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RESEARCH ARTICLE

CARBON EMISSIONS, ENERGY CONSUMPTION AND POVERTY IN SUB-SAHARAN AFRICA

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ABSTRACT

Climate change, energy access and poverty remain among the most pressing development challenges confronting Sub-Saharan Africa (SSA). Despite contributing a very small share of global carbon emissions, the region continues to experience widespread energy poverty and high levels of multidimensional deprivation. This raises important policy questions concerning the nexus between economic development, energy consumption and poverty reduction. This study investigates the effects of carbon emissions and energy consumption on poverty across 44 Sub-Saharan African countries using an unbalanced panel dataset spanning between 2000 and 2019. The study employs pooled Ordinary Least Squares (OLS), Fixed Effects and Random Effects panel regression models. Hausman specification test was used to select the preferred model. The findings indicate that the Fixed Effects model was the most appropriate specification. Findings reveal that increases in CO_2 emissions per capita and GDP per capita are associated with significant reductions in poverty within countries. Energy consumption per capita has a negative but statistically insignificant relationship with poverty. These findings suggest that economic expansion and productive energy use remain important drivers of poverty reduction in SSA. Although aggregate energy consumption alone does not necessarily translate into improved household welfare. The study concludes that poverty reduction and climate objectives should be pursued simultaneously through investments in clean energy access, economic diversification and sustainable industrialization. The findings contribute to the growing literature on the energy–environment–poverty nexus and provide useful evidence for designing balanced climate and development policies in Sub-Saharan Africa.

Keywords: Carbon emissions, energy consumption, poverty, climate change, panel data,; Sub-Saharan Africa.

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1.0. INTRODUCTION

There has been growing global concern regarding the overall impact of climate change on economic wellbeing. The impact of climate change remains more pronounced in Sub-Saharan Africa (SSA). Following the report of the IPCC, Africa faces constant climate risks which can potentially exacerbate regional food insecurity and worsen labour productivity (Trisos et al., 2022). Reports of multiyear droughts and flooding are already causing tremendous adaptation cost. According to World Meteorological Organization (WMO, 2024), the region incurs an annual adaptation cost ranging from \$30 to \$50 billion which is equivalent to about 3% of regional GDP. The World Bank model projected that over 100 million people are likely to be thrown into extreme poverty if decisive mitigation strategy in not implemented to curb worsening climate change by 2030 and that the largest share will come SSA countries (Jafino et al., 2020; Nwosu et al., 2024).

Yet the region's relationship with the climate crisis is defined by a striking asymmetry. The region contributes a small share of global emissions but bears a disproportionate climate damages along with severe electricity deprivation where there is structurally low access to electricity and consumption which impedes economic growth (Adzawla, et al.,2019; Kohnert, 2024). Sub-Saharan Africa's per-capita CO2 emissions remain amongst the lowest in the world. Other regions emissions per capita are in multiples of that of SSA. On the average, SSA citizens emit in a year what an American emit in two to three days. despite. This is irrespective of the fact the region is deficient in clean energy and generally starved of energy (Energy for Growth Hub, 2025).

ISS African Futures (2025) report shows that in 2023, only 58% of Africa's population had access to electricity. This implies that an estimated 626 million people are without a grid connection for even basic household needs. Consequently, Africa is frequently referred to as "rich in the dark" because the continent has failed to structurally convert vast fossil, mineral and renewable energy resources endowment into broad-based energy access or economic diversification (CSIS, 2025). The result is a form of resource curse in which extractive, carbon-intensive growth coexists with persistent energy poverty and only a partial, uneven translation of resource wealth into welfare gains for the wider population (World Economic Forum, 2025).

This paradox has attracted several empirical investigations in the nexus between energy, emissions and poverty. Recently, panel-data studies gained traction towards ascertaining the actual relationship between energy variables and poverty outcomes across African economies. Janjua et al. (2024) find that energy security and economic growth jointly shape poverty trajectories across Sub-Saharan Africa while Barkat, Alsamara and Mimouni (2023) show that external financial flows such as remittances can moderate energy poverty in developing economies more broadly. Deloitte's Africa Energy Outlook (2023) documents the scale of the underlying paradox in descriptive terms and the World Bank's most recent Poverty, Prosperity and Planet report confirms that shared prosperity gains have slowed precisely in the settings where climate risk exposure is highest (World Bank, 2024). However, there is scarcity of empirical studies focusing on relationship between carbon emissions intensity, energy consumption per capita and poverty headcount ratios across SSA countries.

