IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 418-433.

EJ EconJournals

Modelling Structural and Macroeconomic Drivers of Disparities in the Energy–Growth Nexus in Sub-Saharan Africa

Nyeso Christian Azubuike[1]*, Sunday Sunday Ikiensikimama[1,2], Uche Osokogwu[1,2]

[1]The Africa Centre of Excellence in Oilfield Chemicals Research (ACE-CEFOR), University of Port Harcourt. East-West Road, P.M.B 5323, Choba, Rivers State, Nigeria. [2]Institute of Petroleum and Energy Studies, University of Port Harcourt, Choba, Rivers State, Nigeria. *Email: azubuike.nyeso@aceceforuniport.edu.ng

Received: 06 September 2025 **Accepted:** 17 January 2026 **DOI:** https://doi.org/10.32479/ijeep.22115

ABSTRACT

The energy–growth–environment nexus has long been central to debates on sustainable development, yet empirical evidence for Sub-Saharan Africa (SSA) remains fragmented and inconclusive. While earlier studies have explored the impact of energy consumption on growth, limited attention has been given to the drivers of disparities in the nexus across SSA. This gap is particularly significant given the region heterogeneous economic structures, resource endowments, and demographic dynamics. This study investigates the structural and macroeconomic determinants of disparities in the energy–growth relationship across 41 SSA countries between 1990 and 2024. Specifically, it examines how factors such as human development, labour force participation, unemployment, population growth, and foreign direct investment (FDI) interact with energy use to influence economic growth. A dynamic linear growth model is estimated using the Sequential Two-Stage Generalized Method of Moments (GMM). The results show weak evidence of growth persistence, as lagged GDP coefficients were positive but statistically insignificant. Total energy consumption also proved insignificant, suggesting that energy expansion alone does not directly drive growth in SSA. By contrast, the human development index exhibited a strong and significant positive effect, underscoring the centrality of human capital to long-run growth. Labor force participation contributed positively with marginal significance, while unemployment had a slight but negative impact, reflecting structural labour market inefficiencies. Population growth and FDI were both insignificant, pointing to demographic pressures and limited absorptive capacity. These findings highlight the need for integrated policy frameworks that prioritize human capital investment, labour market reforms, expansion in renewable energy access, institutional strengthening, and demographic management. A key limitation of the study is the exclusion of some country-specific structural factors, such as governance, geography and natural endowments. Future research should incorporate these variables and explore country-level asymmetries to better inform targeted policy formulation.

Keywords: Economic Growth, Energy Consumption, Sub-Saharan Africa, Macroeconomic and Structural Drivers
JEL Classifications: Q43; O47; O13; O55

1. INTRODUCTION

Energy is a critical driver of economic transformation, underpinning industrialisation, technological progress, and improvements in living standards. The causal relationship between energy consumption and economic growth has been a focal point for economists and energy researchers since the foundational work by Kraft (Kraft and Kraft, 1978), and the driving force behind this strong research interest is the significant policy implications it holds (Effiong and Hosu, 2025; Kahsai et al., 2012; Ranjbar et al., 2017; Shakouri and Khoshnevis Yazdi, 2017). In Sub-Saharan Africa (SSA), access to reliable and affordable energy is particularly vital for advancing the United Nation's Sustainable Development Goals (UNSDGs) (United Nations, 2015), stimulating productivity, and reducing poverty (Kaygusuz, 2012; Nathwani and Kammen, 2019).

Despite a shared imperative for economic growth and energy expansion, the relationship between energy consumption and economic performance, known as the *energy–growth nexus* has proven far from uniform across SSA countries (see, literature surveys by Refs. [Azubuike et al., 2025; Biala et al., 2025; Isa et al., 2015; Ozturk, 2010; Payne, 2010]). Some economies exhibit strong positive linkages where increased energy use drives economic expansion, while others display weak or negligible connections, reflecting the competing theoretical frameworks, such as the neoclassical and endogenous growth models, used to explain the energy–growth nexus.

The neoclassical growth models, such as the Solow–Swan model, view long-term economic growth as being driven primarily by the accumulation of capital and labour, with technological progress treated as an exogenous factor (Solow, 1956; Swan, 1956). In these models, energy is typically considered an intermediate or supporting input in production, rather than a central driver of sustained growth. The key implication is that, while increasing the use of energy can raise output in the short run, the principle of diminishing marginal returns applies. This means that, if other inputs are held constant, each additional unit of energy yields progressively smaller increases in output (Berndt and Wood, 1975; Stern, 1993).

Conversely, the endogenous growth theory emphasises the role of energy as a productive input that fosters long-term growth through technology adoption and efficiency improvements (Aghion and Howitt, 1998; Pack, 1994; Romer, 1986; Romer, 1990). Within the endogenous framework, energy is not merely an intermediate input but a key enabler of sustained growth, implying that energy availability, its interaction with technological change and efficient utilisation can have persistent effects on economic growth, rather than diminishing returns (Howitt, 2018; Joshua, 2015; Payne, 2010; Sadorsky, 2011; Smulders and de Nooij, 2003; Stern, 2011).

Additionally, several studies within the SSA also find that energy consumption significantly influences carbon emissions, with non-renewable sources increasing emissions and renewable sources reducing them (Antonakakis et al., 2017; Apergis and Payne, 2010b; Apergis and Payne, 2010a; Awodumi and Adewuyi, 2020; Bélaïd and Youssef, 2017; Ganda, 2019; İnal et al., 2022; Tiba and Belaid, 2021). Simultaneously, economic growth is suggested to affect carbon emissions, which is consistent with the Environmental Kuznets Curve (EKC) hypothesis, which describes the interaction, potential trade-offs and synergies between economic development, energy consumption, and environmental outcomes (Bardhan, 1995; Stern, 2004; Stern, 2018).

Generally, four main empirical hypotheses are used to describe energy–growth causality: The growth hypothesis (energy drives growth), the conservation hypothesis (growth drives energy use), the feedback hypothesis (bidirectional causality), and the neutrality hypothesis (no causal link). A detailed explanation of each of these hypotheses, along with supporting empirical studies, is provided in the authors' prior publication (Azubuike et al., 2025).

