ARPA

Asian Review of Public Administration (ARPA)
Volume 34 Issue 2, 117-141
E-ISSN: 3082-5652 P-ISSN: 2094-408X
https://journal.eropa-arpa.co

Spatial Inequality In Clean Cooking Energy Usage In Southern Nigeria Regions

Adewara Sunday Olabisi

Department of Economics, Faculty of Social Sciences Redeemer's University, Ede, Nigeria &
Department of Business Management and Economics, Walter Sisulu University, South Africa
ORCID NO: 0000-0002-7704-5050
Email: adewaras@run.edu.ng; sadewara@wsu.ac.za

ARTICLE INFO:

Received: 10-04-2026
Revised: 01-06-2026
Accepted: 11-06-2026

Keywords:
Energy, Inequality, Region, Cooking, Clean

DOI: https://doi.org/10.64423/arpa.v34i2.89

ABSTRACT

Clean cooking energy is healthier than unclean cooking energy, yet its adoption, especially at sub-national levels, remains less researched. This paper examined spatial inequality in the use of clean cooking energy across three regions in southern Nigeria using the 2024 National Demographic Health Survey. A combination of concentration indices and curves, along with Blinder-Oaxaca decomposition, was used to quantify inequality in the use of clean cooking energy across rural and urban areas and among the three regions of southern Nigeria. The results showed that the use of clean cooking energy is highest in the southwest and lowest in the southeastern region. While about 56% of households in the southwest are predicted to use clean cooking energy, only 36% are predicted to do so in the southeast. Urban households in southern Nigeria have a higher predicted probability of using clean cooking energy than their rural counterparts.

The concentration index of 0.1193 for the southwest region indicates that households in the region are better off than those in the southeast and south-south regions. While the clean cooking energy use concentration index was 0.0133 in the south-south, it was -0.1326 in the southeast. Blinder-Oaxaca decomposition confirmed the concentration indices result for each region. The study suggests that region-specific policies to improve clean cooking energy use should be implemented instead of the usual general approach.

Introduction

In Nigeria, the availability of clean cooking energy is limited, as over 70% of the population relies on traditional biomass fuels, that is, firewood, charcoal, and agricultural waste (IEA, 2020). This has resulted in significant health, environmental, and economic consequences, including respiratory diseases, deforestation, and the release of greenhouse gases (WHO, 2022; IPCC, 2023). Nevertheless, advancements in technology and increased environmental awareness have led to a shift towards cleaner, more efficient cooking energy sources (Smith, 2022; Mallett, A., 2022; Mensah, J. T., Karimu, A., & Adu, G., 2021).

Access to clean cooking energy is crucial to achieving many of the Sustainable Development Goals (SDGs) in Nigeria (Ravita et al., 2025; Clany et al., 2019; Anozie, A. N., Bakare, A. R., & Ojo, K. T., 2021). Although awareness and advocacy on the use of clean energy for cooking are on the increase, persistent inequalities in access to and effective use of clean energy for cooking exist and cut across several groups including the poor and vulnerable households, the resource constrained women and girls living in the rural areas (UNDP, 2021; Ang, B. W., 2019, 2024). Identifying and analyzing the inequalities that exist and understanding the reasons for these inequalities are crucial for the design and effective implementation of targeted interventions to address them (Elianya, 2024; Lewis, J. J., & Pattanayak, S. K., 2021). Access to

clean cooking energy is a basic right that is not currently being fulfilled for many Nigerians who continue to rely on traditional biomass for their cooking needs (WHO 2022; World Bank. 2022; Lambe, F., Rehfuess, E., & Reinders, A. 2020; Jann, B. 2022). Several studies have shown that a number of factors including a combination of which include a person's wealth, education and location influence access to clean energy for cooking (Kline, 2022; Lambe, F., Rehfuess, E., & Reinders, A., 2020). Research using Decomposition analysis has increasingly focused on explaining inequalities in health and energy outcomes (Kowsari et al., 2021; van der Kroon et al., 2019). However, the application of such analysis to examine inequalities in access to and effective use of clean energy for cooking is rare especially in the case of Nigeria where such analysis is needed.

The health and environmental consequences of using traditional biomass fuels for cooking in Nigeria cannot be over emphasized. As a country with a large endowment of oil and gas with over 200 million people, more than two-thirds of Nigerians depend on traditional energy for cooking. Using polluting energy for cooking hampers development goals and causes health impacts. It leads to household air pollution (HAP) that causes over 120,000 premature deaths annually in the country (Chamber et al. 2024; Energy Poverty 2024). This form of pollution can be reduced by adopting clean cooking energy. Such energy brings health benefits like better health (respiratory health in particular), saves time for the women and children to engage in other activities and reduces negative environmental impact such as deforestation. Among the various clean energy options for cooking, LPG and electricity cooking are the most desirable as they offer most of the benefits when used for cooking. However, adoption and penetration of improved energy options for cooking in Nigeria is very low. Less than 15% of the households in Nigeria use LPG as cooking energy, while less than 5% use electricity for cooking (Lambe et al. 2020).

However, there are many inequalities with access to and use of improved cooking stoves at different times of the day, different seasons of the year and different locations. In terms of inequalities between household types, the biggest inequality is wealth, with urban households especially those from higher income above $100 per month using improved cooking stoves at a rate of two to three times that of their poorer counterparts in rural locations. In addition, there are also inequalities between household heads of different levels of education, with those who have completed more education being more likely to use improved cooking stoves than their less educated counterparts. Studies conducted in Nigeria have slightly addressed this challenge by identifying individual determinants that influence use of improved cooking stoves such as income or education, location of residence and household size. However, most of these studies have not quantified how these determinants of improved cooking stoves use combine together to produce the observed inequality or have used decomposition analyses such as the Theil index or Oaxaca–Blinder methods to partition out the share of the inequality that can be attributed to wealth, to education, to urban/rural location and so on.

To better understand the dynamics of energy access inequality, it is important to first recognize that the degree of disadvantage faced by rural and remote area households in terms of energy access can vary to a significant degree between countries. Thus, while wealth or the so-called 'wealth gradient' may be the main driver of inequality in clean fuel access in some countries, regional infrastructure deficiencies may explain the greater part of energy access inequality in other countries. In addition, even when inequality in clean fuel access is explained for the most part by household characteristics, such as education or the gender of the household head, material as well as cultural or social factors that influence the practices of fuel collection and domestic cooking, are always involved. In order to assess the degree to which material and cultural factors explain energy access inequality, decomposition methods have been increasingly applied in recent years to the study of energy access inequality in developing countries. Thus, the central problem for

the study of energy access inequality is to identify and estimate the inequality in household's use of clean cooking fuels, and to decompose the inequality in adoption of clean fuels, or observed inequality in clean fuel adoption (Hanna 2020; Heltberg, R. 2019).

The two main problems that this study is designed to solve are: (1) to determine the degree of inequality that exists in the use of clean cooking energy by households and (2) to decompose the inequality in the adoption of clean fuels into several components that can be used to inform interventions (Hanna 2020; Heltberg, R. 2019).

Although decomposition analysis has been increasingly applied to assess energy access inequality in developing countries, a significant gap remains especially in terms of sub-national analysis. Earlier studies, such as that of van der Kroon et al. (2019) employed decomposition to examine the factors determining energy access for households in developing countries but did not specifically examine inequality between sub-geographic locations or between sub-populations within a country. While Kowsari and Zerriffi (2021) examined three dimensions of energy access for households in developing countries and utilized a framework that distinguished between determinants of energy access including income, physical infrastructure, and social norms influencing energy access, they did not employ a decomposition analysis that could identify and quantify endowment, structural, and interaction components of inequality. Although Akinyemi et al. (2022) employed decomposition analysis to examine the factors explaining inequality in the adoption of clean cooking energy in Nigeria and found that wealth, education, and location explained most of the inequality in the country, the analysis was conducted at the national level and did not reveal the magnitude and structure of inequality in the three geopolitical zones of Southern Nigeria where the study was conducted. The present study addresses this significant gap in the literature by employing concentration indices and Blinder-Oaxaca decomposition to assess inequality in the adoption of clean fuels for cooking at the sub-national regional level in Southern Nigeria utilizing the most recently available nationally representative dataset, the 2024 NDHS.

The present study addresses this gap directly. By estimating separate concentration indices for the Southwest, Southeast, and South-South regions and conducting three paired Blinder-Oaxaca decompositions, each comparing a focal region against the rest of Southern Nigeria, it produces the first sub-nationally disaggregated decomposition evidence on clean cooking energy inequality in Southern Nigeria, revealing that the sources, magnitude, and structural character of inequality differ fundamentally across the three regions in ways that aggregate analyses systematically obscure. This constitutes the study's primary contribution to the decomposition literature on household energy transitions in sub-Saharan Africa.

