JOURNAL OF CULTURAL ANALYSIS AND SOCIAL CHANGE

Journal of Cultural Analysis and Social Change,
2025, 10(4), 350-356
ISSN: 2589-1316

Filling the Access Gap: The Role of Renewable Energy in Reducing Energy Poverty Inequality

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Citation: Chaabouni, I. (2025). Cooperative Learning and the Improvement of Generic Competence Development in University Students. *Journal of Cultural Analysis and Social Change*, *10*(4), 344–349. https://doi.org/10.64753/jcasc.v10i4.2819

Published: December 4, 2025

ABSTRACT

This study examines the relationship between renewable energy consumption and energy poverty inequality in five Sub-Saharan African countries—Kenya, Tanzania, Uganda, Ghana, and Nigeria—over the period 2000 to 2023. Using a panel data fixed effects model, the analysis constructs an Energy Poverty Inequality Index (EPII) based on the disparity in urban and rural electrification rates. The objective is to assess how renewable energy deployment affects the distributional aspect of energy access within these countries. The findings reveal a complex relationship. Overall, renewable energy consumption is associated with an increase in energy poverty inequality. However, this relationship is significantly moderated by rural population share. In countries or regions with higher rural populations, the inequality-widening effect of renewable energy is reduced. This suggests that renewable energy initiatives may have limited impact—or even unintended adverse effects—on equity unless they are specifically designed to meet rural energy needs. Furthermore, the analysis shows that GDP per capita is negatively associated with EPII, indicating that economic growth contributes to reducing energy poverty inequality. On the other hand, Foreign Direct Investment (FDI) appears to have no statistically significant effect on EPII, implying that not all forms of economic engagement lead to improved energy equity. These results underscore the importance of crafting inclusive energy policies that prioritize rural electrification and are integrated with broader development strategies. To foster equitable energy transitions, policymakers must ensure that renewable energy deployment is aligned with local demographic realities and is supported by targeted interventions aimed at marginalized communities.

Keywords: Renewable Energy, Energy Poverty Inequality, Rural Population, Sub-Saharan African countries.

INTRODUCTION

Energy poverty refers to the lack of access to modern energy services, including uninterrupted electricity supply, clean cooking fuel, and access to affordable energy to satisfy basic household needs such as light, warmth, and communication. It not only encompasses physical access but also affordability, quality and consistency of the supply of energy (Pachauri and Spreng, 2011). Here, Energy Poverty Inequality (EPII) accepts energy access disparities within and between areas, most notably the severe urban-rural disparity. Whereas Sub-Saharan African (SSA) urban residents are increasingly connected to national grids and benefit from more consistent grid-based energy services, rural communities are more likely to remain under-supplied or even unprovided, with their livelihoods remaining rooted in traditional biomass and occasional supply. Scholars such as Nussbaumer et al. (2012) have noted multi-dimensional energy poverty measures that capture both access and quality dimensions, whereas Bouzarovski and Petrova (2015) note the spatial as well as social justice dimensions of disproportionate energy distribution. In the SSA case, it is especially important to address inequality in energy poverty because it can reduce wider development inequalities, limit educational and health outcomes, and undermine economic prospects.

Building on this foundation, SSA energy poverty inequality (EPII) dynamics require urgent research and policy attention, especially in the context of the international focus on sustainable development and equitable energy transitions. The United Nations' Sustainable Development Goal 7 emphasizes universal access to modern, affordable, and reliable energy by 2030 (Assembly UG, 2015). However, in SSA, overall progress has been uneven, with rural locations persistently lagging despite the general improvement in electrification. This widening gap has significant implications for the inclusiveness of current energy development plans as well as the effectiveness of renewable energy sources in addressing structural imbalances. Although renewable energy is often highlighted to expand access, particularly for rural off-grid communities, its distributional effects are intricate. New evidence is accumulated to suggest that, unless explicitly targeted and promoted by policies, the deployment of renewable energy can favor more accessible and economically advantaged urban markets, further entrenching existing inequalities.

This study contributes to the literature by empirically examining the impact of renewable energy utilization on energy poverty inequality in five Sub-Saharan African countries: Kenya, Tanzania, Uganda, Ghana, and Nigeria, from 2000 to 2023. Specifically, it explores whether the proportion of the rural population mediates the relationship between renewable energy and EPII.

The remainder of this paper will be organized as follows: Section 2 reviews the relevant literature on the impact of renewable energy on EPII and studies the moderate role played by the rural population share. Section 3 describes the data and the methodology. Section 4 presents and discusses empirical results. Finally, section 5 concludes the paper.