However, as earlier noted, empirical evidence from SSA remains mixed, whether energy consumption is examined in aggregate or disaggregated into non-renewable and renewable sources (Adams et al., 2018; Akinlo, 2008; Albiman et al., 2015; Baz et al., 2021; Bekun et al., 2025; Belloumi, 2009; Bhattacharya et al., 2016; Ebohon, 1996; Effiong and Hosu, 2025; Esso, 2010; Fossong et al., 2021; Ivanovski et al., 2021; Kais and Ben Mbarek, 2017; Sunde, 2020; Tugcu and Topcu, 2018; Wolde-Rufael, 2005; Wolde-Rufael, 2006; Wolde-Rufael, 2009; Yang et al., 2022). For instance, Esso found heterogeneous causal relationships among seven African countries, reporting bidirectional causality for Côte d'Ivoire, support for the conservation hypothesis in Congo and Ghana, and neutrality in Cameroon, Nigeria, Kenya, and South Africa (Esso, 2010). Similarly, Odhiambo, using the same analytical framework, identified growth-driven causality in South Africa and Kenya but a feedback relationship in the Democratic Republic of Congo (Odhiambo, 2010). Akinlo, analysing eleven SSA countries, observed neutrality in Cameroon, Côte d'Ivoire, Nigeria, Kenya, and Togo, while the remaining countries supported either the growth, conservation, or feedback hypotheses (Akinlo, 2008). Adewuyi and Awodumi reported feedback effects for Nigeria, Burkina Faso, The Gambia, Mali, and Togo, with neutrality prevailing in other West African states (Adewuyi and Awodumi, 2017). Earlier studies by Odhiambo and Ebohon also highlighted variation: Odhiambo documented growth-led causality for Tanzania, whereas Ebohon found bidirectional causality in both Tanzania and Nigeria (Odhiambo, 2009; Ebohon, 1996). Collectively, these findings underscore the absence of a uniform energy–growth dynamic in SSA. To further illustrate this, Appendix 1 presents a comprehensive survey of 46 empirical studies within the SSA context, detailing the authors, study periods, countries examined, econometric methodologies employed, and the diverse conclusions on energy–growth causality, as well as their combined impact on carbon emissions. These disparities suggest that the energy–growth relationship is mediated by deeper structural and macroeconomic factors, underscoring the need for an integrated framework to identify and analyse these drivers (Baz et al., 2021; Joshua, 2015; Tugcu and Topcu, 2018).

Conventionally, the growth impact of energy use is shaped by structural factors including sectoral composition, infrastructure quality, institutional strength, demographic dynamics, and technological capacity. Likewise, macroeconomic factors such as GDP level, energy intensity, government expenditure, human capital, labour market conditions, physical capital, and fiscal policies shape the affordability, availability, and efficiency of energy use (Akinlo, 2008; Bhattacharya et al., 2016; Karekezi, 2002; Sadorsky, 2011; Stern, 2011). In combination, these structural and macroeconomic factors create a set of enabling or constraining conditions that mediate the link between energy consumption and economic growth. Industrialised economies with diversified, energy-intensive sectors, robust infrastructure, strong institutions, balanced demographic transitions, high technological capacity, strong GDP levels, low energy intensity, robust public investment, high human capital, efficient physical capital, healthy labour markets, and sound fiscal policies are better positioned to maximise the growth benefits of energy consumption. Conversely, where these conditions are weak, increased energy consumption may yield limited economic gains. These factors are unevenly distributed across SSA, implying that a one-size-fits-all interpretation of the energy–growth nexus is inadequate for policy formulation. This underscores the need to identify and address the drivers of these disparities at sub-regional and country levels, so that policymakers can develop context-specific strategies that not only expand energy access but also enhance its contribution to economic performance.

This study aims to address these research needs, by modelling the structural and macroeconomic drivers underlying disparities in the energy–growth nexus across SSA. Specifically, it seeks to (i) identify the key determinants of heterogeneity in the energy–growth relationship, (ii) quantify the relative influence of each identified structural and macroeconomic factor, and (iii) draw policy-relevant insights for fostering sustainable energy-driven growth. By integrating these perspectives within an econometric modelling framework, the paper contributes to the literature in three ways. First, it moves beyond average regional estimates to examine cross-country variation. Second, it jointly considers structural and macroeconomic determinants, which are often treated separately in prior studies. Third, it provides empirical evidence that can inform tailored policy interventions to bridge development gaps within SSA.

2. METHODOLOGY

2.1. Data Collection

The study relies on secondary data (panel data) including GDP per capita (PPP, constant 2017 US$), per capita energy consumption (measured in kilograms of oil equivalent), carbon dioxide emissions per GDP (expressed in kilograms per US$), populations growth rate (historical estimates), Unemployment, total (% of total labour force), human development index, total labour force, Research and development expenditure (% of GDP), and Foreign direct investment, net inflows (BoP, current US$). These indicators were obtained from reputable international databases, namely, the World Bank's World Development Indicators (WDI) (World Bank, 2023), International Energy Agency (IEA) (IEA, 2019; IEA, 2021; IEA, 2022a; IEA, 2022b), and the Global Footprint Network (GFN) (Global Footprint Network, 2023), which are widely recognised for their accuracy and methodological rigor. The dataset is annual, spanning the years 1990-2024, thereby providing 35 observations per country. The analysis covers 41 Sub-Saharan African (SSA) countries, selected based on the availability of consistent and comparable data across the period, their representativeness of the region, and their relevance to the study's focus on the interlinkages among energy use, economic growth, and environmental sustainability. The countries are; Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Republic of Congo, Democratic Republic of Congo, Côte d'Ivoire, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

2.2. Descriptive Statistics of Variables

Table 1 presents the descriptive statistics for the variables employed in the analysis. Over the study period, the average real GDP across the Sub-Saharan African (SSA) sample was approximately US$26.6 billion, with the mean substantially higher than the median value of US$8.49 billion. This indicates a positively skewed distribution in which most countries generated GDP below the average. The range extends from US$0.17 billion in Equatorial Guinea (1991) to US$ 400.26 billion in South Africa (2024), underscoring wide disparities in economic size. The overall standard deviation of 66.21 reflects considerable dispersion, while the relatively smaller within-country deviation (25.18) suggests that variation is largely attributable to cross-country differences rather than changes within individual economies over time.

Energy consumption displays a similar pattern. The mean value of 7.18 billion kWh exceeds the median of 1.09 billion kWh, again indicating right-skewness. South Africa recorded the highest consumption at 220.40 billion kWh in 2007, whereas Comoros reported the lowest at 0.01 billion kWh in 2000. The high overall and between-country standard deviations (29.35 and 29.39, respectively) highlight strong heterogeneity in consumption levels across SSA, while the relatively low within-country deviation (4.22) points to limited variation over time within individual economies.

Other variables display mixed levels of dispersion. The human development index, unemployment rate, and population growth rate all have relatively low overall standard deviations (0.11, 6.53, and 1.29, respectively), indicating limited variability around their averages. By contrast, the labour force (10.33) and foreign direct investment (7.58) exhibit large standard deviations, suggesting substantial cross-country differences in these structural drivers.