Therefore, this study aims to explore households' usage of clean cooking energy in southern Nigeria. Indoor air pollution from traditional cooking fuels causes serious health problems, including respiratory infections, heart disease, and premature deaths (WHO,2018; Vivian Maduekeh, 2024; Pattanayak, S. K., Jeuland, M., Lewis, J. J., et al., 2019). Deforestation, soil erosion, and biodiversity loss are additional challenges arising from the continued use of firewood and charcoal (Modi et al, 2022; Stanford, E, Mensah y, Hanny T. (2021; Han, Y., Wu, F., Zhang, L. 2025). Compounding the challenge is inequality in the use of clean cooking energy at both national and sub-national levels.

Theoretical framework and Model Specifications

The Sustainable Livelihoods Framework (SLF) of the 1990s is the foundation of this study's theoretical framework. According to Ahmed et al (2023), the sustainable livelihood approach itself depends on the

capability approach and environmental sustainability. The approach clearly explained how individuals maintained their livelihood resource utilization. The framework comprises these basic human assets: human, social, natural, physical, and financial capital (Paulo 2025; Pachauri, S., Mueller, A., Kemmler, A., & Spreng, D. 2020; Mallett, A. 2022).

The Sustainable Livelihoods Framework is efficient for analyzing the multidimensional effects of households' choices of cooking energy on their well-being**.** According to Agnoung (2025), the Sustainable Livelihoods Framework sheds light on how households can achieve a sustainable way of living using all available resources at their disposal**.** Access to clean cooking energy is essential for accomplishing sustainable development goals, especially in low- and middle-income nations such as Nigeria (Adedoyin et al, 2021; Lewis, J. J., & Pattanayak, S. K., 2021). Although initiatives to encourage clean cooking energy have been launched, disparities in accessibility and usage continue, particularly impacting specific groups like rural populations, low-income families, and women (UNEP, 2024)

cce = f(hr, sc, na, pc, fc) **3.1**

Where:
cce = utilization of clean cooking energy in the household
hr = human resources (such as education attainment, family size, age, sex)
sc = social capital (e.g., membership in community groups, access to social networks)
na = natural assets (e.g., availability of natural resources)
pc = physical capital (e.g., type of housing, availability of infrastructure)
fc = financial capital (e.g., income level, employment status)

The Sustainable Livelihoods Framework, as first articulated by Chambers and Conway (1992), formalised by Scoones (1998), and operationalised through the five-capital "asset pentagon" of DFID (1999), conceptualises any livelihood outcome. Here, the adoption of clean cooking energy (*cce*), as a function of the household's endowment across five interdependent forms of capital: human (*hr*), social (*sc*), natural (*na*), physical (*pc*) and financial (*fc*). To translate the conceptual relation *cce = f(hr, sc, na, pc, fc)* into an estimable model, each capital dimension was proxied by observable variables drawn from the 2024 Nigeria Demographic and Health Survey. Human capital (*hr*), the knowledge, skills and health-related capacity that enable households to perceive and act upon the benefits of clean fuels was operationalised through completed years of education (*eduyear*) and the age of the household head (*hhage, hhage*^{2}), the latter capturing experience and life-cycle effects. Financial capital (*fc*), the monetary resources and asset stocks that determine the affordability of both stove acquisition and recurrent fuel purchases, was proxied by the household wealth index and its binary form (*rich, wealth*). Physical capital (*pc*), the basic infrastructure, producer goods and distribution networks that condition the physical availability of modern fuels, was represented by urban residence (*urban*), which captures proximity to liquefied petroleum gas retail, electricity-grid connection and last-mile supply chains. Social capital (*sc*), the networks, norms and identity-based affiliations that shape information flows and the cultural embeddedness of fuel practices, was captured through religious affiliation (*muslim, christian*), ethnicity (*igbo, yoruba, hausa*) and polygamous household structure (*poly*). Finally, natural capital (*na*), the local environmental resource base whose very abundance can paradoxically entrench reliance on freely collected biomass, was represented by the Southern Nigeria regional dummies, which proxy agro-ecological endowment and geographic location. This explicit correspondence situates the present study within a growing body of work that applies the SLF

to household energy transitions in developing contexts, most directly the boosted-regression-trees analysis of 485 rural households in Diqing Tibetan Autonomous Prefecture by Qiu et al. (2023), which reported that "higher financial capital promotes household adoption of clean cooking fuels" while "higher natural capital restrains rural households' acceptance of clean cooking" (see also Mallett 2022; Ahmed et al. 2023). The mapping provides the conceptual scaffold for the empirical specification that follows.

Model Specification

The functional relationship between Clean cooking energy and socioeconomic determinants is for this study is specified below as

$$\text{Clean} = f(\text{Age}, \text{Age}^2,, \text{Muslim}, \text{Christian}, \text{Poly}, \text{Igbo}, \text{Yoruba}, \text{Hausa}, \text{Hsize}, \text{Hhage}, \text{Hhage}^2, \text{Eduyear}, \text{Rich}, \text{Urban}) \quad (1)$$

The above is linearized as:

$$\text{Clean} = \alpha_0 + \alpha_1\text{Age}_i + \alpha_2\text{Age}^2_i + \alpha_3\text{Muslim}_i + \alpha_4\text{Christiani} + \alpha_5\text{Poly}_i + \alpha_6\text{Igbo}_i + \alpha_7\text{Yoruba}_{ii} + \alpha_8\text{Hausa}_i + \alpha_9\text{Hsize}_i + \alpha_{10}\text{Hage}_i + \alpha_{11}\text{Hhage}_{2i} + \alpha_{12}\text{Eduyear}_i + \alpha_{13}\text{Rich}_i + \alpha_{14}\text{Urban}_i + \varepsilon_i \quad (2)$$

Where:

Clean= Clean is a binary for cooking energy having value of 1 and 0. Usage of electricity and gas are coded 1, while firewood, charcoal, kerosene stoves, saw-dust and other unclean cooking methods are coded 0. **Age** = age of respondents in years, **Age2** = Age of Respondent Square to account for nonlinear relationship between adoption of clean cooking energy and age, **Muslim** is a binary coded 1 if the respondent is a muslim or 0 if not, **Christian** is coded 1 if the respondent is a Christian and 0 if not, **Poly** is a dummy for polygamous family, **Igbo**, **Yoruba,** and **Hausa** are the dummies for the three major ethnic groups in the southern Nigeria, Hsize is the house hold size, Hhage stands is the dummy for Age of the household head, Hhage² **is** the Square of household head age, Eduyear is the respondent years of education, Rich is the dummy for the respondent wealth quantile, either rich coded 1 or poor coded 0, Urban is a dummy coded 1 for respondents residing the urban areas and 0 for those in the rural areas.

Logistic regression will be applied because the dependent variable is binary. The probability that a household is using clean cooking energy will be expressed as

$$\text{Logit(P)} = \textbf{Log}\left(\frac{P}{1-p)}\right) = (\alpha_0 + \alpha_1\text{Age}_i + \alpha_2\text{Age}^2\text{i} + \alpha_3\text{Muslim}_i + \alpha_4\text{Christian}_i + \alpha_5\text{Poly}_i + \alpha_6\text{Igbo}_i + \alpha_7\text{Yoruba}_{ii} + \alpha_8\text{Hausa}_i + \alpha_9\text{Hsize}_i + \alpha_{10}\text{Hage}_i + \alpha_{11}\text{Hhage}^2_i + \alpha_{12}\text{Eduyear}_i + \alpha_{13}\text{Rich}_i + \alpha_{14}\text{Urban}_i + \varepsilon_i \quad (3)$$

Where

Prepresents the likelihood of utilizing clean cooking energy,

α_0, α_1,..., α_{14} denote the coefficients for the independent variables and is the error term

The above focuses on the contribution of socioeconomic factors that influence the use of clean cooking energy among households.

To achieve the objective of investigating the presence of spatial inequality in the use of clean cooking energy, the concentration index and Blinder-Oaxaca decomposition were used. The concentration index is a measure of relative inequality (Adewara et al., 2014; O'Donnell, O., E. van Doorslaer, A. Wagstaff, and M. Lindelow. 2008) like the Gini coefficient, and it is defined as:

$$\text{CICCE} = \frac{2}{U}\sum yiR\text{i} - 1 \quad \text{.....} \quad (1)$$

Where:

CICCE = Clean cooking energy use concentration index

y = Clean Cooking Energy

R = Fractional rank of households by wealth index

μ = Mean of clean cooking energy use

The concentration index value is bounded between -1 and 1.

The Oaxaca-Blinder Decomposition method decomposed the difference in clean cooking energy usage between two groups (e.g., region A and region B) into explained and unexplained components (Oaxaca, R. 1973; Blinder, A. S. 1973).

Therefore, the specification is given as:

$$y^{region\,A} - y^{region\,B} = \beta^{region\,A}x^{region\,A} - \beta^{region\,B}x^{region\,B} \quad \text{.....} \quad (2)$$

Where $y^{region\,A}$ and $y^{region\,B}$ depicts vectors of factors that influence the CCE, including individual socio-demographic characteristics and household-level variables, assessed at the mean values for the two regions.

