) approximate that, on average, a poor household in South Africa spends around 20-25% of its income on energy compared to 2% for the most affluent households. Sustainable Energy Agency (SEA, 2003) found similar findings in Cape Town, where households spent between 10-25% of their income on energy consumption, while affluent households spent between 3-5%. Davis (1998) examined the energy utility patterns in rural areas in South Africa, with a focus on identifying the influence of the access to electricity on fuel choices used for everyday activities such as cooking, heating and lighting. He concluded that there is an energy ladder in South African households, where households in rural areas tend to transition away from low quality energy source (biomass and woods) towards gas and electricity as their income rises. Thom (2000) on the other hand explored the impact that access to electricity has on the choice of electrical appliances ownership in rural households in South Africa. Additionally, Thom (2000) point out that households in rural areas tend to utilize a combination of energy sources, such as candles and paraffin, to meet their basic energy needs. Madubansi and Shackleton (2006) corroborate Thom's (2000) findings and assert that despite the accepted consensus that there is sufficient electrification in South Africa, many households still depend on some energy mix for lighting, cooking and heating. Electricity is viewed as a complement and not a substitute in the energy use matrix.

In terms of paraffin use as source of energy for cooking, Annecke (1992) posits that women view paraffin as a feminine fuel since it tends to encourage trends and relationships among them in the community. Moreover, Balmer (2007) asserts that the procurement and management of energy sources for cooking falls mainly to women in the past. While, Ross (1993) argues that consumption choices of a household are closely linked with the type of energy source available. Mehlwana and Qase (1999) suggest that energy choice depends on its efficacy in performing specific tasks depending on the time of the year. Additionally, Bohlmann *et al*., (2018) point out that energy utility across South African households have increased over time due to change in consumer preferences and growth in accessibility of electricity. Notably, having access to electricity in rural households does not substitute the use of traditional energy sources such as wood and paraffin but rather adds to the energy mix. The low cost of paraffin has been the main reason why low-income households have continued to use it for cooking and heating even after electrification (Bohlmann *et al*., (2018).

Westley (1984) and Ayesha (2016) used household size to model household consumption in Paraguay and Pakistan and found that household size had a positive and significant effect on electricity consumption. With a national average household size of 3.5 and the same ranging from 2.6 to 5.7 across districts (StatsSA, 2022), household size has a role to play in the choice of what energy type to use for cooking or lighting. When comparative costs are factored in, it is not surprising that there are evident higher levels of energy poverty and over reliance on poor energy sources, such as wood and paraffin, among many low-income households (Marquard, 2006; Awaworyi, Churchill and Smyth, 2021).

In terms of geography, the domestic use of gas tends to have a greater presence on rural farms and in formal rural areas, especially among higher income electrified households. Mensah and Adu's (2015) study on household energy choice in Ghana identified factors such price, income, education, household size and geographical attributes, such as urban and rural, to have a significant influence on household decision on energy consumption.

3. Study Area, Data, and Methods

3.1. Study Area and Data

Figure 1 shows the 52 district municipalities across the nine provinces in South Africa. According to the RSA (1998), district municipalities are category C in the local government structure in South Africa. The others are category A (metropolitan municipalities) and category B (local municipalities). District municipalities are made up of a given number of local municipalities that fall in one district. In case of metropolitan municipalities, they are all categorized as district municipalities. In non-metropolitan areas, district municipalities together with local municipalities serve to provide infrastructure, deliver services and grow the local economy. In metropolitan areas, metropolitan municipalities are responsible for all local services, development and delivery in the metropolitan area (ETU, 2023).