Addressing this gap is important for policy. A scenario of a systematic association between carbon-intensive, energy-intensive growth and lower poverty within countries over time implies that abrupt decarbonization without compensating investment in energy access risks a genuine welfare trade-off

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for some of the world's poorest economies. This tension is already visible in debates over Africa's role in global critical-mineral supply chains (World Economic Forum, 2025). Conversely, if the association is weak or driven mainly by common regional trends rather than within-country dynamics, this would support the view that energy access, not emissions per se, is the binding constraint on poverty reduction. This reinforces the calls for accelerated and appropriately financed electrification (ISS African Futures, 2025; CSIS, 2025). For Nigeria and other oil-dependent economies in the region where growth has long been tied to fossil-fuel extraction, this question carries direct relevance for ongoing energy-transition and economic-diversification policy debates.

In order to address this gap, the current study constructs an unbalanced panel of 44 Sub-Saharan African countries covering the period 2000 –2019. Thus, the objective of the study is to investigate the effect of carbon emissions and energy consumption on poverty. The remainder of the paper proceeds as follows. Section 2 reviews the theoretical and empirical literature on climate change, energy access and poverty in developing economies. Section 3 describes the data sources, sample construction and variable definitions. Section 4 sets out the econometric methodology. Section 5 presents and discusses the regression results. Section 6 concludes with policy implications.

2.0. LITERATURE REVIEW

2.1. Theoretical Framework

Two theoretical strands underpin this study. Firstly, Environmental Kuznets Curve (EKC) hypothesis credited to Grossman and Krueger (1991). The EKC posits an inverted-U relationship between income per capita and environmental degradation. The theory asserts that pollution rises with early industrialization before falling as economies grow wealthy enough to demand and afford cleaner technology. Secondly, the natural resource curse hypothesis, formalized by Sachs and Warner (1995, 2001). This theory argues that resource-abundant economies systematically underperform resource-scarce ones on growth and welfare. This is possible through channels of real exchange rate appreciation, institutional weakening and crowding-out of manufacturing. Van der Ploeg (2011) later refined this theory into a conditional curse where resource wealth harms development due to weak institutions and poor governance.

2.2. Climate Variability and Economic Outcomes in Sub-Saharan Africa

Several macroeconomic literature links climate variabilities directly to Africa's growth performance. Barrios, Bertinelli and Strobl (2010) utilized a cross-country panel climate change dataset to show that declining and more volatile rainfall trends account for a substantial share of the income gap between Sub-Saharan Africa and the rest of the developing world. This establishes climate variability as a first-order, region-specific growth constraint rather than a marginal factor. Nwosu et al. (2023) examined the effect of climate change on international trade in Nigeria using annual data from 1981 to 2021 and a six-variable structural vector autoregression model. The study found that carbon dioxide emissions significantly reduced Nigeria's total trade and exports. Specifically, a one-megaton increase in CO_2 emissions was associated with about a 21% decline in total trade and a 75% decline in total exports. The impulse-response results further showed that a positive shock to CO_2 emissions caused total trade and exports to fall during the first three years. In addition, the response of economic growth to shocks from CO_2 emissions remained negative throughout the ten-year forecast horizon, confirming the adverse effect of climate change on trade and economic performance in Nigeria.