Considering that there are just two explanatory variables and then,

$$y^{region\,A} - y^{region\,B} = (\beta_0^{region\,A} - \beta_0^{region\,B}) + (\beta_1^{region\,A}x_1^{region\,A} - \beta_1^{region\,B}x_1^{region\,B})$$

$$(\beta_2^{region\,A}x_2^{region\,A} - \beta_2^{region\,B}x_2^{region\,B}) \quad \text{.....} \quad (3)$$

$$= D_0 + D_1 + D_2$$

The difference in y between region A and region B areas is said to be caused by (i) differences in the intercepts (D_0), (ii) differences in x_1 and β_1 (D_1 (iii) differences in x_2, β_2 and (D_2): For example, D_1 may quantify the difference in mean resulting from variations in the use of CCE (x_1) and the effect of using CCE (β_1). Oaxaca decomposition contributes to the explanation of the overall gap in the explanatory variable caused by (i) variations in x2 s (the explained component) and (ii) variations in â2 s (the unexplained component). The discrepancy in the use of CCE between the regions will be further explained in two ways:

$$y^{region\,A} - y^{region\,B} = \Delta x\beta^{region\,A}\,\Delta x\beta^{region\,B} \quad \text{.....} \quad (4)$$

Where Δx = $x^{region\,A} - x^{region\,B}$ **and Δβ** = $\beta^{region\,A} - \beta^{region\,B}$,

As a result, it is considered that the decomposition in (4) represents a specific instance of a more general decomposition:

$$y^{region\,A} - y^{region\,B} = \Delta x\beta^{region\,A} + \Delta x\beta^{region\,B} \quad \text{.....} \quad (5)$$

$$y^{region\ A} - y^{region\ B} = \Delta x\beta^{region\ A} + \Delta x\beta^{region\ B} + \Delta x\Delta\beta \quad \text{..... (6)}$$
$$= \mathbf{E} + \mathbf{C} + \mathbf{CE}$$

The above indicates that the difference in the use of CCE between region A and B in southern Nigeria is caused by differences in endowments (E), coefficients (C), and the interaction of endowments and coefficients (C E).

Data and Scope

Data from the Nigerian Demographic and Health Survey (NDHS 2024) were used for this study, which aims to provide a comprehensive analysis of inequality in the use of clean cooking energy and its decomposition into endowment, coefficient, and interaction effects in Nigeria. Though there are six geopolitical zones in the country, three of them are in southern Nigeria, while the remaining three are in the North. This study will focus on the three regions in southern Nigeria, while the subsequent study will focus on the north. The three regions in southern Nigeria are the Southeast, Southsouth, and the Southwest. The southeast comprises Abia, Ebonyi, Imo, Enugu, and Anambra States. South-South has Delta, Akwa-Ibom, Edo, Cross Rivers, Bayelsa, and Rivers States. In the Southwest, we have: Oyo, Ondo, Osun, Ekiti, Ogun, and Lagos states.

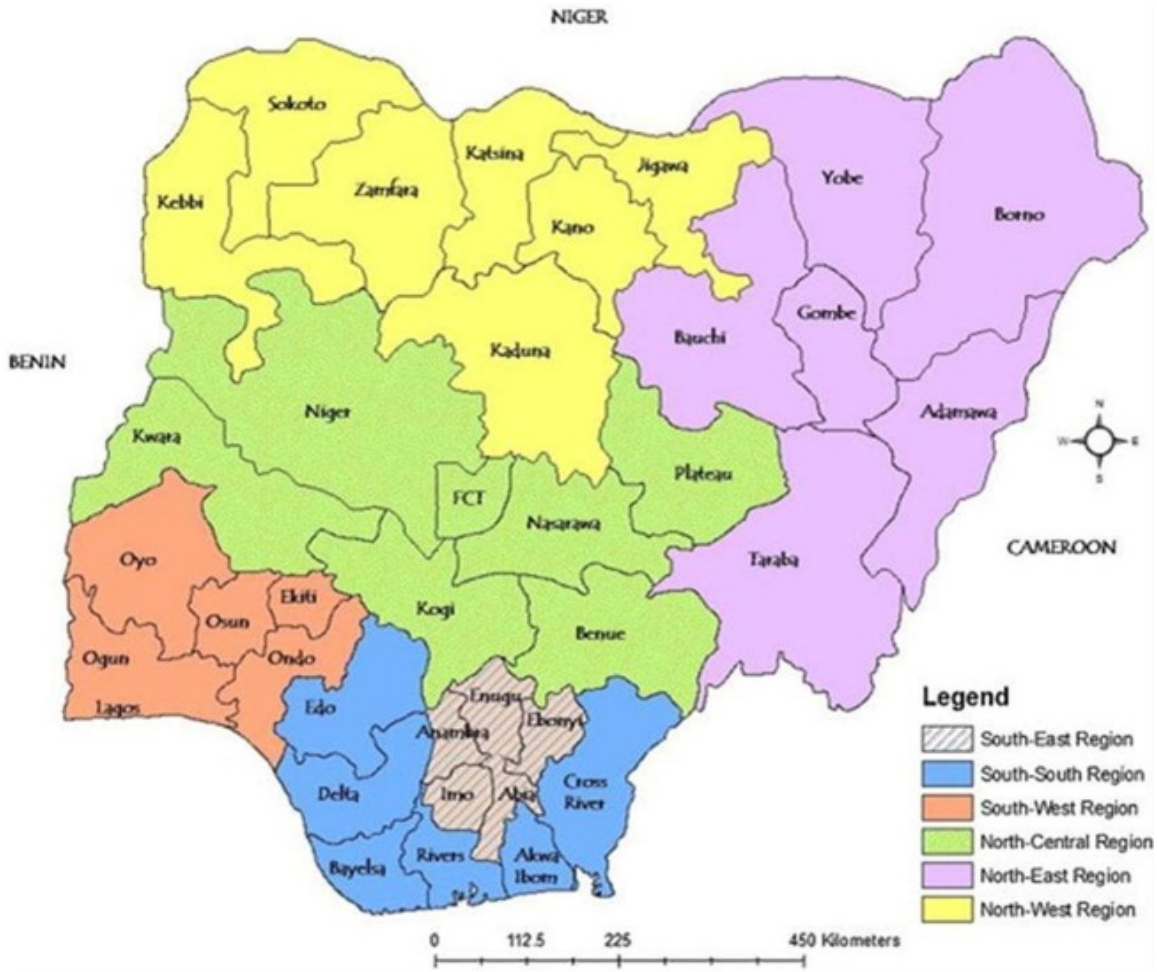

Figure 1: Nigeria's map with the six geopolitical regions demarcation

Results and discussions

Table 1: Summary Statistics of the Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Panel A: Dependent Variable and Individual Characteristics					
clean	5,784	0.4672	0.4990	0	1
age	5,784	30.185	9.698	15	49
age2	5,784	1005.2	606.1	225	2401
muslim	5,784	0.1062	0.3081	0	1
christian	5,784	0.7025	0.4572	0	1
Panel B: Ethnicity and Household Size					
poly	5,784	0.4521	0.4977	0	1
igbo	5,784	0.3791	0.4852	0	1
yoruba	5,784	0.2498	0.4330	0	1
hausa	5,784	0.0066	0.0808	0	1
hsize	5,784	5.253	2.853	1	28
Panel C: Household Head Characteristics					
hhage	5,784	45.077	13.651	16	98
hhage2	5,784	2218.3	1374.2	256	9604
eduyear	5,784	10.913	3.742	0	20
rich	5,784	0.7094	0.4541	0	1
urban	5,784	0.6891	0.4629	0	1
Panel D: Wealth					
wealth	5,784	3.971	1.052	1	5

Note: Obs = number of observations; Std. Dev. = standard deviation; Min = minimum value; Max = maximum value. All variables are based on N = 5,784 observations. clean = dependent variable (clean cooking energy use); age2 and hhage2 are squared terms of age and household head age respectively.

Table 1 presents a summary of the variables included in the study analysis. Based on 5,784 observations, the table covers the dependent variable *clean* (a binary indicator of clean cooking energy use, with a mean of 0.47 suggesting roughly 47% of households use clean cooking energy) and a range of socioeconomic, demographic, and cultural explanatory variables. These include the household head's age (mean ≈ 30 years), religion (Muslim at 11%, Christian at 70%), ethnicity (Poly 45%, Igbo 38%, Yoruba 25%, Hausa less than 1%), household size (average ≈ 5 members), and wealth index scored 1–5 (mean ≈ 3.97).

Additional variables capture household head age squared (*age2*, *hhage2*) to allow for non-linear effects, years of education (*eduyear*, mean ≈ 11 years), a binary indicator for being rich (*rich*, mean ≈ 0.71), and urban/rural location (*urban*, mean H" 0.69, indicating most households are urban). Together, these variables suggest the study examines how household demographic characteristics, ethnicity, religion, education, wealth, and location influence the likelihood of adopting clean cooking energy in southern Nigeria.