2.3. Model Specification

The analytical framework of this study is rooted in Endogenous Growth Theory, which emphasizes that long-run economic

Table 1: Descriptive statistics of selected variables: n=41 countries; T=35(1990-2024)

S/N	Variables	Mean	Median	Overall standard deviation	Between standard deviation	Within standard deviation	Min	Max
1	Real GDP	26.60	8.49	66.21	61.97	25.18	0.17	400.26
2	Total energy consumption	7.18	1.09	29.35	29.39	4.22	0.01	220.40
3	Human development index	0.48	0.47	0.11	0.10	0.05	0.22	0.82
4	Total labour force	7.07	3.60	10.33	9.98	3.08	0.10	70.62
5	Unemployment rate	7.71	4.94	6.53	6.46	1.36	0.32	28.77
6	Population Growth Rate	2.52	2.66	1.29	0.72	1.07	−16.88	16.63
7	Foreign Direct Investment	3.27	1.70	7.58	3.49	6.75	−18.92	161.82

performance depends not only on capital and labour but also on structural factors such as technology, human capital, energy use, and institutional quality. Within this framework, energy and environmental resources are essential inputs whose allocation and efficiency directly shape productivity and growth (Aghion and Howitt, 1998; Lucas, 1988; Pack, 1994; Romer, 1986; Romer, 1990). Building on this perspective, the study adopts the Energy–Environment–Growth Nexus framework, which recognizes the interdependence of economic expansion, energy consumption, and environmental outcomes (Apergis and Payne, 2009; Omri, 2013; Ozturk, 2010). Economic growth stimulates energy use and emissions, while environmental pressures and policy responses feed back into the growth process. In SSA, where economies vary widely in resource endowments, energy intensity, institutional capacity, policy environments, and demographic dynamics, disparities in the energy–growth relationship are largely explained by variations in these underlying drivers.

The functional specification of the models estimated is presented thus (Equation 1 and 2):

$$RGDP = f(TEC_t) \tag{1}$$

$$RGDP = f(TEC,\ HDI,\ TLF,\ UEM,\ POPGR,\ FDI) \tag{2}$$

Where *f* indicates function of, RGDP is real GDP (serves as a proxy for economic growth), TEC_t is total, renewable and non-renewable energy consumption, HDI is Human Development Index (a proxy for human capital development), TLF is Total Labour Force, UEM is Unemployment Rate, POPGR is Population Growth, and FDI is Foreign Direct Investment.

2.4. Pre-estimation Tests

2.4.1. Collinearity diagnostics

In econometric models, multicollinearity occurs when independent variables are highly correlated, making it difficult to separate their individual effects, and compromise the robustness of the regression outcome. Therefore, before estimating the model, a pairwise correlation matrix was employed to examine the degree of linear association among the variables and to detect potential multicollinearity.

2.4.2. Cross-section dependence diagnostics

Cross-sectional dependence (CD) diagnostics provide an essential preliminary check for identifying interdependencies across units in panel data. While conventional panel models often assume cross-sectional independence, especially in large samples, empirical evidence suggests that such independence is rarely observed in practice, with cross-sectional dependence being a common feature of macro-panel datasets (Adams and Klobodu, 2017; Beckmann and Czudaj, 2017; Pesaran, 2015; Pesaran, 2021). Therefore, imposing the assumption of cross-sectional independence in the presence of significant interdependencies can lead to serious econometric problems. Specifically, it may produce inefficient estimators, biased coefficient estimates, and invalid standard errors, which in turn compromise hypothesis testing and the overall reliability of inference (Adams and Klobodu, 2017; Beckmann and Czudaj, 2017; Pesaran, 2015; Pesaran, 2021).

2.4.3. Stationarity diagnostics

Testing for stationarity in panel data is critical to determine whether the underlying time-series processes are stable over time. A non-stationary process can lead to spurious regression results, as such series are difficult to represent using equations with fixed coefficients (Pindyck and Rubinfeld, 1988). To address this concern, a range of panel unit root tests has been developed to examine the stochastic properties of panel data.

For the present study, the Cross-Sectionally Augmented Dickey-Fuller (CADF) test proposed by Pesaran (Pesaran, 2003), was employed (Equation 3). The CADF test is specifically designed to account for cross-sectional dependence by including cross-sectional averages ($\bar{y}_{t-1}$, $\Delta\bar{y}_{t-j}$), a limitation of traditional first-generation unit root tests such as the Levin–Lin–Chu and Im–Pesaran–Shin approaches (Caporale and Pittis, 1999; Im et al., 2003). By incorporating these cross-sectional averages of lagged levels and first differences into the regression, the CADF framework provides a more reliable assessment of stationarity in macro-panel datasets where units are likely to be correlated (Le and Ozturk, 2020; Ullah et al., 2024). In practice, the CADF test runs an augmented Dickey-Fuller regression for each cross-sectional unit, while including additional terms to capture common shocks and interdependencies across units. The null hypothesis of a unit root is tested for each cross-sectional unit individually. The CADF test yields a t-statistic for each unit, which is then used to compute a panel test statistic (Im et al., 2003).

$$\Delta y_{i,t} = \alpha_i + \beta i y_{i,t-1} + \gamma i t + \delta i \bar{y}_{t-1} + \Sigma\,\theta ij\,\Delta\bar{y}_{t-j} + \Sigma\,\lambda ij\,\Delta y_{i,t-j} + \varepsilon i,t \tag{3}$$

Where, $\Delta y_{i,t}$ is the first difference of the time series variable for unit *i* at time *t*; a_i is a unit-specific intercept (heterogeneous across cross-sections), $\beta i y_{i,t-1}$ is the lagged dependent variable capturing persistence (unit root component); γit is the deterministic trend term; $\delta i \bar{y}_{t-1}$ is the cross-sectional average of the lagged dependent variable, accounting for common factors across units; $\theta ij\,\Delta\bar{y}_{t-j}$ is the lags of the differenced cross-sectional average, further controlling for global shocks and cross-unit dependence; $\Sigma\lambda ij\,\Delta y_{i,t-j}$ is the lags of the differenced dependent variable, addressing autocorrelation and $\varepsilon_{i,t}$ is the error or residual term.