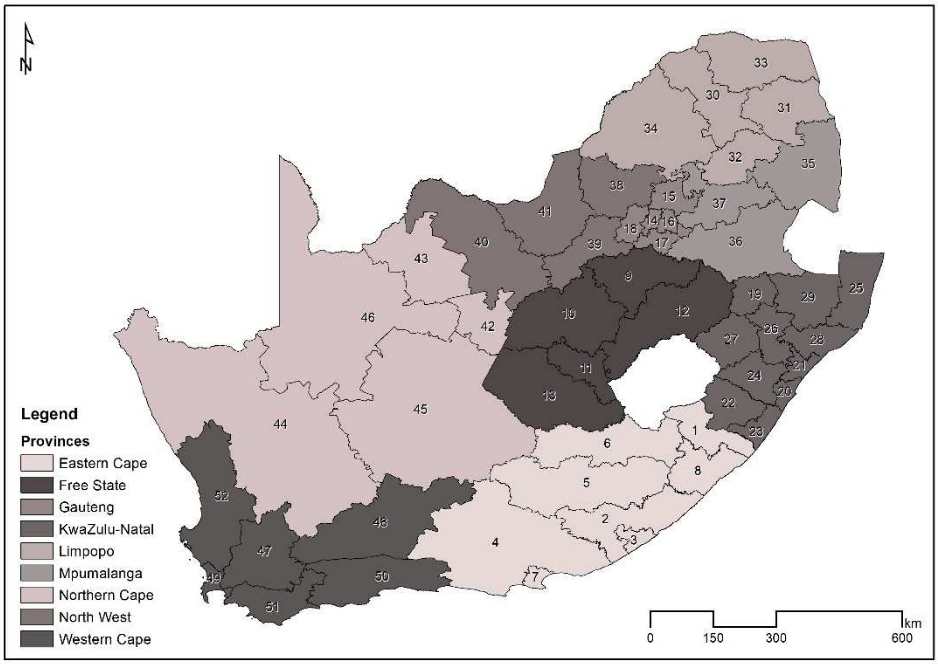

Figure 1. District Municipalities across provinces in South Africa. Data Source: Municipal Demarcation Board (MDB). Notes: District Municipalities: 1. Alfred Nzo 2. Amathole 3. Buffalo City 3. Chris Hani 4. Joe Gqabi 6. Nelson Mandela Bay 7. O.R. Tambo 8. Sarah Baartman 9. Fezile Dabi 10. Lejweleputswa 11. Mangaung 12. Thabo Mofutsanyane 13. Xhariep 14. City of Johannesburg 15. City of Tshwane 16. Ekurhuleni 17. Sedibeng 18. West Rand 19. Amajuba 20. eThekwini 21. Harry Gwala 22. iLembe 23. King Cetshwayo 24. Ugu 25. uMgungundlovu 26. uMkhanyakude 27. uMzinyathi 28.

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uThukela 29. Zululand 30. Capricorn 31. Mopani 32. Sekhukhune 33. Vhembe 34. Waterberg 35. Ehlanzeni 36. Gert Sibande 37. Nkangala 38. Bojanala 39. Dr Kenneth Kaunda 40. Dr Ruth Segomotsi Mompati 41. Ngaka Modiri Molema 42. Frances Baard 43. John Taolo Gaetsewe 44. Namakwa 45. Pixley ka Seme 46. Z.F. Mgcawu 47. Cape Winelands 48. Central Karoo 49. City of Cape Town 50. Garden Route 51. Overberg 52. West Coast.

Our dependent variables were broadly measuring energy for cooking and energy for lighting. Dependent variables capturing energy for cooking were four – percentage of households cooking with electricity, cooking with gas, cooking with paraffin, and cooking with wood. Dependent variables capturing energy for lighting were three – percentage lighting with electricity, percentage lighting with candles, and percentage lighting with solar. Several predictor variables (drivers) were hypothesized as explaining the patterns and the levels of households' choices regarding energy type for cooking and lighting. The choice of variables was largely determined by a review of existing literature and empirical work (see section 2 of this paper) and data availability in Statistics South Africa (StatsSA, 2022) census database. While it is straight forward what the other explanatory variables measure, the dependency ratio was used as a proxy for household income that was not possible to find in the StatsSA (2022) initial data release. The level of household education was used to complement the dependency ratio in proxying household income, since the level of education is highly correlated to the levels of household income (Banerjee et al., 2021). Table 1 shows the univariate statistics of the model variables used in the study.

Table 1. Univariate statistics of model variables.