Table 2: Concentration Indices of Clean Cooking Energy Usage in Southern Nigeria

Comparison Group	Welfare Ranking Variable	Concentration Index (CI)	Std. Error of CI
Rural vs. Urban	Urban residence	0.1987	0.0063
Southwest vs. Rest of South	Southwest residence	0.1193	0.0066
South-South vs. Rest of South	South-South residence	0.0133	0.0067
Southeast vs. Rest of South	Southeast residence	-0.1326	0.0065

Note: *Concentration Index (CI) computed using the grouped approach of Kakwani, Wagstaff, and van Doorslaer (1997). A positive CI indicates pro-rich (or pro-urban/pro-region) inequality, while a negative CI indicates pro-poor (or disadvantaged-group) concentration. A CI close to zero denotes near-equality. N = 5,784.*

The concentration indices (CI) reported in Table 2 are estimated using the grouped approach of Kakwani, Wagstaff, and van Doorslaer (1997), and measure the degree to which clean cooking energy usage is concentrated among wealthier or more privileged groups across different dimensions of inequality in Southern Nigeria. A positive CI indicates that clean cooking energy usage is disproportionately concentrated among better-off (wealthier or urban) groups, a negative CI signals concentration among the worse-off (poorer or rural) groups, and a value close to zero implies a near-equitable distribution of usage relative to the ranking variable.

The concentration index (CI) of the rural-urban gap is 0.199, while the standard error is 0.006. This result indicates a significant difference between the rural and urban populations in the usage of clean cooking energy in southern Nigeria. The result shows that the urban population uses far more clean cooking energy compared to their rural counterparts**.** It shows that cooking energy pollution is higher in rural areas, thereby subjecting the rural population to health risks associated with unclean cooking energy.

There are three regions in the southern part of the country. The Southwest positive CI of 0.119 (Std. Error = 0.007) indicates that rich households use more clean cooking energy in the region than poor households. In the Southeast region, a negative CI of −0.133 (Std. Error = 0.007) indicates that poor households use more clean cooking energy than rich households. This result, though contrary to expectations, reflects the unique demographic and socioeconomic structure of the Southeast, which requires deeper analysis, focusing mainly on the region to unravel the actual reasons for the unexpected result. The Blinder-Oaxaca decomposition results presented in Table 6 provide the analytical basis for explaining this paradox.

A closer look at the results reveals that rather than households lacking wealth in the Southeast, weak structural returns on observable household endowments (such as wealth) is a major issue in the region that is not translated into adoption of clean cooking energy. The coefficient component of the Blinder-Oaxaca decomposition in Table 6 is positive and significant at the 1% level of 0.1912. This implies that even when households in the Southeast possess the same set of endowments as households in other regions of Southern Nigeria, the probability of adoption or expected value of endowments in the Southeast would be less than what their endowments would have been in other regions. Notably, returns are especially weak for the Igbo, a major ethnic group in the Southeast and the core demography of the region's population. In such predominantly Igbo communities, the relationship between a household's wealth and its likelihood of adoption of clean cooking energy is severely disadvantaged structurally. This disadvantage could be as a result of deeply ingrained cooking practices, poor LPG distribution infrastructure as well as strict social norms around fuel use that extend beyond a simple measure of the observed socioeconomic status of a

household. Within the Southeast, the disadvantage is also greatly exacerbated by larger household sizes. In fact, each additional member of the household (beyond 1 person) decreases the concentration index by 0.1162 (significant at the 1% level). This is because of larger average household sizes in the Southeast than the other sub-regions and with larger households of more than one person before, such households experience greater and more frequent and higher costs of expensive fuels than smaller households before. Thus, while in the South-West and South-South, wealthier households in those regions concentrate more on clean cooking energy use than their less wealthy counterparts, the reverse is the case for the Southeast region. The negative CI for the Southeast is therefore not an anomaly due to statistical artifacts. Instead, it is structurally justified through a combination of ethnic-specific institutional and supply-side factors that create a unique inequality profile for the Southeast when compared with the other two southern sub-regions of Southern Nigeria. Interventions in the region would thus need to be specially designed to change the structure of determinants of adoption to that which income transfer would achieve rather than solely focusing on income transfer.

Table 3: Determinants of clean cooking energy adoption in Southern Nigeria

VARIABLES	Logistics Clean (1)	Robust Logit Clean (2)	Probit Clean (3)	Robust Probit Clean (4)
	Odds Ratio	Odds Ratio	Marginal Effect	Marginal Effect
age	-0.0480*	-0.0480*	-0.00972	-0.00972
	(0.0286)	(0.0291)	(0.00617)	(0.00624)
age2	0.000749*	0.000749	0.000150	0.000150
	(0.000452)	(0.000460)	(9.75e-05)	(9.86e-05)
muslim	0.577***	0.577***	0.134***	0.134***
	(0.159)	(0.161)	(0.0365)	(0.0365)
christian	0.449***	0.449***	0.100***	0.100***
	(0.0991)	(0.0975)	(0.0206)	(0.0202)
poly	-0.139	-0.139	-0.0330*	-0.0330*
	(0.0897)	(0.0924)	(0.0190)	(0.0194)
igbo	-0.256***	-0.256***	-0.0577***	-0.0577***
	(0.0890)	(0.0877)	(0.0190)	(0.0188)
yoruba	0.0513	0.0513	0.0112	0.0112
	(0.0997)	(0.104)	(0.0213)	(0.0221)
hausa	0.139	0.139	0.0146	0.0146
	(0.478)	(0.609)	(0.0974)	(0.115)
hsize	-0.164***	-0.164***	-0.0358***	-0.0358***
	(0.0177)	(0.0188)	(0.00372)	(0.00391)
hhage	-0.0344**	-0.0344**	-0.00712**	-0.00712**
	(0.0166)	(0.0169)	(0.00348)	(0.00349)
hhage2	0.000154	0.000154	3.00e-05	3.00e-05
	(0.000160)	(0.000162)	(3.39e-05)	(3.38e-05)
eduyear	0.124***	0.124***	0.0270***	0.0270***
	(0.0112)	(0.0113)	(0.00242)	(0.00244)
rich	3.825***	3.825***	0.559***	0.559***
	(0.167)	(0.162)	(0.0102)	(0.0101)
urban	1.198***	1.198***	0.241***	0.241***
	(0.0881)	(0.0885)	(0.0160)	(0.0159)
Constant	-3.113***	-3.113***		
	(0.639)	(0.661)		
Observations	5,784	5,784	5,784	5,784

Note: Standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.1

The concentration index for clean cooking energy use in the South-South region equals 0.013 (std. error 0.007). This is below the equity line of zero and thus implies that there is still a considerable amount of inequality with regards to the use of clean cooking energy in the region. However, compared to the Southeast, the region's inequality is more equitable. The Blinder-Oaxaca decomposition analysis for the clean cooking energy use indicator in the South-South region is presented in Table 7. Similar to the results presented in Table 6 for the Southeast region, the analysis for South-South reveals a considerable amount of structural inefficiency in the returns to household endowments. Moreover, the decomposition for South-South also explicitly brings out the ethnic and wealth effects.

Table 3 above presents the results of the logistic regression analysis of the energy for clean cooking adoption in Southern Nigeria. As the coefficients for both the standard errors and the robust standard errors estimates were similar, the discussion below focuses on the robust standard errors specification.

The results in Table 3 show that age has a non-linear relation with the adoption of clean cooking energy. The negative coefficient for age ("0.0480; p-value<0.1) indicates that the older the household head the less likely they are to use clean cooking energy. However, the positive coefficient for age squared (0.000749; p-value<0.1) indicates a U shaped relationship where the negative effect of age on adoption of clean cooking energy diminishes as age increases and at some point even reverses. The life cycle of the elderly in later stages of life goes back to clean fuels as economic constraints are released and the composition of the household changes.

The followers of Islam (0.577; p<0.01) or Christianity (0.449; p<0.01) differ from followers of traditional religions most probably because of the social networks, educational exposure or even urban connection of followers of these two religions. The coefficient for Muslim followers, however, is much larger in absolute value than the coefficient for Christian followers. This most probably is due to the characteristic of geographic and socio-economic structures of Muslim communities in Southern Nigeria.

Ethnicity: Being Igbo is negatively associated with the adoption of clean energy for cooking (coefficient: "0.256; p-value: <0.01). Yoruba and Hausa have no differential effect on the adoption of clean energy for cooking when compared with the reference group (p-values: 0.56 and 0.45 respectively).

Household size negatively and highly significantly affects the probability of adoption of clean cooking energy (-0.164; p<0.01). As household size increases so does absolute demand for cooking energy. However, the recurring costs of clean fuels such as LPG as a proportion of total spending increases as the zero monetary cost of collecting biomass for cooking increases. Household composition therefore represents a major structural barrier to the clean energy transition in Southern Nigeria.

The age of the household head also is negatively significant at 5% level, ("0.0344). This supports the behavioral inertia argument earlier posited and would suggest that older household heads would be less likely to adopt clean cooking energy in order to continue with deeply ingrained cooking behavior and associated risk aversion to new unfamiliar energy sources for cooking. The coefficient for the square of the age of the household head is however not statistically significant. Thus, there is no support for the earlier stated non-linear reversal found for an individual's age.