2.4.4. Cointegration diagnostics

Panel cointegration diagnostics were carried out to evaluate whether a stable long-run equilibrium relationship exists among the variables under consideration. Unlike traditional time-series techniques that emphasize normalization or the precise number of cointegrating vectors, panel cointegration tests focus on detecting statistical evidence of cointegration across multiple cross-sectional units (Engle and Granger, 1987; Granger, 1981; Kao, 1999; Pedroni, 2004). According to Granger (1981), if each individual series becomes stationary only after first differencing (that is, they are integrated of order one), but a linear combination of them is stationary in levels, then those series are cointegrated, implying they share a long-run relationship (Granger, 1981). Based on the results of the stationarity diagnostics, which indicated that the variables are non-stationary in their levels, the next step was to investigate potential long-run relationships. For this purpose, the study employed the panel cointegration test developed by Kao (Kao, 1999), which is widely used in the econometric literature for assessing cointegration in panel datasets (Equation 4).

$$y_{i,t} = \alpha_i + \delta_{i,t} + \beta_{1i}x_{1i,t} + \beta_{2i}x_{2i,t} + \cdots + \beta_{Mi}x_{Mi,t} + e_{i,t} \quad (4)$$

For t =1…, T; i =1…, N; m=1…, M

Where, T refers to the number of observations over time, and M refers to the number of regression variables. $y_{i,t}$ is the dependent variable for unit i (e.g., country) at time t; a_i is a unit-specific effect (captures unobserved heterogeneity across countries/individuals); $\delta_{i,t}$ is the time-specific effect (accounts for common shocks or time effects that vary across t); $\beta_{1i}, \beta_{2i}, \cdots, \beta_{Mi}$ are coefficients measuring the effect of explanatory variables $x_{1i,t}, x_{2\,i,t}, \cdots, x_{M\,i,t}$ and $e_{i,t}$ is the error term.

2.5. Panel Data Modelling using Generalized Method of Moments (GMM)

The application of a panel autoregressive distributed lag (ARDL) model with symmetry tests to assess the impact of total energy consumption, disaggregated into renewable and non-renewable sources, on economic growth and carbon emissions in the selected SSA countries was undertaken in the author's earlier study (Azubuike et al., 2025). In that work, the model robustness was further validated using a non-linear ARDL model and asymmetric causality techniques. The present paper builds on that analysis by extending the analytical scope to model the structural and macroeconomic drivers of disparities in the energy–growth–environment nexus across SSA using the Sequential Two-Stage Generalized Method of Moments (GMM) (Kripfganz and Schwarz, 2019), presented as Equation (5).

$$lnrgdp_{it} = \beta_0 + \beta_1 lnrgdp_{it-1} + \beta_2\, lntec_{it} + \beta_3\, lnhdi_{it} + \beta_4\, lntlf_{it} + \beta_5\, lnuem_{it} + \beta_6\, popgr_{it} + \beta_7\, lnfdi_{it} + \varepsilon_{it} \quad (5)$$

Where, for country i at time t: $lnrgdp_{it}$ is the Natural log of real GDP (proxy for economic growth); $lnrgdp_{it-1}$ is the Lagged Natural log of real GDP; $lntec_{it}$ is the Natural log of total energy consumed; $lnhdi_{it}$ is the Natural log of human development index; $lntlf_{it}$ is the Natural log of total labour force; $lnuem_{it}$ is the Natural log of unemployment rate; $popgr_{it}$ is the Population growth rate; $lnfdi_{it}$ is the Natural log of foreign direct investment; and ε_{it} is the error term.

A priori = $\beta_1 > 0, \beta_2 > 0, \beta_3 > 0, \beta_4 > 0, \beta_5 < 0, \beta_6 > 0$, and $\beta_7 > 0$ (6)

The choice of this estimator is motivated by several econometric considerations. First, the dynamic nature of the model, which includes a lagged dependent variable as a regressor, introduces endogeneity that renders traditional estimators such as pooled ordinary least-squares (OLS) or fixed effects biased and inconsistent. Second, because disparities are shaped by both structural and time-varying factors, it is necessary to control for unobserved heterogeneity across countries and potential simultaneity between regressors and the error term.

The GMM approach, as developed by Arellano and Bond (1991) and extended by Arellano and Bover (1995) and Blundell and Bond (1998), provides consistent estimates under these conditions by exploiting internal instruments derived from lagged levels and differences of the variables (Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). This estimator also corrects for heteroskedasticity and autocorrelation within panels, thereby improving efficiency compared with single-equation methods.

However, the Arellano and Bond (1991) estimator is not suitable for estimating the coefficients of time-invariant regressors, as these are eliminated by first-differencing. Identification of such coefficients requires the assumption that a sufficient number of regressors (or excluded instruments) are uncorrelated with the unit-specific error component, and incorrect assumptions regarding exogeneity may lead to inconsistency in all estimates. The sequential procedure provides partial robustness to such misspecification, by estimating coefficients of time-varying regressors in the first stage and recovering coefficients of time-invariant regressors in the second stage. Given the relatively short time dimension (T) and larger cross-sectional dimension (N) characteristic of SSA data, the Sequential Two-Stage GMM is particularly well suited for this study.

Consider the dynamic panel data model with units i = 1, 2., N, and a fixed number of time periods t = 1, 2,…, T, with $T \geq 2$:

$$y_{it} = \lambda y_{i,t-1} + x_{it}'\beta + f_i'\gamma + e_{it}; \quad e_{it} = \alpha_i + u_{it} \quad (7)$$

where x_{it} is a $K_x \times 1$ vector of time-varying variables. The initial observations of the dependent variable, y_{i0}, and the regressors, x_{i0}, are assumed to be observed. f_i is a $K_f \times 1$ vector of observed time-invariant variables that includes an overall regression constant, and α_i is an unobserved unit-specific effect of the *i-th* cross section. In a strict sense, α_i is called a fixed effect if it is allowed to be correlated with all of the regressor variables x_{i0} and f_i, and it is a random effect if it is independently distributed.

2.5.1. Arellano-bond test of serial correlation

The Arellano–Bond (AR) tests for autocorrelation were implemented in this study to detect serial correlation in the error terms of dynamic panel models estimated with GMM (Arellano and Bond, 1991). It is applied to the residuals of the first-differenced equation to check whether they are correlated with their own lags. The null hypothesis assumes no autocorrelation, and while first-order correlation [AR(1)] is expected, the absence of second-order correlation [AR(2)] is critical for model validity, as its presence would indicate misspecification and invalidate the moment conditions. The test is also central to assessing instrument validity, since valid instruments must be orthogonal to the error term; higher-order autocorrelation would imply endogeneity and weaken reliability (Arellano and Bond, 1991; Roodman, 2009b). Empirical applications in growth, energy, and environmental economics frequently employ this test to confirm the robustness of dynamic panel estimates, particularly in studies where endogeneity and feedback effects are of concern (e.g., Bond et al., 2001).