Similarly, Nwosu et al. (2024) investigated the relationship between carbon emissions and international trade in 41 Sub-Saharan African countries over the period 1980–2020 using a dynamic panel threshold model. The findings revealed a nonlinear relationship between CO_2 emissions and total trade, exports, and imports. The estimated emission thresholds were 3,281.2 million metric tons for total trade, 4,939.4 million metric tons for exports, and 914.2 million metric tons for imports, with an average threshold of 2,455.29 million metric tons. Below the threshold, emissions were positively associated with total trade and imports, but above the threshold, emissions negatively affected all trade indicators. The export threshold exceeded the import threshold, indicating that Sub-Saharan African countries exported more emission-embodied goods than they imported. However, the findings did not support the Pollution Haven Hypothesis in the region

The IPCC's Sixth Assessment Report Africa chapter (Trisos et al., 2022) synthesizes two decades of vulnerability research to conclude that multiple African countries face compounding risks to food systems, labour productivity and human settlements. Poverty and livelihoods have been identified as a distinct vulnerability sector in these dynamics. This body of work motivates treating climate-related variables as structurally linked to poverty outcomes in SSA, rather than as a peripheral environmental concern.

2.3. CO2 Emissions and the Energy-Growth-Environment Nexus

A large panel-econometric literature has tested the EKC hypothesis specifically for Africa with mixed findings. Espoir, Sunge and Bannor (2023) employed pooled mean group ARDL estimation across 47 African countries from 1996 to 2019 and found support for the EKC hypothesis once urbanization, renewable energy and governance quality are controlled for. By contrast, a spatial econometric analysis of 35 SSA countries finds that the EKC holds for natural resource depletion but not for CO2 emissions once spatial interdependence between neighboring countries is controlled for. This implies that non-spatial panel models may produce biased inference (PMC, 2023). Other studies narrow the analysis to specific channels: research applying fully modified OLS to thirteen SSA countries finds that fossil-fuel-intensive industrial financing raises CO2 emissions substantially, while also finding support for a pollution-haven dynamic in the region's industrial sector. Collectively, this literature establishes that the emissions-growth relationship in SSA is real, non-trivial in magnitude, but highly sensitive to model.

2.4. Energy Access and Poverty Reduction: Micro-Level Evidence

A separate, more micro-oriented literature examines whether energy access causally reduces poverty. Dinkelman (2011) exploits South Africa's mass rural electrification roll-out and finds that electrification significantly raised female employment within five years, largely by releasing women from home production. Lenz, Munyehirwe, Peters and Sievert (2017) evaluate Rwanda's large-scale electricity access programme and find measurable poverty-alleviating effects of grid connection on household welfare. Similar findings recur across the region: quasi-experimental evidence from Ghana's rural electrification programme shows household expenditure roughly 64 percent higher in electrified communities and recent work on Senegal using propensity-score matching and differencein-differences finds that on-grid electrification raises both food and non-food household expenditure. This micro-level literature suggests that energy access operates as a distinct, largely welfare-enhancing channel. This is conceptually separated from the aggregate emissions-growth relationship examined in the EKC.

3.0. METHODOLOGY

3.1 Data Sources and Sample

This study utilized an unbalanced country-year panel of Sub-Saharan African (SSA) economies constructed by merging two secondary data sources. Poverty data were drawn from the World Bank's Poverty and Inequality Platform (PIP), which reports the headcount ratio at the international poverty line ($2.15/day, 2017 PPP) for each country in the years in which a nationally representative household survey was conducted. CO2 emissions, energy consumption and GDP data are drawn from Our World in Data's CO2 and Greenhouse Gas Emissions dataset. The two datasets were merged on country and year and restricted to the SSA 49 countries. Because household surveys are not conducted annually in every country, the resulting panel is unbalanced and the final analysis sample comprises 148 country-year observations across 44 countries spanning 2000 to 2019.

3.2 Variable Definitions and Measurement

The dependent variable is the poverty headcount ratio at the international poverty line expressed as a percentage of the national population. The three independent variables of the study are CO2 emissions per capita, primary energy consumption per capita and GDP per capita. Each of these variables were expressed in natural logarithms to reduce the influence of skewness and outliers and to allow coefficients to be interpreted as approximate elasticities. GDP per capita was included as the principal control variable. This is because both emissions and energy consumption are structurally correlated with income. Its inclusion isolates the association between emissions/energy intensity and poverty net of the general income effect. The indicators are presented in Table 1.

Table 1 summarizes the variables, their construction, and their sources.