The number of years of education the respondent is positively and highly significant at 0.124 (p < 0.01). As is well established in the energy economics literature, human capital increases the likelihood of energy adoption. The educated women have advantages in acquiring information on clean cooking technologies as well as accessing programs and subsidies to buy the technologies. Such women can also compare short term costs and benefits of clean energy cooking technologies with long term health benefits and financial returns. Thus, for Southern Nigeria, education policy is very critical in increasing adoption of clean energy cooking technologies.

The wealth index variable carries the largest and most statistically significant coefficient in the model (3.825, $p < 0.01$), confirming that household wealth is the single most powerful determinant of clean cooking energy adoption. This finding is consistent with the energy ladder hypothesis, which posits that households transition to cleaner fuels as incomes rise. The magnitude of the coefficient substantially larger than all other covariates indicates that the clean cooking energy transition in Southern Nigeria is overwhelmingly constrained by income, reinforcing the argument that financial affordability, rather than supply availability or awareness, is the primary barrier. Urban location is positively and significantly associated with clean cooking energy adoption (1.198, $p < 0.01$). Urban residents benefit from better market access, more reliable gas distribution networks, greater awareness of clean cooking technologies, and higher average incomes. This result, considered alongside the rural-urban decomposition in Table 3, suggests that urbanisation is both a direct driver of adoption and a mediating pathway through which other socioeconomic advantages translate into clean energy use.

Further robustness analysis was conducted using probit regression and robust probit regressions. The two models likewise confirmed the reliability of the logit regression results. The only main difference between the logit and the probit regressions was that, polygamy was not a significant determinant of clean cooking energy from the logit regression but was significant at 10% level in probit. All other variables of interest maintained their levels of significance.

Table 4: Rural-Urban inequality in the use of clean cooking energy in Southern Nigeria

VARIABLES	(1) Differential	(2) Endowments	(3) Coefficients	(4) Interaction
age		-0.00111	0.123	0.000704
		(0.00198)	(0.241)	(0.00178)
age2		0.000887	-0.0600	-0.000517
		(0.00190)	(0.127)	(0.00150)
muslim		-0.0102***	-0.0165**	0.0106**
		(0.00259)	(0.00717)	(0.00468)
christian		-0.00393***	-0.0480**	0.00277**
		(0.00149)	(0.0190)	(0.00141)
poly		0.000656	-0.00350	0.000256
		(0.000601)	(0.0112)	(0.000823)
igbo		-0.00455	-0.00644	-0.00484
		(0.00384)	(0.00756)	(0.00569)
yoruba		-0.00131	0.0177*	-0.0118*
		(0.00363)	(0.0106)	(0.00707)
hausa		-0.000529	0.00191**	0.00151
		(0.000495)	(0.000778)	(0.00106)
hsize		-0.0282***	0.0810***	0.0211***
		(0.00436)	(0.0189)	(0.00516)
hhage		-0.0108*	0.0218	0.00104
		(0.00612)	(0.186)	(0.00886)
hhage2		0.00447	0.00699	0.000706
		(0.00584)	(0.0866)	(0.00874)
eduyear		-0.0319***	-0.0837**	0.0122**
		(0.00390)	(0.0337)	(0.00498)
rich		-0.228***	-0.218***	0.103***
		(0.0104)	(0.0205)	(0.0102)
Total		-0.314***	-0.255***	0.136***
		(0.0121)	(0.0134)	(0.0125)
Rural Prediction_1	0.169***			
	(0.00885)			
Urban Prediction_2	0.602***			
	(0.00776)			
Difference	-0.433***			
	(0.0118)			
Constant			-0.0712	
			(0.168)	
Observations	5,784	5,784	5,784	5,784

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4 presents the Blinder-Oaxaca decomposition of the rural-urban gap in clean cooking energy use in Southern Nigeria. The decomposition partitions the observed gap into three components: endowments (differences in observed characteristics between rural and urban households), coefficients (differences in the returns to those characteristics), and the interaction between the two. The predicted probability of clean cooking energy use is 16.9% in rural areas and 60.2% in urban areas, yielding a statistically significant raw gap of -43.3 percentage points ($p < 0.01$). This is a stark disparity and one of the most telling findings of the study: urban households are more than three and a half times more likely to use clean cooking energy than their rural counterparts in Southern Nigeria.

The endowments component reflecting differences in observed characteristics between rural and urban households accounts for 25.5 percentage points of the total gap. This is the portion of the inequality attributable to rural households having less favourable endowments than urban households. The dominant contributors to the endowments effect are: Wealth (-0.228, $p < 0.01$): The largest single contributor to the endowments gap. Rural households' significantly lower wealth levels relative to urban households explain most of the rural disadvantage in clean cooking energy adoption, consistent with the energy ladder hypothesis. Rural households tend to be larger, which, given the negative relationship between household size and adoption established in the logistic Table, further depresses rural adoption rates (Household size (-0.0282, $p < 0.01$)). Lower average educational attainment in rural areas, relative to urban areas contributes meaningfully to the endowments gap (-0.0319, $p < 0.01$), reflecting the well-established urban-rural education divide in Nigeria. The lower prevalence of Muslim and Christian affiliations in rural areas contributes marginally but significantly to the endowments-driven gap (Muslim: -0.0102, $p < 0.01$; Christian: -0.00393, $p < 0.01$).

The coefficients component (+13.6 Percentage Points, $p < 0.01$), reflecting differences in the returns to identical characteristics between rural and urban areas is positive and significant, indicating that even if rural households had the same observable characteristics as urban households, the structural and institutional environment of rural areas would continue to generate a disadvantage. The structural penalty associated with large household size in clean cooking energy adoption is more pronounced in rural areas, where the cost burden of LPG relative to income is more severe from the results (0.0810, $p < 0.01$). Translating wealth into clean cooking energy adoption are significantly lower in rural areas, suggesting that even wealthier rural households face supply-side constraints, such as limited gas distribution infrastructure and fewer retail points for clean fuel that constrain their ability to convert income into clean cooking energy use (-0.218, $p < 0.01$). Education's facilitating clean cooking energy adoption are lower in rural areas, possibly because rural education systems produce lower quality human capital or because rural educated individuals face supply-side barriers that limit the efficacy of their knowledge (-0.0837, $p < 0.05$).

The significant negative interaction term (-31.4 Percentage Points, $p < 0.01$) suggests that the joint effect of having both worse endowments and lower returns to those endowments compounds the rural disadvantage, creating a mutually reinforcing cycle of deprivation that cannot be fully addressed by improving either endowments or structural conditions alone. Both dimensions must be tackled simultaneously for meaningful progress.

Table 5 decomposes the inequality in clean cooking energy use between the Southwest zone and the rest of Southern Nigeria. The Southwest (Prediction 2 = 0.6453) records a markedly higher probability of clean cooking energy use compared to the rest of Southern Nigeria (Prediction 1 = 0.3860), yielding a difference of -0.2593, which is negative and highly significant ($z = -18.96$, $p < 0.001$). The negative sign reflects the convention of the decomposition: the Southwest is the reference group (Prediction 2), and the difference captures the shortfall of the other regions relative to the Southwest. In substantive terms, households in the Southwest are approximately 26 percentage points more likely to use clean cooking energy than their counterparts in the rest of the South.

Table 5: Southwest-Southern inequality in clean cooking energy use in Nigeria

VARIABLES	(1) Differential	(2) Endowments	(3) Coefficients	(4) Interaction
age		-0.000126	-0.0196	-3.77e-05
		(0.000739)	(0.263)	(0.000538)
age2		-0.000206	-0.000733	3.17e-06
		(0.000965)	(0.139)	(0.000602)
muslim		-0.0546***	-0.0620**	0.0595**
		(0.0155)	(0.0252)	(0.0242)
christian		0.0122***	-0.0752**	-0.00858**
		(0.00426)	(0.0334)	(0.00411)
poly		-0.000543	-0.0221*	0.00184
		(0.000884)	(0.0126)	(0.00123)
igbo		0.0437**	-0.00844***	-0.0651***
		(0.0204)	(0.00288)	(0.0214)
yoruba		0.0979***	0.219***	-0.216***
		(0.0197)	(0.0473)	(0.0466)
hausa		0.000678	0.00313**	-0.00137
		(0.000579)	(0.00147)	(0.00101)
hsize		-0.0385***	0.121***	0.0311***
		(0.00581)	(0.0230)	(0.00620)
hhage		0.00185	-0.516***	-0.0182**
		(0.00557)	(0.195)	(0.00825)
hhage2		-0.00283	0.186**	0.0120*
		(0.00484)	(0.0914)	(0.00680)
eduyear		-0.00472**	0.0131	-0.000329
		(0.00200)	(0.0355)	(0.000899)
rich		-0.102***	-0.111***	0.0239***
		(0.00831)	(0.0267)	(0.00597)
urban		-0.0276***	0.0481*	-0.0129*
		(0.00679)	(0.0273)	(0.00734)
Total		-0.0744***	0.00906	-0.194***
		(0.0239)	(0.0449)	(0.0489)
Prediction_1	0.386***			
	(0.00773)			
Prediction_2	0.645***			
	(0.0113)			
Difference	-0.259***			
	(0.0137)			
Constant			0.233	
			(0.185)	
Observations	5,784	5,784	5,784	5,784