2.5.2. Sargan-Hansen test

The Sargan–Hansen test evaluates the validity of overidentifying restrictions in GMM estimation (Hansen, 1982; Sargan, 1958). Its null hypothesis is that the instruments are valid, meaning uncorrelated with the error term and correctly excluded from the estimated equation. The test statistic follows a chi-squared distribution with degrees of freedom equal to the number of overidentifying restrictions. While the original Sargan test assumes homoskedastic errors, Hansen's J statistic provides a robust version suitable for heteroskedastic panel data (Baum et al., 2003; Roodman, 2009b). A failure to reject the null supports instrument validity, whereas rejection raises concerns about model misspecification or instrument endogeneity (Roodman, 2009b). Empirical studies in growth, energy, and environmental economics often rely on this test to validate the use of GMM estimators. For example, Bond et al. Kindly provide these author details in the reference list highlight its importance in testing the robustness of instruments in empirical growth models (Bond et al., 2001), while recent applications in the energy–growth–environment literature underscore the need to ensure valid instrument sets when addressing endogeneity and feedback dynamics (Omri, 2013). In this study, the Sargan–Hansen test was employed to confirm the reliability of the instruments in the Sequential Two-Stage GMM estimation.

3. EMPIRICAL FINDINGS AND DISCUSSIONS

3.1. Collinearity Diagnostics Findings

The correlation analysis indicates that all pairwise coefficients fall below the conventional threshold of 0.90, suggesting that multicollinearity is not a significant concern in the model (Table 2). Empirical research in applied econometrics suggests that multicollinearity becomes problematic primarily when correlation coefficients exceed 0.90 or when variance inflation factors (VIFs) surpass the threshold of 10 (Gujarati and Porter, 2009; Kennedy, 2008; Kutner et al., 2004). The highest observed correlation, at 88.1%, is between the natural logarithm of total energy consumption (lntec) and the natural logarithm of real GDP (lnrgdp), which is theoretically expected given the strong link between energy demand and economic activity. This is followed by a coefficient of 78.0% between the natural logarithm of the total labour force (lntlf) and lnrgdp, reflecting the close association between labour availability and output in developing economies. All remaining correlation coefficients are well below 70%, confirming that the explanatory variables are sufficiently distinct to be included in the model without raising concerns of spurious results. Moreover, the strong but non-problematic correlation between energy consumption and GDP is consistent with prior evidence on the energy–growth relationship in SSA (Acaravci and Ozturk, 2010; Ozturk, 2010), further validating the model's specification.

3.2. Cross-Sectional Dependency Diagnostics Findings

The CD tests, following (Pesaran, 2015; Pesaran, 2021; Fan et al., 2015), were conducted, and the results are reported in Table 3. The findings strongly reject the null hypothesis of cross-sectional independence at the 1% significance level. Specifically, the Pesaran CD test statistics for lnrgdp, tec, lntec, lnhdi, and lntlf (141.02, 119.76, 116.42, 154.98, and 158.51, respectively), with corresponding P = 0.00, confirm significant cross-sectional dependence across the variables. This outcome indicates the presence of strong inter-unit correlations among the selected SSA countries.

The existence of cross-sectional dependence in macro-panel data is not surprising. As noted by Pesaran (2021) and Chudik and

Table 2: Pairwise correlations matrix

Variables	lnrgdp	gdpgr	lntec	lnhdi	lntlf	uem	popgr	fdi
lnrgdp	1.000							
gdpgr	−0.014(0.609)	1.000						
lntec	0.881(0.000)	−0.079(0.004)	1.000					
lnhdi	0.346(0.000)	−0.024(0.398)	0.423(0.000)	1.000				
lntlf	0.780(0.000)	−0.027(0.334)	0.650(0.000)	−0.219(0.000)	1.000			
uem	−0.018(0.510)	−0.057(0.039)	0.196(0.000)	0.531(0.000)	−0.430(0.000)	1.000		
popgr	0.082(0.003)	0.184(0.000)	−0.070(0.011)	−0.208(0.000)	0.174(0.000)	−0.271(0.000)	1.000	
fdi	−0.074(0.007)	0.314(0.000)	−0.073(0.008)	0.073(0.011)	−0.100(0.000)	0.034(0.224)	0.101(0.000)	1.000

P-values are in parenthesis(). **and *implies significance at 1% and 5% levels of significant errors respectively. ln(x) represents the natural logarithm of x to the base e, where 'e' is Euler's number, ≈ 2.71828

Table 3: Cross-sectional dependence diagnostic results

S/N	Variables	Pesaran(2015; 2021) CD		Fan et al.(2015) CD		H_0 Decision
		Statistics	Probability	Statistics	Probability	
1	lnrgdp	141.02**	0.00	4031.57**	0.00	H_0 rejected
2	gdpgr	18.17**	0.00	752.45**	0.00	H_0 rejected
3	tec	117.47**	0.00	3608.12**	0.00	H_0 rejected
4	lntec	116.42**	0.00	3579.53**	0.00	H_0 rejected
5	lnhdi	154.98**	0.00	4441.57**	0.00	H_0 rejected
6	lntlf	158.51**	0.00	4546.84**	0.00	H_0 rejected
7	uem	20.22**	0.00	2258.54**	0.00	H_0 rejected
8	popgr	7.17**	0.00	1536.66**	0.00	H_0 rejected
9	fdi	23.41**	0.00	1082.42**	0.00	H_0 rejected

**and *implies significance at 1% and 5% levels of significant errors respectively

Pesaran (2015), globalization, trade linkages, financial integration, and regional shocks often generate spillover effects that lead to interdependencies across economies (Chudik and Pesaran, 2015; Pesaran, 2007; Pesaran, 2021). In the context of Sub-Saharan Africa, countries share common exposure to external shocks such as fluctuations in global oil prices, climate change impacts, and international capital flows. These shared vulnerabilities create correlated disturbances across panels, making the assumption of cross-sectional independence unrealistic. Similar findings of strong cross-sectional dependence in African energy–growth–emissions studies are reported by Adams and Klobodu (2017) and Chudik & Psarian, (2015), reinforcing the view that ignoring such interdependencies can bias parameter estimates and lead to misleading inferences (Adams and Klobodu, 2017; Chudik and Pesaran, 2015). Given these results, it becomes necessary to adopt estimation techniques that explicitly account for cross-sectional dependence and dynamic interlinkages.

3.3. Stationarity Diagnostics Findings

The results from the cross-sectional dependence tests indicate strong cross-sectional dependence across all variables. To this end, the Cross-Sectionally Augmented Dickey-Fuller (CADF) test proposed by Pesaran (2003) was employed (Pesaran, 2003). The results presented in Table 4 reveal that lnrgdp, tec, lntlf, and uem are non-stationary in levels but become stationary after first differencing, implying they are integrated of order one, I(1). Conversely, other variables such as lnhdi, lnfdi, and popgr are stationary in levels, indicating they are integrated of order zero, I(0). This mixture of I(0) and I(1) processes highlights the heterogeneous stochastic properties of the variables and confirms the need for cointegration analysis to determine whether a long-run equilibrium relationship exists among them (Kao, 1999; Pedroni, 2001). These findings are consistent with prior empirical studies in the energy–growth–environment literature, which often report a mix of stationary and non-stationary variables in panel settings. In particular, while the null hypothesis of a unit root can be rejected for some variables at levels, it is rejected only after first differencing for others (Acaravci and Ozturk, 2010; Omri, 2013; Ozturk and Acaravci, 2011; Saidi and Omri, 2020). By establishing the integration properties of the variables, this study ensures the suitability of subsequent panel cointegration analysis and the application of a dynamic panel GMM framework.