Variable	Symbol	Definition	Source
Poverty headcount ratio	POV_{it}	% of population below $2.15/day (2017 PPP)	OWID
CO2 emissions per capita	$CO2_{it}$	Territorial CO2 emissions per person	OWID
Energy consumption per capita	EPC_{it}	Primary energy consumption per person	OWID
GDP per capita	$PGDP_{it}$	GDP per person, (2017 PPP)	OWID
Country fixed effect	α_{it}	Time-invariant country characteristics	—
Year fixed effect	λ_{it}	Common shocks affecting all countries in year t	—

Note: i indexes country and t indexes year. All logged variables are natural logarithms.

3.3 Model Specification

The baseline empirical model takes the standard panel linear form:

$$POV_{it} = \beta_0 + \beta_1 CO2_{it} + \beta_2 EPC_{it} + \beta_3 PGDP_{it} + \alpha_{it} + \lambda_{it} + \varepsilon_{it} \quad (1)$$

where POV_{it} is the poverty headcount ratio for country i in year t, EPC_{it}, $CO2_{it}$, $PGDP_{it}$ are as defined in Table 1, α_i captures time-invariant, country-specific heterogeneity (institutional quality, geography, colonial history, and similar slow-moving factors); λ_{it} captures common shocks affecting all SSA countries in a given year and ε_{it} is the idiosyncratic error term. Four estimators of this model were computed to allow explicit comparison rather than reliance on a single specification: (i) Pooled OLS, which ignores both α_{it} and λ_{it} and is consistent only if unobserved heterogeneity is uncorrelated with the regressors; (ii) a Fixed Effects model with country effects only (iii) a Fixed Effects model with both country and year effects and (iv) a Random Effects model, which treats α_{it} as a random draw uncorrelated with the regressors and is more efficient than Fixed Effects if that assumption holds.

3.4 Estimation Technique and Model Selection

All models were estimated in Python using the linear model's package (Panel OLS for the Pooled OLS and Fixed Effects specifications, and Random Effects for the Random Effects specification). The Standard errors were clustered at the country level throughout in order to allow for arbitrary heteroskedasticity and serial correlation within each country's error terms over time. Because Fixed and Random Effects rest on different, non-nested assumptions about the correlation between α_{it} and the regressors, a Hausman specification test was used to choose between them. which is distributed as χ^2 under the null hypothesis that the Random Effects estimator is consistent and efficient (i.e., that α_{it} is uncorrelated with the regressors). Rejection of the null hypothesis favours the Fixed Effects estimator which remains consistent regardless of any such correlation at the cost of being unable to estimate the effect of any time-invariant regressor.

The test statistic is computed as:

$$H = (b_{FE} - b_{RE})' \left[Var(b_{FE}) - Var(b_{RE})\right]^{-1} (b_{FE} - b_{RE}) \qquad (2)$$

4.0. PRESENTATION OF RESULTS AND DISCUSSION

4.1. Presentation of Results

Descriptive Statistical Assessment of the Key Indicator

Table 2 summarizes the sample used for analysis. The average poverty headcount ratio across the 148 country-year observations is 40.9% with substantial cross-country dispersion (standard deviation of 22.2 percentage points). The full range of the sample spanning from 0.2% to 94.3% reveal the well-documented heterogeneity of poverty outcomes across Sub-Saharan Africa. CO2 emissions per capita averaged 0.85 tonnes with a heavily right-skewed distribution (maximum of 9.68 tonnes). This is consistent with the region's low average emissions. GDP and energy consumption per capita display similarly wide ranges which motivated the log transformation of the variables.

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Median	Max
Poverty headcount	40.89	22.17	0.21	40.87	94.28
CO2 per capita	0.85	1.72	0.02	0.27	9.68
GDP per capita	3,522.98	4,333.63	485.17	1,780.40	25,929.73
Energy per capita	3,865.69	7,771.98	101.88	1,318.97	52,513.86

Source: Authors' Analysis (2026).