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Decomposing this advantage, the endowments component is −0.0744 (p = 0.002), indicating that about 7.4 percentage points of the Southwest's advantage is attributable to its superior endowment of observable household characteristics. Specifically, the Southwest has a significantly higher concentration of wealthy households (*rich*: −0.1016, p < 0.001) and higher rates of urbanisation (*urban*: −0.0276, p < 0.001), both of which are strong predictors of clean energy adoption. The higher prevalence of the Yoruba ethnic group in the Southwest (*yoruba*: +0.0979, p < 0.001) and the Ibo group (*Ibo*: +0.0437, p = 0.033) also contribute positively to the endowment gap. Household size (*hsize*: −0.0385, p < 0.001) works in the opposite direction, as larger households in other regions are associated with lower clean energy uptake. The coefficients component, capturing structural differences in returns to these characteristics is small and statistically insignificant (0.009, p = 0.840), suggesting that the way in which household and individual characteristics translate into clean energy use does not differ significantly between the Southwest and the rest of the South. The interaction term, however, is large, negative, and highly significant (−0.1939, p <

0.001), indicating that the joint effect of the Southwest simultaneously possessing both better endowments and different structural returns amplifies its overall advantage. The interaction is driven notably by Yoruba ethnicity (−0.2159, $p < 0.001$), household size (+0.0311, $p < 0.001$), and wealth (*rich*: +0.0239, $p < 0.001$). Taken together, the Southwest's lead in clean cooking energy adoption is primarily the product of its favourable socioeconomic and demographic profile, particularly its higher wealth levels, greater urbanisation, and Yoruba ethnic concentration.

Table 6: Southeast-Southern inequality in clean cooking energy use in Nigeria

VARIABLES	(1) Differential	(2) Endowments	(3) Coefficients	(4) Interaction
age		-0.000249	-0.0783	-0.000644
		(0.00172)	(0.255)	(0.00221)
age2		0.000381	0.0469	0.00112
		(0.00260)	(0.133)	(0.00328)
muslim		0.0546	-0.000487	-0.0374
		(0.0445)	(0.000631)	(0.0447)
christian		0.00364	0.0439**	0.0135**
		(0.00308)	(0.0171)	(0.00536)
poly		-0.00181	0.0141	0.00161
		(0.00113)	(0.0108)	(0.00132)
igbo		0.101**	0.259***	-0.238***
		(0.0484)	(0.0577)	(0.0531)
yoruba		0.120	-0.000155	-0.114
		(0.141)	(0.000246)	(0.141)
hausa		0.000556	-0.000598	-0.000752
		(0.00102)	(0.000861)	(0.00110)
hsize		0.00823*	-0.116***	0.0316***
		(0.00461)	(0.0263)	(0.00732)
hhage		0.0283**	0.147	-0.0109
		(0.0130)	(0.212)	(0.0158)
hhage2		-0.0154	-0.0436	0.00621
		(0.0118)	(0.105)	(0.0149)
eduyear		0.00862***	-0.0652*	-0.00257*
		(0.00238)	(0.0342)	(0.00149)
rich		0.0543***	0.115***	0.0297***
		(0.00544)	(0.0159)	(0.00476)
urban		0.0432***	0.00189	0.00109
		(0.00536)	(0.0123)	(0.00709)
Total		0.405***	0.191***	-0.320**
		(0.149)	(0.0255)	(0.150)
Prediction_1	0.561***			
	(0.00803)			
Prediction_2	0.284***			
	(0.0102)			
Difference	0.277***			
	(0.0130)			
Constant			-0.132	
			(0.188)	
Observations	5,784	5,784	5,784	5,784

Note: Standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.1

Table 6 decomposes clean cooking energy use inequality between the Southeast zone and the rest of Southern Nigeria. Unlike the Southwest, the Southeast (Prediction 2 = 0.2837) records a substantially lower probability of clean cooking energy use relative to the rest of Southern Nigeria (Prediction 1 = 0.5607), with a positive and highly significant difference of +0.2770 (z = 21.31, p < 0.001). This positive sign opposite in direction to Table 5 confirms that the Southeast is the only geopolitical region in Southern Nigeria that falls below the average of the rest of the South, exhibiting a shortfall of approximately 27.7 percentage points. This is the largest regional clean energy deficit in the South.

Table 7: Southern-Southsouth inequality in clean cooking energy use in Nigeria

VARIABLES	(1) Differential	(2) Endowments	(3) Coefficients	(4) Interaction
age		0.00125	0.0248	-0.000243
		(0.00233)	(0.259)	(0.00255)
age2		-0.00135	-0.00787	0.000148
		(0.00238)	(0.137)	(0.00258)
muslim		-0.00281	0.00213	0.0120
		(0.00864)	(0.00167)	(0.00927)
christian		-0.0167**	-0.0127	0.00363
		(0.00675)	(0.0274)	(0.00786)
poly		0.000205	0.00528	-0.000108
		(0.000359)	(0.0118)	(0.000288)
igbo		0.0565***	-0.0296***	-0.141***
		(0.0134)	(0.00412)	(0.0173)
yoruba		0.0502**	-0.00569***	-0.0833***
		(0.0197)	(0.00167)	(0.0215)
hausa		-3.95e-05	-0.00106	8.37e-05
		(0.000173)	(0.00100)	(0.000352)
hsize		-0.00813***	0.00391	0.000506
		(0.00283)	(0.0236)	(0.00305)
hhage		-0.0217**	0.296	0.0135
		(0.00899)	(0.209)	(0.00983)
hhage2		0.0159*	-0.124	-0.0127
		(0.00911)	(0.0985)	(0.0103)
eduyear		-0.00226	0.0406	-0.000551
		(0.00158)	(0.0357)	(0.000611)
rich		0.00837	-0.0582***	-0.00137
		(0.00641)	(0.0191)	(0.00114)
urban		-0.0120***	-0.00530	0.000495
		(0.00265)	(0.0195)	(0.00183)
Total		0.0674**	0.114***	-0.209***
		(0.0270)	(0.0208)	(0.0312)
Prediction_1	0.458***			
	(0.00813)			
Prediction_2	0.485***			
	(0.0111)			
Difference	-0.0273**			
	(0.0138)			
Constant			-0.0143	
			(0.181)	
Observations	5,784	5,784	5,784	5,784

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The endowments component is +0.4054 (p = 0.006), suggesting that a substantial portion of the Southeast's deficit is attributable to disadvantageous observable characteristics relative to the rest of the South. In particular, the gap in wealth (*rich*: +0.2834, p < 0.001) and urbanisation (*urban*: +0.0432, p < 0.001) are the most powerful drivers: the rest of the South has higher concentrations of wealthy and urban households, which strongly favour clean energy adoption, and the Southeast's relative deficit in these

endowments accounts for a large share of its shortfall. The Ibo ethnicity endowment effect (+0.1011, p = 0.037) and years of education (*eduyear*: +0.0086, p < 0.001) also contribute to the explained gap. The coefficient component is positive and significant (+0.1912, p < 0.001), revealing that not only does the Southeast have less favourable household characteristics, but those characteristics also yield lower returns in terms of clean energy use. This structural disadvantage is driven largely by the Ibo ethnic returns (+0.2590, p < 0.001) and household size penalties (*hsize*: −0.1162, p < 0.001), indicating deep-seated structural barriers to clean cooking energy adoption in the Southeast that go beyond observable socioeconomic attributes. The interaction term is negative (−0.3195, p = 0.034), partially moderating the combined effect of endowment and returns disadvantages, and is shaped primarily by the Ibo interaction (−0.2384, p < 0.001). Overall, the Southeast's clean energy deficit is both explained and structural: it reflects genuine disadvantages in household wealth and urbanisation, compounded by structural inefficiencies in converting existing endowments into clean energy uptake.

Table 7 decomposes clean cooking energy inequality between the South-south zone and the rest of Southern Nigeria. The South-South (Prediction 2 = 0.4849) exhibits a probability of clean cooking energy use that is only marginally below that of the rest of Southern Nigeria (Prediction 1 = 0.4576), producing a difference of −0.0273 that is negative and marginally significant (z = −1.98, p = 0.048). While statistically significant, the South-South's shortfall of approximately 2.7 percentage points is by far the smallest of the three regions, and the region comes closest to parity with the rest of the South in clean cooking energy adoption.