LITERATURE REVIEW

Impact of Renewable Energy on Energy Poverty Inequality (EPII)

Renewable energy is directly linked to enhancing energy access, particularly in remote and off-grid areas. Cook (2011) and Sovacool (2012) indicate that decentralized renewable technologies, such as solar home systems, wind energy, and mini hydropower, can overcome the infrastructural barrier of traditional grid extension. These technologies have succeeded in alleviating energy poverty where electricity from the grid is not expected to arrive for some time. In theory, renewable energy should reduce EPII by providing marginalized societies with independent and sustainable access to electricity.

However, there is caution from new research that the deployment of renewable energy does not necessarily translate into fair outcomes. Most studies indicate renewable energy programs have the unintended effect of perpetuating current energy inequalities, with policy and market forces tilting toward commercial viability rather than equity. Sovacool (2012) and Monyei et al. (2018) note that private renewable energy investments are in richer and denser urban centers because they have higher returns and more logistical complexities. Rural regions, already being entrenched in endemic under-electrification, may therefore be left behind even more, exacerbating EPII.

Bhattacharyya (2012) emphasizes that rural electrification with renewables must be harmonized with infrastructure, local capacity, affordability, and local ownership to be successful, lest renewable energy options will overlook the most vulnerable communities or be underutilized. Similarly, Szabó et al. (2011) illustrate that energy access initiatives in Sub-Saharan Africa must be calibrated to the geographies and socio-economic environments of rural societies to be sensitive to inequality.

The Moderate Role of the Rural Population

Empirical observation suggests that renewable energy can also have an indirect impact on EPII through the proportion of the rural population. For instance, where populations are predominantly rural, the marginal benefits of renewable energy can be distributed more widely, with the potential to decrease inequality (Pachauri and Spreng, 2011). Conversely, where renewable energy policies are not pro-poor or where inclusive financing arrangements are lacking, clean energy growth may completely overlook the very poor (Gonzalez-Eguino, 2015).

Rural societies normally face particular infrastructural, geographical, and economic conditions that impact the viability and effectiveness of energy projects (Bhattacharyya, 2012). In Sub-Saharan Africa, where rural societies are often in the majority, marginalization of rural communities from schemes of energy development, may broadly spread EPII. Szabó et al. (2011) add that without rural-specific design elements, renewable energy solutions may also be unable to bridge the urban-rural divide. Moreover, access gaps may persist even with enhanced overall electrification levels, provided that renewable energy investments are focused on grid-connected urban areas (Monyei et al., 2018). To this end, rural society acts as a structural moderator. Its presence increases the need for inclusive planning and determines whether renewable energy will aggravate or reduce inequality. To that end, empirical investigations that include rurality as an interactive or moderating variable are key to identifying differentiated impacts of energy policy (Cook, 2011; Pachauri and Rao, 2013). So, getting rural-sensitive interventions is not only a matter of equity but also a strategic imperative for closing longstanding energy poverty gaps in poor environments.

MATERIALS AND METHODS

Data Source and Definition of Variables

This study examines the effect of renewable energy on energy poverty. Variables are collected from the World Bank (World Development Indicators, WDI). The dataset encompasses five Sub-Saharan countries (Kenya, Tanzania, Uganda, Ghana, Nigeria) from the year 2000 to 2023. Table 1, shown below, presents the data and sources used.

Table 1. Definition of variables.

	Variables	Measures
Energy Poverty Indicator Index	EPII	Urban Access Rate – Rural Access Rate
Renewable energy consumption	REN	Percentage of total final energy consumption
Rural population	RUR	Percentage of the total population
Gross Domestic Product	GDP	GDP per capita
Foreign Direct Investment	FDI	BoP, current US$

The Energy Poverty Indicator Index (EPII) is the dependent variable, and it is defined as the gap in electricity access between rural and urban areas. It is computed by the difference in electrification levels between these two domains. The independent variable is the proportion of consumption derived from renewable energy, reflecting the extent to which sustainable energy technologies are integrated into the national energy mix. Moreover, the proportion of the rural population represents the mediator variable. Control variables include Gross Domestic Product, measured by the GDP per capita, and Foreign Direct Investment FDI, reflecting foreign investor confidence and integration into the global economy.

Models

To examine the impact of renewable energy on energy poverty inequality, we employ a Fixed Effects (FE) model using panel data. The Fixed Effects approach allows us to analyze how changes within countries over time in renewable energy adoption affect energy poverty inequality while controlling unobserved, time-invariant characteristics unique to each country, such as geography, historical infrastructure, or institutional factors.