Table 4: Pesaran's CADF second generation (heterogeneous) panel unit root test results

S/N	Variables	Levels		First difference		Status
		Z[t-bar]	P-value	Z[t-bar]	P-value	
1	lnrgdp	−0.382	0.351	−9.498**	0.000	I(1)
2	gdpgr	−10.180**	0.000			I(0)
3	tec	2.296	0.989	−9.757**	0.000	I(1)
4	lntec	−1.683*	0.046			I(0)
5	lnhdi	−6.869**	0.000			I(0)
6	lntlf	−0.165	0.435	−4.752**	0.000	I(1)
7	uem	7.348	1.000	−6.453**	0.000	I(1)
8	popgr	−3.096**	0.001			I(0)
9	fdi	−4.872**	0.000			I(0)

**and *implies significance at 1% (i.e., P<0.01) and 5% levels (i.e., P<0.05) of significant errors respectively. Decision is based on the inverse normal (Z) statistic

3.4. Cointegration Diagnostics Findings

The results of the Kao (1999) panel cointegration test for the dynamic linear model examining the structural and macroeconomic drivers of disparities in the energy consumption–economic growth nexus in SSA are presented in Table 5. The test evaluates the null hypothesis of no cointegration against the alternative of a long-run equilibrium relationship among the variables. The findings show that the null cannot be rejected, as all test statistics are statistically insignificant at the 5% level, with P-values ranging from 0.141 to 0.473. This outcome provides no evidence of cointegration among the variables in the model.

The absence of cointegration implies that the variables under investigation, while possibly linked in the short run, do not share a stable long-run relationship within the panel. This result aligns with the theoretical perspective advanced by Granger, which suggests that cointegration exists only when a linear combination of integrated series becomes stationary (Granger, 1981). Since the test fails to establish such a relationship, it indicates that disparities in the energy–growth nexus across SSA are primarily driven by short-term fluctuations and structural heterogeneity rather than by long-term equilibrating forces.

Empirically, similar findings have been reported in studies on developing regions, where structural rigidities, weak institutional capacity, and external shocks often disrupt the formation of long-run energy–growth–environment linkages (Acaravci and Ozturk, 2010; Apergis and Payne, 2010b; Apergis and Payne, 2010a; Narayan and Smyth, 2008; Ozturk, 2010). In the SSA context, the absence of cointegration may also reflect divergent energy structures, varying levels of industrialization, and differences in policy frameworks, which prevent convergence toward a common long-run relationship (Adams and Klobodu, 2017; Ozturk, 2010; Wolde-Rufael, 2009). These results justify the use of dynamic panel GMM estimation, which is well-suited to capture short-run dynamics and heterogeneity without imposing the assumption of a stable long-run equilibrium.

3.5. Drivers of Disparities in the Energy Consumption–Economic Growth Nexus in SSA

To identify the structural and macroeconomic drivers of disparities in the energy consumption–economic growth nexus in SSA, a dynamic linear growth model was estimated using the Sequential Two-Stage GMM technique. The estimation results are reported in Table 6.

The coefficients of the first and second lags of real GDP (0.226 and 0.085) appeared positive but statistically insignificant, as indicated

Table 5: Panel cointegration diagnostics results

Modified(D-F *t*)	D-F *t*	Augmented(D-F *t*)	Unadjusted modified(D-F *t*)	Unadjusted(D-F *t*)	Comment
1.076(0.141)	0.350(0.363)	0.073(0.471)	0.568(0.284)	−0.068(0.473)	No Cointegration

D-F=Dickey–Fuller. **and *implies significance at 1% and 5% levels of significant errors respectively. P value are in parenthesis(…)

Table 6: Sequential 2-Stage GMM estimation of the factors driving disparities in energy consumption and economic growth in SSA

Independent variables	Dependent variable: Natural Log of Real GDP			
	Coeff.	WC-Robust standard error	z	P>|z|
lnrgdp_L1	0.226	0.225	1.00	0.316
lnrgdp_L2	0.085	0.061	1.38	0.167
lntec	0.012	0.010	1.22	0.221
lnhdi	1.669***	0.357	4.68	0.000
lntlf	0.283*	0.161	1.76	0.078
uem	−0.011*	0.006	−1.79	0.073
popgr	−0.001	0.002	−0.39	0.698
fdi	0.001	0.0005	1.42	0.156
Constant	12.972***	2.906	4.46	0.000
No. of cross sections	41			
No. of observation	1142			
Hansen's J-test	chi2=0.4351(Prob>chi2=0.8045)			
AR(1)	z=−0.1099(Prob>|z|=0.9125)			
AR(2)	z=0.0152(Prob>|z|=0.9879)			

***, ** and *implies significance at 1% (i.e., P<0.01), 5% (i.e., P<0.05), and 10% (i.e., P<0.10) levels of significant errors respectively

by the high White Corrected (WC) robust standard error (0.225 and 0.061), z-scores below 2 (i.e., 1.00 < 2 and 1.38 < 2), and P-values above the 5% threshold. This suggests weak evidence of growth persistence within the panel. Although endogenous growth theory emphasizes the importance of past growth in reinforcing future output (Lucas, 1988; Romer, 1986), the insignificant findings here may reflect structural volatility, policy instability, and weak institutions that limit growth momentum across many SSA economies. Similar results have been reported by Bond, Hoeffler, and Temple (Bond et al., 2001), who argue that low-income countries often exhibit weaker convergence dynamics compared with advanced economies.

The coefficient of total energy consumption (lntec) was positive (0.012) but statistically insignificant, as shown by the WC robust standard error (0.010), z-score that is <2 (i.e., 1.22 < 2), and a z-score P-value that is >5% (i.e., 0.221 > 0.05). This finding indicates that higher energy use does not translate directly into long-term growth benefits in SSA. This is theoretically consistent with the "energy–growth paradox" in developing economies, where inefficiencies, infrastructural bottlenecks, and reliance on non-renewable, low-quality energy sources reduce the productivity impact of energy consumption (Payne, 2010). Empirical studies such as Apergis and Payne (2009) and Omri (2014) have similarly found that in many developing countries, energy consumption does not exert a robust impact on output, largely due to structural inefficiencies and uneven energy access (Apergis and Payne, 2009; Omri, 2013).