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Panel Regression Results

Table 3 reports coefficient estimates from all four estimators specified in equation (1) with t-statistics from country-clustered standard errors shown in parentheses. Two patterns are immediately evident. Firstly, the coefficients on $CO2_{it}$ and $PGDP_{it}$ are negative and substantially larger in the Fixed Effects model than in the Pooled OLS or Random Effects specifications models. This indicates that cross-country differences in levels were masking a stronger within-country relationship. Secondly, once year effects are added in Column 3, both the magnitude and statistical significance of the $CO2_{it}$ and $PGDP_{it}$ coefficients fall sharply and the sign on $PGDP_{it}$ reverses.

Table 3. Panel Regression Results — Dependent Variable: Poverty Headcount Ratio (%)

Variable	Pooled OLS	FE (Country)	FE (Country+Year)	Random Effects
Constant	106.88** (2.71)	—	—	132.49*** (3.03)
$Co2_{it}$	-4.56 (-0.99)	-13.85* (-1.96)	-8.87 (-1.34)	-5.40 (-1.12)
$PGDP_{it}$	-3.92 (-0.95)	-13.76** (-2.01)	6.76 (0.63)	-7.29* (-1.78)
EPC_{it}	-5.64 (-1.17)	-9.52 (-1.38)	-3.70 (-0.61)	-5.76 (-1.10)
Observations	148	148	148	148
Countries	44	44	44	44
R^2 (within)	0.281	0.447	0.144	0.333
R^2 (overall)	0.531	–17.951	0.862	0.498
F-statistic	54.39***	27.24***	3.55**	35.35***
Effects included	None	Entity	Entity + Time	None (random)

Note: t-statistics from country-clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10. The F-test for poolability (Fixed Effects vs. Pooled OLS) is significant at the 1% level in both Fixed Effects specifications ($F(43,101) = 7.88$, $p<0.001$ for Column 2; $F(62,82) = 7.71$, $p<0.001$ for Column 3), confirming that country heterogeneity is jointly significant and pooling is inappropriate.

In the preferred Fixed Effects (Country) specification (Column 2), a one-percent within-country increase in CO2 emissions per capita is associated with a 0.139 percentage-point reduction in the poverty headcount ratio ($\beta = -13.85$, $p = 0.053$), significant at the 10% level. The coefficient on GDP per capita is of similar magnitude and reaches conventional significance ($\beta = -13.76$, $p = 0.048$): a one-percent increase in income per capita is associated with a 0.138 percentage-point reduction in poverty. The coefficient on energy consumption per capita is negative but not statistically significant ($\beta = -9.52$, $p = 0.170$). This specification explains 44.7% of within-country variation in poverty (R^2 within = 0.447), a marked improvement over the 28.1% explained by Pooled OLS.

Model Selection Using the Hausman Test

To choose between the Fixed Effects and Random Effects specifications, a Hausman test was conducted comparing the Column 2 and Column 4 estimates. The test statistic is $\chi^2 = 30.09$ (df = 3, $p < 0.0001$), decisively rejecting the null hypothesis that the Random Effects estimator is consistent and efficient. This indicates that the country-specific effects (α_{it}) are significantly correlated with the regressors which is plausible given that unobserved factors such as institutional quality, resource endowment, and statistical capacity are likely correlated with both a country's emissions/energy profile and its poverty trajectory. The Fixed Effects (Country) specification in Column 2 is therefore treated as the preferred model for interpretation.

4.2. Discussion

The results showed that within SSA countries over the 2000 to 2019, periods of higher carbon emissions and higher income per capita which are both markers of more energy and capital intensive economic activity coincided with statistically significant reductions in poverty. This finding confirms the micro-level electrification-poverty relationship of Dinkelman, (2011) and Lenz et al., (2017) which documents welfare gains from expanded energy access. This finding is contrary to the more pessimistic resource-curse hypothesis of Sachs and Warner (1995, 2001) which predicted weak or negative associations between carbon-intensive growth and broad-based welfare. Even though this may not be judged as evidence against the resource curse hypothesis because CO2 emissions per capita is an aggregate and economy-wide measure. The present results are consistent with an energy-access channel operating alongside or independently of aggregate emissions growth.