We select the Fixed Effects model primarily because of the relatively small number of cross-sectional units (only 5 countries) in our dataset. In such cases, the Fixed Effects approach is generally more appropriate than alternatives such as the Random Effects model, as it reduces the risk of biased estimates resulting from omitted variables that do not change over time but differ across countries.

$$EPII_{i,t} = \alpha_0 + \alpha_1 REN_{i,t} + \alpha_2 GDP_{i,t} + \alpha_3 FDI_{i,t} + \varepsilon_t \qquad \textbf{Equation 1}$$

To estimate the moderating role of the rural population on the relationship between renewable energy and energy poverty, we build the following equation 2:

$$EPII_{i,t} = \alpha_0 + \alpha_1 REN_{i,t} + \alpha_2 RUR + \alpha_3 REN * RUR + \alpha_4 GDP_{i,t} + \alpha_5 FDI_{i,t} + \varepsilon_t \qquad \textbf{Equation 2}$$

RESULTS AND DISCUSSION

Descriptive Statistics

Table 2 presents the descriptive statistics for the key variables used in the analysis, including the number of observations, mean, standard deviation, minimum, and maximum values.

Table 2. Descriptive Statistics.

Variables	Obs.	Mean	Std. Dev.	Min	Max
EPII	120	44.6091	11.5119	17.4000	70.5000
REN	120	78.6941	14.8694	39.000	95.6000

RUR	120	65.8995	12.9109	40.7620	85.2140
GDP	120	1179.094	705.6162	236.0212	3088.7210
FDI	120	-1.48E+09	1.59E+09	-8.02E+09	3.87E+08

The descriptive statistics in Table 2 give details of the nature of the dataset with 120 observations. The mean of the Energy Poverty Inequality Index (EPII) is 44.61, indicating large differences in the availability of electricity between urban and rural areas throughout the sample. A variance of 17.40 to 70.50 and a standard deviation of 11.51% indicate large differences in levels of energy inequality among countries or over time. Renewable energy (REN) accounts for an average of 78.69% of total energy consumption, reflecting heavy reliance on renewables in most of sub-Saharan Africa, but the 39 % to 95.60% range suggests differential adoption. Rural population share (RUR) averages 65.90%, confirming the rural character of most of the sample nations; the 40.76% to 85.21% range further demonstrates the preponderance of rural people and could contribute to energy access differentials. GDP per capita is averaging $1,179.09 and with significant variation between $236.02 and $3,088.72, expressing heterogeneity of the economic nature of the sample. Lastly, Foreign Direct Investment (FDI) has a negative mean value (−1.48 billion), expressing the overall net inflow tendency, and the big standard deviation and range express significant investment flow volatility.

Variables Correlations

Table 3 presents the correlation matrix between variables and the variance inflation factor (VIF) values.

Table 3. Correlation Matrix.

Variable	EPII	REN	RUR	GDP	FDI	**VIF**
EPII	1.0000					
REN	0.3319	1.0000				**2.3446**
RUR	-0.1211	0.7118	1.0000			**3.1261**
GDP	-0.0585	-0.5038	-0.6607	1.0000		**2.1208**
FDI	-0.1713	0.1548	0.4892	-0.5579	1,0000	**1.7379**

To evaluate the potential presence of multicollinearity among the independent and control variables, a Pearson correlation matrix was examined. The results displayed in Table 3 reveal that most pairwise correlations are below the conventional threshold of 0.80. Additionally, all VIF values are below the commonly accepted threshold of 5, which suggests that multicollinearity is not a significant concern in the model. Therefore, the independent and control variables are sufficiently independent from one another, and their inclusion in the regression model is statistically justified.

Regression Results

Table 4 presents the results of the baseline regression model, which examines the impact of renewable energy (REN) on the Energy Poverty Inequality Index (EPII), controlling for GDP per capita and Foreign Direct Investment (FDI).

Table 4. Impact of Renewable Energy on Energy Poverty Indicator Index.

Dependent variable: EPII				
Variable	**Coef.**	**Std. Err.**	**t-stat.**	**Prob.**
REN	.74295***	.18948	3.92	0.0002
GDP	.00057	.00212	-0.88	0.3778
FDI	7.39077	6.38E-10	0.53	0.5928
_Cons	-143.719	16.7523	-0.66	0.5079

Note: *** indicates 1% significance level.

The coefficient for renewable energy is positive and statistically significant at the 1% level. This indicates a strong and positive relationship between renewable energy usage and EPII, suggesting that higher reliance on renewable energy is associated with increased energy inequality. In contrast, the coefficients for GDP and FDI are statistically insignificant, indicating that variations in these economic indicators do not have a meaningful direct effect on energy poverty inequality within the model.

Table 5 presents the estimation results of Equation 2, which examines the moderating role of the rural population in the relationship between renewable energy usage and the Energy Poverty Inequality Index (EPII).

Table 5. Moderating Role of Rural Population on the Relationship between Renewable Energy and Energy Poverty Indicator Index.