Variables	N	Mean	Std. Dev.	Min	Max
Dependent variables					
Cooking with electricity (%)	52	66.629	9.156	34.8	81.5
Cooking with gas (%)	52	23.065	6.654	13.8	45
Cooking with paraffin (%)	52	2.108	1.572	0	7.1
Cooking with wood (%)	52	7.513	10.218	0	50.6
Electricity for lighting (%)	52	94.562	2.027	90.1	98.5
Candles for lighting (%)	52	3.242	1.592	.7	8.1
Solar for lighting (%)	52	.833	.909	0	5
Explanatory variables					
Formal dwelling (%)	52	87.871	6.23	66.2	98.8
Informal dwelling (%)	52	6.9	5.227	.6	26.4
Traditional dwelling (%)	52	4.854	7.104	0	30.4
Level of higher education (%)	52	9.775	3.713	5.1	22.2
Household size	52	3.815	.703	2.6	5.7
Dependency ratio	52	53.49	9.357	36.8	73.7

3.2. Methods

This paper employed spatial and regression analyses using choropleth mapping and ordinary least squares (OLS) regression models, respectively. An OLS model shown below was used to estimate the predictors of energy type choices for cooking and lighting for formal, informal, and traditional dwellers.

$$\text{Energy type}^{a} = \beta_0 + \beta_1\text{dwellingtype}^{b} + \beta_2\text{Educationlevel} + \beta_3\text{Householdsize} + \beta_4\text{Dependencyratio} + \varepsilon \quad [1]$$

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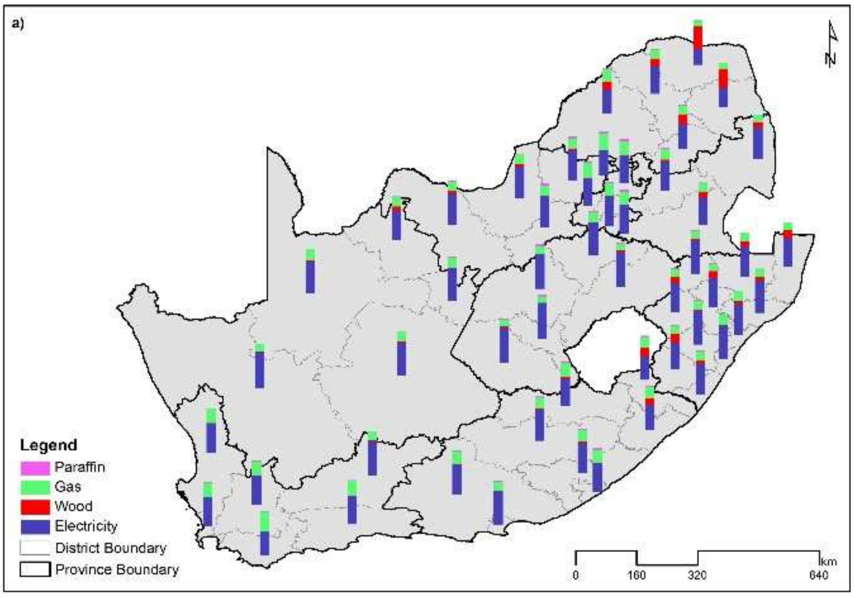
where: ε is the error term, $\beta_0 - \beta_4$ are estimated regression coefficients of the various predictor variables as described in Table 1. Energy type[a] indicates that six models were estimated for each of the dependent variables, while dwelling type[b] indicates the three different dwelling types that were used in OLS regressions in turn.

4. Findings and Related Discussions

4.1. Descriptives Analysis

Figure 2a shows the four types of energy used for cooking – paraffin, gas, wood and electricity. Figure 2b shows the three types of energy used for lighting – candles, solar and electricity. It is clear from Figure 2a that electricity is the main source of energy for cooking across South Africa. The exception is Limpopo where wood is the predominantly used energy type in Vhembe district, followed by Mopani where wood is almost as high as electricity. Wood is also significantly used in Mpumalanga, KwaZulu-Natal and the northern districts of Eastern Cape. The use of wood as an energy type is extremely small in Gauteng and Western Cape. Paraffin is seen, although very minimally, in Gauteng, Free State and North West provinces. Gas is in district municipalities in South Africa, although lower than electricity. Electricity is the main energy source for lighting in South Africa (see Figure 2b). Candles are the second most used energy source for lighting, given loadshedding. Surprisingly, solar energy is the least used for lighting.