The sharp decrease of results once year fixed effects are added suggests that a meaningful share of the country-level association between CO2/GDP growth and poverty reduction reflects a common regional trend. The reflects the continent-wide expansion of electricity access and income documented rather than a mechanism specific to each country's own emissions trajectory. This is broadly consistent with the climate-variability of Barrios et al., (2010) who found that region-wide climatic and economic trends are central to explaining SSA outcomes.

The weak and insignificant coefficient on energy consumption per capita, despite its conceptual centrality to the energy-poverty literature is a notable non-result. One plausible explanation is that primary energy consumption per capita is a poor proxy for the household-level electricity access variable (grid connection, hours of reliable supply) that the micro-literature shows to matter most.

These results support three major conclusions. Firstly, the choice of panel specification matters substantially in this literature: the Pooled OLS, Fixed Effects, and Random Effects estimates differ not only in magnitude but in sign. Secondly, once appropriate country heterogeneity is controlled for, carbon-intensive and income growth are associated with lower poverty within SSA countries. This is relevant to policy debates over the pace and sequencing of decarbonization in energy-poor economies such as Nigeria. Thirdly, the decrease in size of this relationship once regional year effects are introduced counsels caution against attributing the full association to country-specific policy choices, and against any causal interpretation of these estimates.

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study examined the relationship between carbon emissions, energy consumption, and poverty across 44 Sub-Saharan African countries between 2000 and 2019 using panel data econometric techniques. By comparing pooled OLS, Fixed Effects, and Random Effects estimators and applying the Hausman specification test, the study established that the Fixed Effects model provides the most reliable estimates after accounting for country-specific heterogeneity.

The empirical results indicate that increases in CO_2 emissions per capita and GDP per capita are associated with lower poverty levels within countries, suggesting that periods of economic expansion and productive industrial activity have contributed to poverty reduction in the region. In contrast, although energy consumption per capita exhibits the expected negative relationship with poverty, its effect is not statistically significant. This finding implies that higher aggregate energy consumption does not automatically improve household welfare, particularly where energy access remains uneven and infrastructure is inadequate.

Overall, the findings demonstrate that the challenge confronting Sub-Saharan Africa is not merely reducing carbon emissions but achieving sustainable economic growth while expanding access to reliable, affordable and clean energy. The study therefore highlights the importance of balancing climate commitments with poverty reduction objectives. Rather than viewing environmental sustainability and economic development as competing goals, policymakers should pursue integrated strategies that promote inclusive growth, expand modern energy access, strengthen institutional capacity and support a just energy transition capable of reducing poverty without compromising long-term environmental sustainability.

5.2. Recommendations

Based on the findings of this study, the following recommendations are proposed

1. Governments should prioritize investments in electricity generation, transmission and renewable energy infrastructure to improve household welfare and stimulate productive economic activities.
2. Governments should implement policies that encourage industrial growth based on cleaner technologies that simultaneously generate employment, increase incomes and minimize environmental degradation.
3. Resource-dependent economies should diversify into manufacturing, agriculture, technology, and services to reduce excessive dependence on fossil fuel revenues while sustaining poverty reduction.
4. Public and private sector investments in solar, wind, hydroelectric and other renewable energy sources should be expanded to improve energy security while supporting climate mitigation goals.
5. Strong institutions are needed to ensure efficient management of natural resources, transparent implementation of climate policies and effective delivery of energy infrastructure.

Conflict of Interest

The authors declare that no conflict of interest exist in this manuscript.

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APPENDIX

Sampled Countries

Angola	Gabon	Niger
Botswana	Gambia	Nigeria
Burkina Faso	Ghana	Rwanda
Burundi	Guinea	Sao Tome and Principe
Cameroon	Guinea-Bissau	Senegal
Cape Verde	Kenya	Seychelles
Central African Republic	Lesotho	Sierra Leone
Chad	Liberia	South Africa
Comoros	Madagascar	Tanzania
Congo	Malawi	Togo
Cote d'Ivoire	Mali	Uganda
Democratic Republic of Congo	Mauritania	Zambia
Djibouti	Mauritius	Zimbabwe
Eswatini	Mozambique	
Ethiopia	Namibia	