Dependent variable: EPII				
Variable	**Coef.**	**Std. Err.**	**t-stat.**	**Prob.**
REN	2.4679***	.31694	7.78	0.0000
RUR	2.49485***	.74765	3.33	0.0012
REN*RUR	-.03565***	.00676	-5.27	0.0000
GDP	-.00586***	.00223	-2.62	0.0098
FDI	-1.12 E-10	5.80E-10	-0.19	0.8469
_Cons	-117.5614***	36.66677	-3.20	0.0018

Note: *** indicates 1% significance level.

The renewable energy coefficient is positive and significant, confirming that higher utilization of renewable energy is associated with increased energy poverty inequality. Similarly, the rural population variable is also positively and significantly associated, showing that larger shares of the rural population are related to increased energy access inequality.

Notably, the REN*RUR interaction term is significant and negative, implying the effect of moderation. This means that the relationship between renewable energy and EPII diminishes when the rural population increases. That is, although growth in renewable energy is positively correlated with inequality initially, that effect subsides where rural populations are larger, perhaps because rural renewable energy initiatives are equitable or better targeted towards the poor.

The control variable GDP per capita is negatively correlated with EPII; the more the economic growth, the less will be the inequality of energy poverty. But, Foreign Direct Investment (FDI) is statistically insignificant; it has no direct influence over EPII according to this model.

DISCUSSION

The association between increased renewable energy usage and higher levels of energy poverty inequality in Sub-Saharan Africa can be explained by several structural and socio-economic factors. While renewable energy initiatives have expanded across the region, particularly through off-grid solar and mini-grid systems, their deployment has often been uneven, favoring urban or more commercially viable rural areas over the poorest and most remote communities (Szabó et al., 2013). Our findings contrast with those of Sen et al (2024), who, using the GMM Model, demonstrated that a greater share of renewable energy enhances energy justice by promoting more equitable access to energy services and reducing disparities in energy distribution. Additionally, the positive effect of rural population on EPII implies that countries with larger rural populations face greater energy access inequality, due to persistent infrastructure deficits and economic marginalization in rural regions (Karekezi and Kithyoma, 2002).

However, as the rural population increases, the effect of renewable energy on energy poverty becomes significantly negative. That means, in countries with a higher rural population, the inequality-increasing effect of renewable energy becomes weaker. In the context of Sub-Saharan Africa, this may be because in these highly rural regions, even limited renewable energy interventions, such as off-grid solar systems, mini-grids, or donor-driven rural electrification initiatives, are specifically targeted toward underserved rural areas, thus mitigating the gap (Bhattacharyya, 2012; Trotter, 2016). Therefore, while renewable energy alone may exacerbate energy inequality if poorly distributed, its impact becomes more equitable when rural inclusion is prioritized, highlighting the need for rural-sensitive energy policies to ensure fair outcomes across regions.

On the other hand, the results demonstrate that GDP decreases energy inequality. As economies grow, governments and private actors are more capable of extending energy access beyond urban centers, reaching marginalized rural areas through grid expansion or decentralized solutions like solar mini-grids (Bhattacharyya, 2012). Furthermore, increased GDP often correlates with improvements in household incomes, which enhances the ability of rural populations to afford energy services and technologies. The same idea was reported by Simionescu and Cifuentes-Faura (2024), who assessed that sustainable economic growth could help reduce energy poverty.

Foreign direct investment (FDI) does not affect Energy poverty inequality. This result can be attributed to the fact that foreign investments often prioritize urban and industrial zones where returns on investment are higher, leading to a concentration of energy infrastructure development in cities and economically productive centers (Asiedu, 2002). Consequently, rural areas remain marginalized, and the gap in energy access between urban and rural populations persists or even widens, leaving energy poverty inequality largely unaffected by FDI inflows.

CONCLUSION

The study investigates the association between renewable energy consumption and energy poverty inequality in five Sub-Saharan African countries from 2000 to 2023. Using panel data and the fixed effects model, the findings establish that while the use of renewable energy is generally associated with increased energy poverty inequality, primarily due to unequal deployment, the effect decreases in more rural communities. The intense negative relationship of renewable energy with the rural population suggests that rural-oriented renewable programs can help bridge the energy access gap between rural and urban societies.

Additionally, the results identify that a higher rural population is positively correlated with energy access disparity, highlighting the role of infrastructural development and inclusive energy planning in rural regions. Interestingly, GDP per capita is found to reduce inequality in energy, reasserting the role of economic development in enhancing equitable access to energy services. On the contrary, Foreign Direct Investment has no impact on energy poverty inequality, explained by its concentration in urban and industrial areas.

Overall, the study calls for the rural relevance of renewable energy policies and the explicit incorporation of energy access objectives in economic development strategies. Rural energy projects, pro-poor financing schemes, and decentralized energy options should be prioritized by decision-makers to achieve inclusive energy transitions in Sub-Saharan Africa.

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