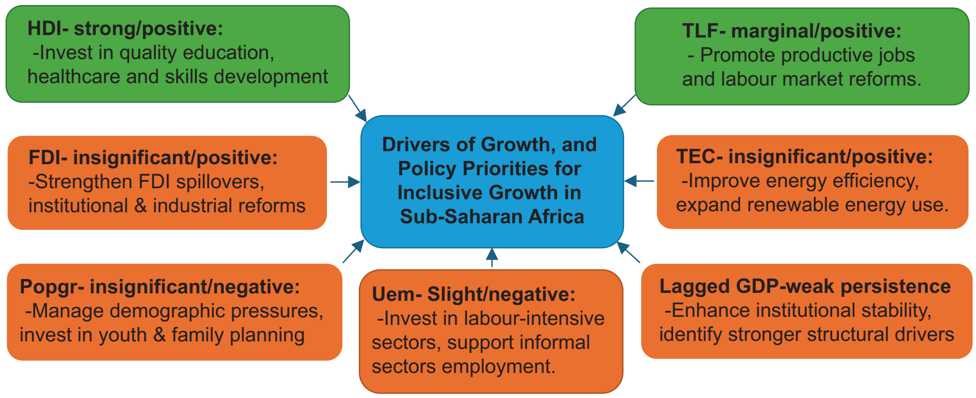
Human development, proxied by the Human Development Index (HDI), displayed a large positive and statistically significant effect (1.669), as shown by the low WC robust standard error (0.357), z-score that is >2 (i.e., 4.68 > 2), and a z-score P-value that is <5%. This result is consistent with endogenous growth theory, which identifies human capital accumulation as a central driver of long-run growth (Lucas, 1988). The empirical evidence reinforces the finding include studies by Barro (1999) and Gyimah-Brempong et al. (2006) which demonstrated that improvements in education, health, and human capital outcomes substantially enhance growth prospects in African economies (Barro, 1999; Gyimah-Brempong et al., 2006). This result highlights the critical role of investing in people as a mechanism for narrowing disparities across SSA.

The total labour force also exhibited a positive coefficient (0.283), with marginal significance at the 10% level. This suggests that labour contributes positively to economic growth, though its effect is less robust. Classical and neoclassical growth theories predict a positive relationship between labour supply and output; however, the marginal nature of the finding may reflect underemployment, low labour productivity, and the dominance of informal markets in SSA (AfDB, 2020). Likewise, the coefficient of foreign direct investment (FDI) was positive (0.001) but statistically insignificant. While FDI is theoretically expected to stimulate growth through technology transfer and capital inflows (Borensztein et al., 1998), its impact in SSA has often been muted due to concentration in extractive sectors, limited spillover to domestic industries, and weak absorptive capacity (Asiedu, 2002). The current finding therefore resonates with prior empirical evidence that the growth effects of FDI in Africa are conditional on institutional quality and human capital development (Adams, 2009).

By contrast, the unemployment rate carried a negative coefficient (−0.011), also marginally significant at the 10% level. This finding accords with theoretical expectations and underscores the drag that unemployment exerts on output by reducing effective labour utilization. Empirically, this aligns with Okun's Law, which has been validated in African contexts by studies such as Kouakou (2011), showing that unemployment reduces growth capacity despite rising labour supply (Kouakou, 2011; Okun, 1962). Similarly, population growth exhibited a negative but statistically insignificant coefficient (−0.001). This suggests that rapid population increases do not, on average, contribute meaningfully to economic expansion in SSA. Malthusian and neo-Malthusian theories warn that high population growth can strain resources, while modern endogenous growth frameworks emphasize that population dynamics must be coupled with human capital development to translate into productivity gains (Bloom and Canning, 2004). The insignificant effect observed here may reflect the demographic burden in SSA, where high dependency ratios dilute the growth benefits of a large population.

Finally, the constant term (12.972) was positive and highly significant, indicating that baseline growth remains positive even when the explanatory variables are held at zero. This reflects the contribution of unobserved country-specific factors not explicitly captured in this model, such as geography, governance, and other structural endowments. Kindly provide these author details in the reference list Taken together, the results underscore that while energy consumption does not exert a significant direct effect on growth, human capital development remains a robust driver of output in SSA. Labour force participation and unemployment effects are marginal, reflecting labour market rigidities, while FDI and population growth fail to generate significant impacts without supporting structural reforms (Figure 1). These findings highlight

Figure 1: Drivers of economic growth and recommended policy priorities for inclusive growth across SSA



the primacy of human development and institutional capacity as drivers of inclusive and sustainable growth in SSA, consistent with both endogenous growth theory and recent empirical work in energy–growth–environment literature (Acaravci and Ozturk, 2010; Omri, 2013; Ozturk, 2010).

3.5.1. Post-estimation diagnostic tests

The validity of the Sequential Two-Stage GMM estimates was further assessed using standard post-estimation diagnostic tests, and the results are also presented in Table 6. The Hansen J test of overidentifying restrictions produced a P = 0.8045, which is well above the 5% significance threshold. This implies a failure to reject the null hypothesis that the instruments are jointly valid (Hansen, 1982). In other words, the instruments employed in the estimation are uncorrelated with the error term and are correctly excluded from the estimated equation. This outcome enhances confidence in the robustness of the GMM results, as invalid instruments are a well-known source of bias and inconsistency in dynamic panel estimations (Roodman, 2009b; Roodman, 2009a). Similar outcomes have been reported in empirical growth and energy–environment studies, where a non-rejection of the null in the Hansen test is taken as evidence of instrument reliability (Bond et al., 2001; Omri, 2013).

In addition, the Arellano–Bond test for autocorrelation was applied to the differenced residuals to check for serial correlation in the error structure (Arellano and Bond, 1991). The results show that the null hypotheses of no first-order and no second-order autocorrelation could not be rejected, with P-values of 0.9125 and 0.9879, respectively. Since AR(1) correlation is expected by construction in the differenced model, the critical test is for AR(2). The failure to detect significant AR(2) correlation indicates that the moment conditions are appropriately specified and that the instruments are not endogenous to the error process. This finding is consistent with theoretical expectations in dynamic panel modelling, where the absence of higher-order autocorrelation is a necessary condition for the consistency of GMM estimators (Arellano and Bond, 1991; Blundell and Bond, 1998).

To sum, these diagnostic results confirm that the model is properly specified, the instruments are valid, and the GMM estimation is robust. They align with empirical evidence from previous studies in similar contexts. For example, Bond et al. (2001) found that the robustness of growth regressions in developing economies hinges on the validity of instruments confirmed through Hansen-type tests, while Omri (2014) demonstrated the necessity of addressing autocorrelation in GMM models applied to energy–growth–emissions data. The present findings therefore offer both theoretical assurance and empirical comparability, reinforcing the reliability of the estimated results. They provide a solid foundation for deriving meaningful policy implications to address disparities in the energy–growth–environment nexus across Sub-Saharan Africa.