The endowments component is positive and significant (+0.0674, p = 0.013), indicating that observable characteristic differences modestly disadvantage the South-South relative to the rest of the region. The ethnic composition of the South-South, with lower concentrations of Ibo (*Ibo*: +0.0566, p < 0.001) and Yoruba (*yoruba*: +0.0502, p = 0.011) groups, both associated with higher clean energy use accounts for a meaningful share of this endowment gap. Household head age (*hhage*: −0.0217, p = 0.016) and urbanisation (*urban*: −0.0120, p < 0.001) also contribute to the disadvantage. The coefficients component is significant (+0.1142, p < 0.001), with notable structural effects arising from Ibo ethnicity returns (*Ibo*: −0.0296, p < 0.001) and education (*eduyear*: +0.0406, p = 0.002), indicating that some structural inefficiencies persist in the South-South's conversion of characteristics into clean energy outcomes. The interaction term is large, negative, and highly significant (−0.2089, p < 0.001), driven principally by the Ibo (−0.1410, p < 0.001) and Yoruba (−0.0833, p < 0.001) interaction effects, suggesting that the particular combination of ethnic endowments and their associated returns in the South-South creates a compound offsetting disadvantage. Despite this, the relatively small overall gap points to the South-South's comparatively stronger structural position in clean cooking energy use among the non-Southwest regions, leaving it positioned between the high-performing Southwest and the considerably lagging Southeast.

Post-estimation model specification tests

The Tables below presents three post-estimation tests used to validate the logistic regression model used for the analysis of clean cooking energy usage among 5,784 households in Southern Nigeria.

The Linktest analysis checks whether the model is correctly specified. The key predictor _hat (the linear prediction) is highly significant (p < 0.001), confirming that the model has genuine predictive power. Crucialy, _hatsq (the squared prediction) is not significant (p = 0.661), meaning there is no evidence of model misspecification, indicating that the model has been correctly specified. The Pseudo R^2 of 0.3852 also indicates a reasonably strong overall model fit for a survey data analysis used for this study.

Table 8: Linktest for Model Specification

Variable	Coefficient	Std. Error	z	P > |z|	[95% Conf. Interval]	
					Lower	Upper
_hat	0.9937	0.0329	30.20	0.000	0.9292	1.0582
_hatsq	−0.0062	0.0141	−0.44	0.661	−0.0337	0.0214
_cons	0.0120	0.0460	0.26	0.793	−0.0781	0.1021
N = 5,784	*Log likelihood = −2456.9857*		*LR chi2(2) = 3079.37*		*Prob > chi2 = 0.0000*	*Pseudo R^2 = 0.3852*

Note: _hat = linear prediction; _hatsq = squared linear prediction. _hat is significant (p < 0.001), confirming model predictive power. _hatsq is not significant (p = 0.661), indicating no model misspecification. N = 5,784; Pseudo R^2 = 0.3852.

Table 9: Classification Statistics of the Logistic Regression Model

Variable	Coefficient	Std. Error	z	P > |z|	[95% Conf. Interval]	
					Lower	Upper
_hat	0.9937	0.0329	30.20	0.000	0.9292	1.0582
_hatsq	−0.0062	0.0141	−0.44	0.661	−0.0337	0.0214
_cons	0.0120	0.0460	0.26	0.793	−0.0781	0.1021
N = 5,784	*Log likelihood = −2456.9857*		*LR chi2(2) = 3079.37*		*Prob > chi2 = 0.0000*	*Pseudo R^2 = 0.3852*

Note: Classified positive (+) if predicted Pr(D) > 0.5. True D defined as clean ≠ 0. The model correctly classified 79.13% of all observations, with sensitivity of 86.53% and specificity of 72.65%.

The Classification Statistics above assesses how well the model distinguishes households that use clean cooking energy from those that do not, using a 0.5 probability threshold. The model correctly classifies 79.13% of all observations, which is a very strong performance. It is particularly good at identifying actual users of clean energy (sensitivity of 86.53%), meaning it rarely misses true positive cases, while its ability to correctly identify non-users (specificity of 72.65%) is slightly lower but higher than the threshold minimum of 70%

Table 10: Hosmer–Lemeshow Goodness-of-Fit Test

Table collapsed on quantiles of estimated probabilities

Group	Prob	Obs_1	Exp_1	Obs_0	Exp_0	Total
		(D = 1)	(D = 1)	(D = 0)	(D = 0)	
1	0.0090	1	2.6	578	576.4	579
2	0.0257	12	9.2	566	568.8	578
3	0.1491	29	33.6	550	545.4	579
4	0.4178	175	172.4	403	405.6	578
5	0.5717	303	288.0	275	290.0	578
6	0.6709	372	361.7	207	217.3	579
7	0.7385	390	408.3	188	169.7	578
8	0.7933	429	443.5	150	135.5	579
9	0.8460	473	473.5	105	104.5	578
10	0.9476	518	509.2	60	68.8	578
Hosmer–Lemeshow $chi^2(8)$ = 11.00	*Prob > chi^2 = 0.2014*		*Number of observations = 5,784*		*Number of groups = 10*	

Note: Obs_1 and Exp_1 = observed and expected outcomes for D = 1; Obs_0 and Exp_0 = observed and expected outcomes for D = 0. The Hosmer–Lemeshow test is not significant ($\chi^2(8)$ = 11.00, p = 0.2014), indicating that the model adequately fits the data.

The Hosmer–Lemeshow Test above further confirms the model's goodness-of-fit: the test statistic is $\chi^2(8) = 11.00$ with $p = 0.2014$, which is not statistically significant. This means the observed and expected outcomes across all ten probability groups are sufficiently close, providing additional confirmation that the model fits the data well and its predictions are reliable.

Discussion

Reading through the lens of the Sustainable Livelihoods Framework, the present results offered strong support for the framework's central proposition that differential access to livelihood capitals, rather than fuel preference alone, governs sustainable energy transitions (Scoones 1998; DFID 1999). The Blinder-Oaxaca decomposition was especially instructive in this regard. The 43.3-percentage-point rural-urban gap in clean cooking usage was dominated by the endowments component (-0.314, $p < 0.01$), which was in turn driven overwhelmingly by wealth (-0.228, $p < 0.01$), education (-0.0319, $p < 0.01$) and household size (-0.0282, $p < 0.01$). In SLF terms, the rural deficit was therefore principally a deficit of financial and human capital rather than of disposition, a reading directly corroborated by Qiu et al. (2023), who found in 485 Diqing Tibetan households that "higher financial capital promotes household adoption of clean cooking fuels" whereas "higher natural capital restrains rural households' acceptance of clean cooking," and by the systematic review of Lewis and Pattanayak (2012), whose vote-count of 32 studies found household-head education positively associated with improved-cookstove adoption in 67% of analyses (and male education in 100%), alongside income, while the age of the household head carried a negative association in 50%. The dominance of the wealth term echoed the SLF premise that financial capital is the most readily substitutable asset, simultaneously underwriting the upfront cost of clean stoves and recurrent fuel expenditure (Pachauri et al. 2020; Adedoyin et al. 2021). The regional decompositions reinforced this interpretation: the Southwest's 25.9-percentage-point advantage over the rest of the South reflected a superior endowment of financial and physical capital, higher household wealth combined with the dense urban LPG and electricity infrastructure concentrated along the Lagos-Ibadan corridor, whereas the Southeast's 27.7-percentage-point deficit and the South-South's near-parity gap of just 2.7 percentage points illustrated how unevenly physical and financial capital are distributed across otherwise geographically proximate regions. The negative coefficient on Igbo ethnicity (-0.256, $p < 0.01$) and the positive religious-affiliation effects (*muslim* 0.577, *christian* 0.449, both $p < 0.01$) are interpreted here as manifestations of social capital, whose role in shaping clean-cooking adoption, including through socially marginal status, which Lewis and Pattanayak (2012) found negatively associated with adoption in 67% of relevant analyses, is well documented in the SLF-energy literature (Agnoung 2025; Paulo 2025). Taken together, these patterns confirmed the framework's core analytic claim that spatial inequality in clean cooking is, in essence, the spatial footprint of unequal capital endowments.

As explained above, this study examined spatial inequality in clean cooking energy use across three geopolitical regions of Southern Nigeria, the Southwest, Southeast, and South-South, using the 2024 Nigerian Demographic and Health Survey (NDHS), concentration indices, and Blinder-Oaxaca decomposition. The findings reveal stark spatial disparities that are both statistically significant and policy-relevant, and they largely corroborate the patterns identified in earlier studies on energy poverty and inequality in sub-Saharan Africa (Lewis and Pattanayak, 2012; van der Kroon et al., 2019).

The logistic regression results in Table 3 establish the key determinants of clean cooking energy adoption in Southern Nigeria. Household wealth emerges as the single most powerful predictor, with a coefficient of 3.825 ($p < 0.01$), confirming the energy ladder hypothesis that posits a positive relationship between income and the transition to cleaner fuels (van der Kroon et al., 2019; Heltberg, 2019).