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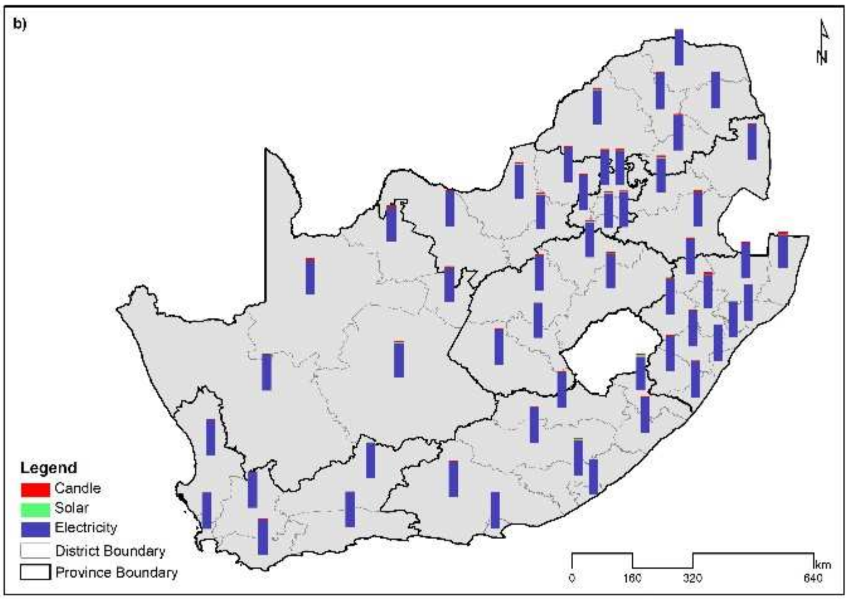


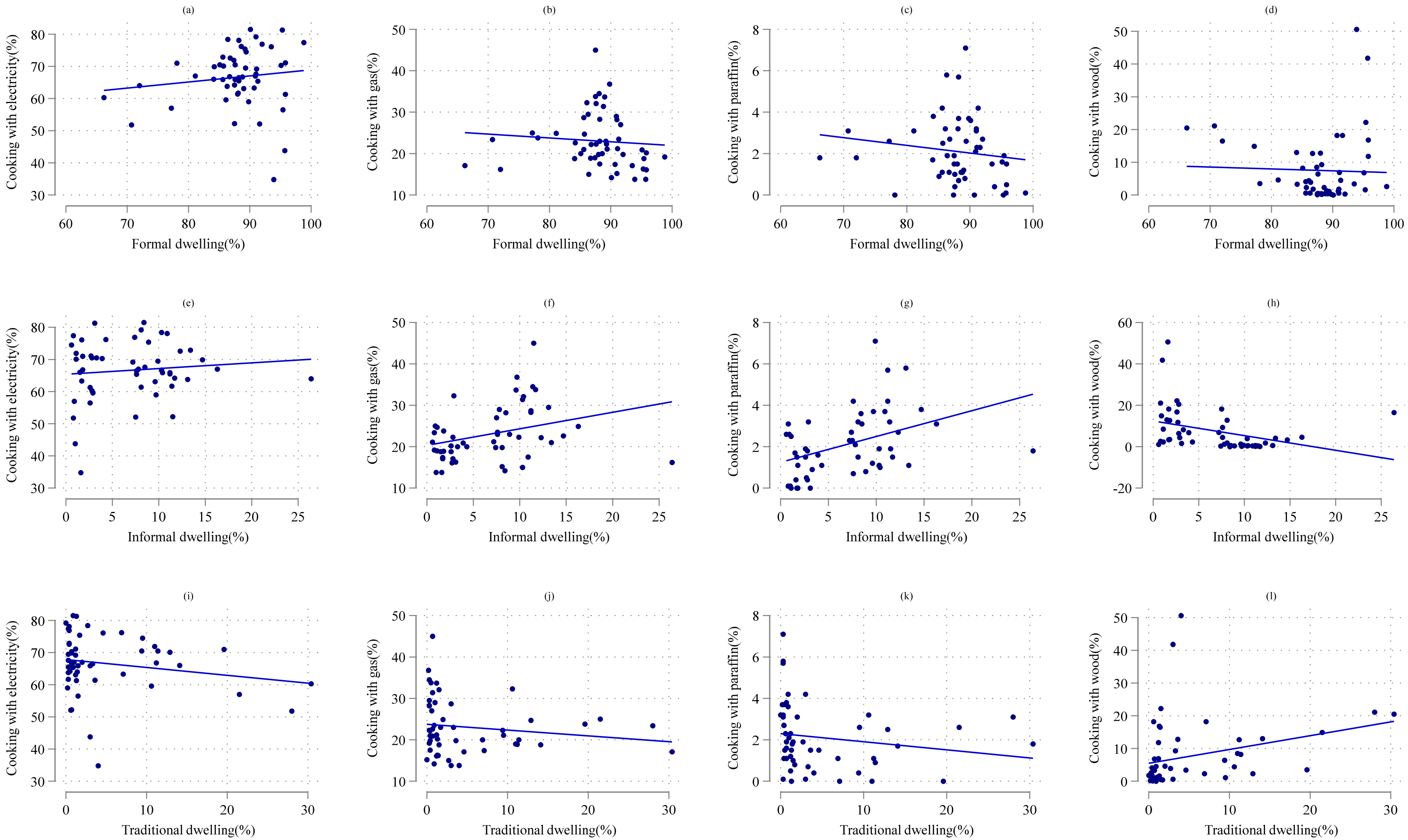
Figure 2. Proportion (%) of energy for cooking (2a) and energy for lighting (2b). Data Source: StatsSA (2022).