These findings further reinforce the body of evidence on determinants of household's use of clean fuels previously reported in other studies such as Lambe et al. (2020); Ibitoye et al. (2020) for Nigeria for instance who reported that financial challenges rather than lack of awareness on existence and where to obtain clean fuels are the impediments to adoption of clean fuels. Thus, wealth to access clean fuels follows in importance to other determinants influencing adoption of clean fuels and this is followed by urban location (1.198 **; $p<0.01$). These findings further support the assertion of Adebayo et al. (2019) who posited that urbanization is a driver of use of clean fuels and also a channel through which other determinants of clean fuel use are expressed. Thus, Education (in years of schooling) ranked third and is therefore a very important determinant (0.124 **; $p<0.01$). Negative relationship between household size and use of clean fuels was also confirmed ("0.164 **; $p<0.01$). The reason adduced is that as household size increases, the cost of using clean fuels such as LPG increases and this is as opposed to apparently free collection and use of biomass for fuel. In terms of Religion, being Muslim or Christian has a more positive relationship with use of clean fuels than Traditional Religion. Among the ethnic groups investigated, Igbo followed negative relationship with use of clean fuels ("0.256 **; $p<0.01$) and this finding projects spatially downstream location of Southeast (which is predominantly Igbo) in the decompositions that follow.

The concentration indices reported in Table 2 provide the first layer of spatial inequality evidence. The rural-urban concentration index of 0.199 is the largest of all comparisons, reflecting that clean cooking energy use is disproportionately concentrated among urban households and confirming that geographic location is one of the most powerful axes of energy inequality in Southern Nigeria (UNDP, 2021; World Bank, 2022). At the regional level, the Southwest records the highest positive concentration index (CI = 0.119), indicating that clean cooking energy use is pro-rich within the region and that the region as a whole outperforms the rest of Southern Nigeria. The South-South registers a modest positive CI of 0.013, suggesting a near-equitable distribution relative to the regional average, though marginally concentrated among better-off households. The Southeast, by contrast, records a strikingly negative CI of "0.133, indicating that clean cooking energy use is disproportionately concentrated among poorer households in that region. This unexpected result implies that the wealthier households in the Southeast are, paradoxically, not the primary users of clean cooking energy, a pattern that may reflect unique structural and cultural features of the region that require further investigation.

Table 5 presents the Blinder-Oaxaca decomposition comparing the Southwest (Prediction 2 = 0.6453) with the rest of Southern Nigeria (Prediction 1 = 0.3860). Southwest probability of clean cooking energy use was approximately 64.5%, compared with 38.6% for the rest of the South. This represents a gap of 25.9 percentage points that is negative in the decomposition framework, signifying that the other regions fall short of the Southwest's level. This negative difference ("0.2593, $p < 0.001$) represents the shortfall of non-Southwest households relative to the Southwest and is among the largest spatial energy use disparities documented in the Nigerian literature. These findings are consistent with Kowsari and Zerriffi (2021) and van der Kroon et al. (2019), who document that energy transitions in developing countries are rarely driven by a single factor but by the compounding of multiple socioeconomic advantages.

In the Southeast adoption of clean cooking energy was 28.4% compared with 56.1% for the rest of the South. The resulting gap of 27.7 percentage points is positive (0.2770, $p < 0.001$), confirming that the Southeast is the only geopolitical region in Southern Nigeria that falls substantially below the regional average. This is also the largest absolute regional deficit documented in this study and places the Southeast in a position of acute energy deprivation relative to its neighbours. This finding resonates with Anozie et al. (2021), who documented the role of cultural determinants in shaping cooking energy choices in rural Nigeria, and with Akinyemi et al. (2022), who identified decomposition-based evidence of structural barriers in Nigerian energy transitions.

Table 7 compares the South-South to the rest of Southern Nigeria. While the South-South has the smallest regional gap with a clean cooking energy use probability of about 48.49% as compared to 45.76% for the rest of Southern Nigeria at a significance of $p = 0.048$, it is however placed in an intermediate position between the clean cooking energy use probability of the Southwest and that of the Southeast. Consistent with the structural and compositional arguments advanced by Pachauri et al. (2020) and Mensah et al. (2021), the findings here suggest that there are substantial heterogeneities in the energy transition pathways of sub-national units in developing economies.

Looking at the tables above, from the prediction results for Southern Nigeria, the Southwest has the highest probability of using clean cooking energy for cooking followed by the South-South and then the Southeast. This finding is consistent with the concentration indices for clean cooking energy use presented in Table 2 earlier. The negative concentration indices for the South-South and Southeast indicated that clean cooking energy use is concentrated in the Southwest and less concentrated in the South-South and the least concentrated in the Southeast. Differences in wealth, urbanization, education and cooking energy infrastructure between the three regions in Southern Nigeria as noted earlier contribute to the disparities in the probability of using clean cooking energy for cooking. Additionally, disparities in clean cooking energy use for cooking are ascribed by differences in household endowments, differences in structural returns to these endowments and the interactions between the two sets of differences. Hence, a region-specific approach as opposed to a generic approach is required to promote effective use of clean cooking energy for cooking in Southern Nigeria.

Conclusion and recommendations

This study examines spatial inequality in the use of households' using clean cooking energy in Southern Nigeria. The study used 2024 NDHS data for the analysis. We conducted a logistic regression for the likelihood of a household using clean cooking energy. We then used results from the regression to calculate concentration indices for clean cooking energy use across the five southern states and twenty-two study areas. We also conducted a Blinder-Oaxaca decomposition to examine inequality in clean cooking energy use into two types of inequality: endowment inequality and coefficient inequality. The analysis was based on a sample of 5,784 households.

The study finds that, at individual and household level, wealth is the single most important factor influencing use of clean cooking energy followed by urban residence, education and household size. Thus the energy ladder hypothesis holds for Southern Nigeria. It is the high income households, those with more years of schooling and living in urban locations that are more likely to use clean cooking fuels. Larger households are however constrained by costs of using clean cooking energy. Also, Igbo speaking households are less likely to use clean cooking energy compared to their counterparts in other ethnic groups in Southern Nigeria. These results help to explain energy poverty in Southeastern Nigeria.

The concentration indices for clean cooking energy for the clean cooking fuels and technologies across the clean cooking energy hierarchy for the five study regions, and for the rural and urban sectors are presented in Table 3. Among the clean cooking energy fuels and technologies across the energy ladder, the Southwest region is the most advantaged region followed by the South-South region, which is almost on par with the rest of the South region or perfectly equitable. However, contrary to the concentration patterns among the clean cooking energy fuels and technologies in other regions of Southern Nigeria where the clean energy fuels are more concentrated among richer households, the clean cooking energy fuels are more concentrated or inversely concentrated among wealthier households in the Southeast region, the only region in Southern Nigeria where this is the case. In terms of the concentration indices for the rural

and urban sectors, the largest of all the concentration indices calculated for this study is the rural-urban concentration index of 0.199 for clean cooking energy, reinforcing the finding above that the rural-urban divide is the biggest axis of disparity in clean cooking energy use in Southern Nigeria.

We used the Blinder-Oaxaca decomposition to analyze the effect of endowments (individual and household characteristics) and returns (the relationship between endowments and the outcome variable, or the structure of opportunity) in each of the regions under study and how these contribute to the differences in clean cooking energy adoption between a given region and the rest of the South. Results for Southwest are provided in the first column of Table 6. We note that the 25.9 percentage points by which Southwest households are more likely to use clean cooking fuel than the rest of the South are entirely explained by endowments, i.e. the rich, urban households in Southwest form a critical mass in terms of numbers that are able to sustain a structure of opportunity that maximally exploits their advantages. Note that in contrast, households in the Southeast experience both endowment disadvantages (low wealth and low likelihood of urban residence) and returns deficits (i.e. that the returns to adoption of clean cooking energy for poor households in the region are structured to disadvantage them, and thus that simple income support to alleviate energy poverty in the region is unlikely to be sufficient). Those in South-South have clean cooking fuel adoption rates near parity with the rest of the South but still experience a number of disadvantages in terms of both endowments and coefficients that could drive a widening of the gap in clean cooking fuel adoption in the long run if not addressed.

In summary, wealth is the major determinant of access to clean cooking energy. In addition, urban residency, education, household size, ethnicity and culture are other important factors that influence energy inequality. Energy inequality also exists at the subnational level in Southern Nigeria. There are marked differences between the regions in the South. Therefore, general policies for clean cooking energy in Southern Nigeria will not address energy inequality in the region. Rather, region-specific policies that address the various determinants of energy inequality are required.

This study has a number of limitations. It is based on cross-sectional data and so it is not possible to use the study to establish causality between the factors that determine whether or not a household uses clean cooking energy and the use of clean cooking energy itself. The NDHS used in this study for the analysis of the sample of households from Southern Nigeria uses a binary indicator of whether or not a household uses clean cooking energy. In this sense, the study does not allow for an analysis of the differences in the quality of fuels that are used by households for cooking as well as allow for an analysis of the differences that exist between the stages of the energy ladder that are used by households. Future studies should utilize a panel or quasi-experimental design to determine the causal effects of a variety of determinants on a household's likelihood of using clean cooking energy. The study should also be extended to Northern Nigeria where energy poverty is more severe and have different characteristics than the South. Such a study would help to build a national evidence base for the design of policies that are aimed at promoting the use of clean cooking energy in Nigeria.

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