4.2. Scatter Plots

Several scatter plots were constructed to show the linear association between variables used in the paper. Figure 3 shows the spread of the observations, the slope of the relationships in each of the scatterplots, and the extent to which this points to a significant bivariate relationship. The scatter plots in the first row of Figure 3 show the bivariate relationships between the *percentage of formal dwellers* and percentage who cook with electricity (3a), percentage who cook with gas (3b), percentage who cook with paraffin (3c), and percentage who cook with wood (3d), respectively. The slope in Figure 3(a) shows a positive relationship, while Figures 3(b) and 3(c) show negative relationships – with the slope of the latter steeper. The slope for Figure 3(d), while negative, is close to zero (almost horizontal). None of these relationships are statistically significant ($p<0.05$).

The scatter plots in the second row of Figure 3 show the bivariate relationships between the *percentage of informal dwellers* and percentage who cook with electricity (3e), percentage who cook with gas (3f), percentage who cook with paraffin (3g), and percentage who cook with wood (3h), respectively. The slopes in Figures 3(e)-3(g) show positive relationships, while Figures 3(h) show negative relationships. The relationships in Figures 3(f)- 3(h) are statistically significant ($p<0.05$).

The set of scatterplots in the last row in Figure 3, show the bivariate relationships between the *percentage of traditional dwellers* and percentage who cook with electricity (3i), percentage who cook with gas (3j), percentage who cook with paraffin (3k), and percentage who cook with wood (3l), respectively. The slopes in Figures 3(i)-3(k) show negative relationships, albeit at different magnitudes. The slope in Figure 3(h) show positive relationship. Only the relationship in Figures 3(l) is statistically significant ($p<0.05$).



Source:StatsSA (2022): Author's own compilation

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Figure 3. Scatterplots plots.

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4.3. Empirical Results

4.3.1. Energy Use for Cooking

This section focuses on results where we regressed the four dependent variables – percentage who cook with electricity, percentage who cook with gas, percentage who cook with paraffin, and percentage who cook with wood – on the predictor variables in Table 1 in turn. The results are presented in Tables 2, 3, and 4, respectively, for each of the dependent variables. All the results are robust since we estimate them under robust standard errors.

Table 2 shows estimation results for formal dwelling across the different energy types as shown in the respective models. For the electricity model, all the explanatory variables, except formal dwelling, are statistically significant. The coefficients for formal dwelling in the gas and the paraffin models are negative (p<0.05 in both cases), implying that the more formal dwellings there are, there is less use of gas and paraffin for cooking. This is an interesting finding since, while paraffin may be considered an inferior and unsustainable energy source, thus less of formal dwellers using it, it would be expected that the use of gas as a source of energy for cooking should increase in tandem with the increase in formal dwelling. Sarkodie and Adams (2020) and Kahouli (2020) suggest that poverty hinders accessibility and affordability to electricity and modern energy services.

The results for the highest level of education which proxy for skill and experience of workforce are mixed. The negative (p<0.05) coefficient for the level of highest of education in the electricity model is in contrast with its counterpart in the gas model, where it is positive (p<0.05). These results imply that as the level of higher education increases, the use of electricity and gas for cooking decrease and increase, respectively. This pattern of electricity and gas use could be explained by the fact that the more educated households are, they are also likely to have more employed members, have more income, are likely economically stable, and are more aware of the comparative long-term cheaper gas costs than electricity for cooking, hence they opt to use gas and less of electricity for cooking. Bekun et al. (2019) found evidence of a positive influence on energy consumption in South Africa. Sarkodie and Adom (2018) found a positive impact of economic development on energy consumption in Kenya and Ghana. Mensah and Adu (2015) also found income to have a positive and significant influence on energy choice in Ghana.

Similarly, the results for the dependency ratio are mixed. Results show that the higher the dependency ratio, there is less use of electricity for cooking and more use of wood for cooking in the electricity and wood model, respectively. These results could be explained by the fact that a higher dependency ratio may imply less disposal income, meaning wood as a cheaper energy source for cooking is preferred to electricity and gas that are relatively expensive.

The results further show that as household size increases, there is more use of electricity and less of gas and paraffin for cooking. These results could be explained by the history of non-paying of electricity in the country, which sometimes manifests itself in terms of illegal connections, especially in the informal dwelling. This could mean that electricity is a preferred energy source for cooking for larger households compared to gas and paraffin that for the most part are well regulated and households are required to pay for them.

Table 2. Estimation results of energy for cooking in formal dwellings.

Variables	Electricity model	Gas model	Paraffin model	Wood model
Formal dwelling	0.119	-0.342***	-0.083***	0.313
	(0.188)	(0.108)	(0.025)	(0.250)
Highest level of education	-0.952***	0.454**	0.077	0.508
	(0.330)	(0.199)	(0.081)	(0.369)
Household size	5.431***	-4.722***	-1.288***	0.490
	(1.992)	(1.503)	(0.267)	(1.731)

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Dependency ratio	-0.787***	-0.072	0.020	0.868***
	(0.216)	(0.090)	(0.027)	(0.273)
Constant	86.885***	70.501***	12.528***	-73.247**
	(27.360)	(14.596)	(4.063)	(34.122)
Observations	52	52	52	52
R^2	0.332	0.493	0.357	0.457
Adj. R^2	0.275	0.450	0.303	0.411

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

Table 3 shows estimation results for informal dwelling across the different energy types as shown in the respective models. In Table 3, only the coefficient for informal dwelling is positive (p<0.05) in the paraffin model, implying that more informal dwellers use paraffin for cooking. These results could be explained by the easy access and affordable cost of paraffin, compared to electricity and gas. While wood would be another affordable option, the dense housing patterns in informal settlements, may be triggering the need for caution related to the possibility of fire outbreaks. Moreover, wood is a solid biomass-based fuel source which is discouraged in SDG 7 (Pachauri and Rao, 2017; Banerjee *et al*., 2021).

The results for the rest of the other drivers are similar to the respective results in Table 2. For the level of higher education, the results still imply that as the level of higher education increases, the use of electricity and gas for cooking decrease and increase, respectively, in informal dwelling. Similar to informal dwelling results (see Table 2), the results for the dependency ratio in the informal dwelling models show that the higher the dependency ratio, there is less use of electricity for cooking and more use of wood for cooking in the electricity and wood model, respectively. The results further show that as household size increases, there is more use of electricity and less of gas and paraffin for cooking. Similar suggestions as speculated under energy type for cooking in formal dwellings could explain results related to energy types for cooking in informal dwellings. Mensah and Adu (2015) found similar results for Ghana households in term of household size and education level for different energy types.

Table 3. Estimation results of energy for cooking in informal dwellings.

Variables	**Electricity model**	**Gas model**	**Paraffin model**	**Wood model**
Informal dwelling	0.132	0.110	0.087***	-0.340
	(0.191)	(0.097)	(0.031)	(0.245)
Highest level of education	-0.991***	0.514**	0.085	0.478
	(0.327)	(0.225)	(0.078)	(0.342)
Household size	5.362**	-3.781***	-0.967***	-0.734
	(2.003)	(1.403)	(0.262)	(2.244)
Dependent ratio	-0.791***	-0.009	0.041	0.787***
	(0.188)	(0.114)	(0.027)	(0.242)
Constant	97.259***	32.217***	2.160	-34.096***
	(10.359)	(6.992)	(2.220)	(10.340)
Observations	52	52	52	52
R^2	0.331	0.411	0.335	0.451

Adj. R^2	0.274	0.361	0.278	0.405

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

Except for the coefficient of traditional dwellings, the rest of estimation results for the various drivers of energy type use in traditional dwelling (see Table 4) are similar to the results in Tables 2 and 3 that focused on formal and informal dwelling, respectively. The traditional dwelling coefficient, on the coefficients for gas in the gas model is positive and significant (p<0.05), implying that more traditional dwellers use more gas, and vice versa.

Table 4. Estimation results of energy for cooking in traditional dwellings.

Variables	Electricity model	Gas model	Paraffin model	Wood model
Traditional dwelling	-0.222	0.279***	0.023	-0.080
	(0.134)	(0.102)	(0.028)	(0.168)
Highest level of education	-0.951***	0.492**	0.091	0.453
	(0.308)	(0.201)	(0.085)	(0.349)
Household size	6.011***	-5.017***	-1.186***	0.087
	(2.116)	(1.533)	(0.274)	(1.879)
Dependent ratio	-0.749***	-0.090	0.027	0.841***
	(0.210)	(0.103)	(0.032)	(0.286)
Constant	94.154***	40.856***	4.211	-41.856***
	(12.135)	(7.522)	(2.551)	(13.799)
Observations	52	52	52	52
R^2	0.345	0.462	0.270	0.428
Adj. R^2	0.290	0.416	0.208	0.379

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

4.3.2. Energy use for lighting

This section focuses on the results where we regressed the three dependent variables – percentage who use electricity for lighting, percentage who use candles for lighting, and percentage who use solar for lighting – on the predictor variables in Table 1 in turn. The results are presented in Tables 5, 6, and 7, respectively, for each of the dependent variables. All the results are robust since we estimate them under robust standard errors.

Table 5 shows estimation results for formal dwelling across the different energy types as shown in the respective models. The estimated models are weakly fitted, with the adjusted R^2 ranging from about 10% to 15%. None of the drivers are statistically significant in the candles model. For the electricity model, formal dwelling is the only statistically significant driver of energy use for lighting. Being positive implies that the percentage of formal dwellers increase, the use of electricity for lighting also increases, and vice versa. This is expected since formal dwellers have almost universal access to electricity infrastructure in the country. In the solar model, only household size is the only statistically significant driver of energy use for lighting. Being a negative coefficient, it implies that as household size increases the use of solar for lighting decreases. Several reasons could explain this result. First, the high cost related to the installation of solar infrastructure that in some ways hinders households with more members to invest in solar infrastructure. Exploratory results from the data show that households with more members are also likely to have higher dependency ratios, lower

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household incomes, and coupled with higher energy requirements, all these household characteristics work to hinder such households to invest in solar infrastructures.

Table 5. Estimation results of energy use for lighting in formal dwellings.

Variables	Electricity model	Candles model	Solar model
Formal dwelling	0.120**	-0.052	-0.047
	(0.053)	(0.036)	(0.029)
Highest level of education	0.154	-0.151	-0.034
	(0.114)	(0.097)	(0.034)
Household size	0.596	0.101	-0.555**
	(0.675)	(0.556)	(0.243)
Dependency ratio	-0.004	-0.012	0.030
	(0.040)	(0.030)	(0.023)
Constant	80.396***	9.524**	5.767**
	(5.864)	(4.299)	(2.495)
Observations	52	52	52
R^2	0.188	0.168	0.220
Adj. R^2	0.119	0.097	0.154

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

Table 6 presents results focusing on informal dwellings as the key variable of interest. The three estimated models have low adjusted R^2. The electricity model has informal dwelling with a negative and statistically significant coefficient, implying that as the percentage of informal dwellers increase, their use of electricity for lighting decreases. This is expected since informal dwelling settlements have low to no access to electricity. In fact, the only access to electricity, in some instances, is through illegal connections. The positive and statistically significant coefficient for informal dwelling in the candles model is expected as well. It is in informal dwellings that inhabitants face low to no access to electricity, leaving candles as an easily accessible and cheap alternative to energy source for lighting. The coefficient for the percentage of informal dwelling in the solar model is similar to Table 5 (where the variable of interest was formal dwelling). The same explanations provided in the previous section apply here as well.

Table 6. Estimation results of energy use for lighting in informal dwellings.

Variables	Electricity model	Candles model	Solar model
Informal dwelling	-0.150***	0.103***	0.045
	(0.041)	(0.032)	(0.039)
Highest level of education	0.145	-0.151	-0.029
	(0.123)	(0.096)	(0.040)
Household size	0.095	0.374	-0.381**
	(0.554)	(0.468)	(0.186)
Dependency ratio	-0.037	0.006	0.042
	(0.051)	(0.035)	(0.030)
Constant	95.796***	2.264	0.012
	(3.457)	(2.473)	(1.704)

Observations	52	52	52
R^2	0.196	0.229	0.188
Adj. R^2	0.127	0.163	0.119

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

Table 7 presents results where the variable of interest is traditional dwelling. All the models have very low adjusted R^2. It is only the solar model that has household size as the only driver of solar use for lighting. Like results in Tables 5 and 6, the same possible explanations provided in the previous sections apply here as well.

Table 7. Estimation results of energy for lighting in traditional dwellings.

Variables	Electricity model	Candles model	Solar model
Traditional dwelling	-0.015	-0.021	0.015
	(0.057)	(0.032)	(0.032)
Highest level of education	0.131	-0.138	-0.027
	(0.130)	(0.104)	(0.037)
Household size	0.381	0.298	-0.508**
	(0.683)	(0.551)	(0.218)
Dependency ratio	-0.018	0.001	0.034
	(0.049)	(0.035)	(0.028)
Constant	92.858***	3.519	1.156
	(3.576)	(2.811)	(1.088)
Observations	52	52	52
R^2	0.071	0.138	0.140
Adj. R^2	-0.008	0.065	0.067

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

5. Conclusions

This study provides a comprehensive exploration of the patterns and drivers of energy consumption in South African households, and highlights the challenges faced by both rural and urban communities in accessing clean and affordable energy. Despite South Africa's vast potential for renewable energy, the persisting reliance on coal, especially in the context of rural communities, underscores the pressing need for sustainable energy development.

The results of this study have significant support for the energy ladder and fuel stacking hypotheses. The varied coefficients for dwelling types across all energy sources suggest that different households adopt a variety of energy strategies based on their socio-economic and living conditions. This informed understanding of energy patterns contributes to the ongoing discussion on energy transition and calls for customized interventions that consider the context and specific needs of diverse communities.

The similarity in results for all drivers across different dwelling types highlights the pervasive nature of certain factors influencing energy choices. Education levels, household size, and dependency ratios consistently emerge as key determinants, emphasizing the need for holistic policies that address these common drivers to promote sustainable energy practices.

Importantly, this study prompts considerations for future sustainable energy development in South Africa. The findings shed light on the need for and importance of policies that not only prioritize renewable sources but also address the socio-economic factors and living conditions that influence energy choices. Informed by the results, it becomes imperative for policymakers to develop strategies that bridge the gap between the potential for renewable energy and the current reliance on coal, particularly in the context of varying dwelling types.

As a potential mechanism to enhance public welfare, this study suggests that the government could play a pivotal role in reducing fuel poverty by making energy more affordable. Such a measure has the potential to minimize public expenditure on healthcare, enhance education outcomes, and contribute to poverty reduction. By aligning energy policies with broader socio-economic objectives, South Africa can make significant strides toward a more sustainable and equitable future, and ultimately, enhancing public welfare of its citizens.

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