4. CONCLUSIONS, POLICY IMPLICATIONS AND RECOMMENDATIONS

This study investigated the structural and macroeconomic drivers of disparities in the energy consumption–economic growth nexus in Sub-Saharan Africa, using a Sequential Two-Stage GMM dynamic panel framework. Kindly provide these author details in the reference list The main findings are summarized as follows:

- Lagged GDP showed a positive but statistically insignificant effect, indicating weak evidence of growth persistence across SSA economies.
- Total energy use exhibited a positive but insignificant impact on growth, highlighting inefficiencies and structural challenges in the region's energy sector.
- Human Development Index had a strong, positive, and statistically significant effect on growth, underscoring the central role of human capital in driving long-term development.
- The labour force contributed positively to growth with marginal significance.
- Unemployment had a slight but significant negative effect, reflecting labour market rigidities and underutilization of human resources.
- Population dynamics exerted a negative but insignificant effect on growth, consistent with demographic pressures and high dependency ratios
- FDI was positive but insignificant, suggesting that its benefits are constrained by weak absorptive capacity and concentration in extractive sectors.

By implication, the study collectively highlight the need for integrated policy frameworks that simultaneously address human capital development, labour market efficiency, energy sector reforms, and institutional strengthening. Disparities in the energy–growth nexus across SSA are driven not by single factor but by the interplay of structural and macroeconomic conditions. Policies that target only one dimension, such as energy expansion or FDI attraction, without addressing human capital and institutional quality, are unlikely to yield sustainable results. A coordinated approach that prioritizes inclusive human development, efficient energy use, productive employment creation, and structural diversification is therefore essential for bridging growth disparities across the region.

Specifically, human capital development emerged as the most significant driver of growth, pointing to the urgency of investing in quality education, improved healthcare, and skills development. It is recommended that policymakers across SSA should allocate greater resources to expanding vocational and technical training, following the template seen in Rwanda's Technical and Vocational Education and Training (TVET) programs, The Nigerian Content Development and Monitoring Board (NCDMB) on-the-job (OJT) training in Nigeria's oil and gas sector through its Nigerian Content Human Capital Development (NC-HCD) Framework, and subscribe to strengthening healthcare systems through regional initiatives such as the Africa Centres for Disease Control and Prevention Kindly provide these author details in the reference list (CDC), which will Kindly provide these author details in the reference list help enhance labour productivity and innovation capacity.

Likewise, investment should be channelled towards labour-intensive sectors such as agriculture and manufacturing, while simultaneously promoting policies that encourage entrepreneurship and the formalization of small and medium-sized enterprises (SMEs). Initiatives like the AfDB's Feed Africa Strategy and SME financing mechanisms, such as the Africa Guarantee Fund, provide effective models to reduce unemployment, harness the demographic dividend, and improve the efficiency of labour utilization.

The insignificant role of energy consumption in driving growth suggests that expanding energy use alone will not automatically translate into higher economic output. This finding emphasizes the importance of improving energy efficiency and shifting toward sustainable and reliable energy infrastructure. Projects such as Kenya's Lake Turkana Wind Power Project and regional integration through the Southern African Power Pool (SAPP) demonstrate how reliable and sustainable energy infrastructure can reduce disparities, and thus, recommended to policymakers.

Similarly, The insignificant impact of FDI highlights the structural constraints that limit its growth benefits. Although FDI inflows to SSA are often substantial, they are concentrated in extractive industries with limited linkages to the broader economy. Policymakers should implement strategies to diversify FDI and improve institutional quality as exemplified by Ethiopia's Industrial Parks Development Corporation (IPDC) to attract investment into manufacturing, technology, and services, where spillover effects on domestic firms and human capital are stronger. Finally, the insignificant and negative effect of population growth points to the challenge of demographic pressures. While a large population could be a source of growth, high dependency ratios and inadequate investment in human capital reduce its potential. Policymakers should address this through comprehensive demographic and social policies, including family planning and targeted youth empowerment programs, with examples such as Nigeria's National Youth Service Corps (NYSC), and UNFPA-supported maternal health initiatives offering practical pathways. Kindly provide these author details in the reference list These measures would help manage the demographic transition and ensure that population growth translates into a productive workforce rather than a burden on economic resources.

While this study provides valuable insights into the macroeconomic drivers of asymmetries in the energy–growth nexus selected SSA countries, its scope is not exhaustive. The positive and highly significant constant term (12.972) suggests that unobserved country-specific characteristics, such as geography, governance quality, and structural endowments, also contribute meaningfully to baseline growth but were not explicitly captured in the model. Future research should therefore integrate both structural variables (e.g., governance indicators, energy mix, infrastructure quality, and sectoral economic structure) and macroeconomic variables to provide a more comprehensive assessment of the drivers of disparities. Moreover, country- and region-specific analyses that reflect the unique institutional, political, and resource landscapes of SSA economies would generate more granular insights. Such extensions would improve the robustness of empirical evidence and enhance the design of context-sensitive policies for fostering inclusive and sustainable growth.

5. ACKNOWLEDGEMENT

The authors express their gratitude to World Bank Africa for sponsoring the PhD program of Nyeso Christian Azubuike at the Africa Centre of Excellence in Oilfield Chemical Research (ACE-CEFOR), University of Port Harcourt. Additionally, we extend our appreciation to Professor S.S. Ikiensikimama's Research Group and the anonymous reviewers for their valuable peer review and constructive feedback that enhanced the quality of this article.

6. CONFLICT OF INTEREST

The authors declare that they have no known conflicts of interest to disclose.

REFERENCES

Acaravci, A., Ozturk, I. (2010), On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. Energy, 35(12), 5412-5420.

Adams, S. (2009), Foreign direct investment, domestic investment, and economic growth in Sub-Saharan Africa. Journal of Policy Modeling, 31(6), 939-949.

Adams, S., Klobodu, E.K.M. (2017), Capital flows and the distribution of income in Sub-Saharan Africa. Economic Analysis and Policy, 55, 169-178.

Adams, S., Klobodu, E.K.M., Apio, A. (2018), Renewable and non-renewable energy, regime type and economic growth. Renewable Energy, 125, 755-767.

Adewuyi, A.O., Awodumi, O.B. (2017), Biomass energy consumption, economic growth and carbon emissions: Fresh evidence from West Africa using a simultaneous equation model. Energy, 119, 453-471.

AFDB. (2020), African Economic Outlook 2020: Developing Africa's Workforce for the Future. Abidjan: African Development Bank.

Aghion, P., Howitt, P. (1998), Endogenous Growth Theory. MIT Press, Cambridge, MA. Available from: https://mitpress.mit.edu/9780262528467/endogenous-growth-theory

Akinlo, A.E. (2008), Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries. Energy Economics, 30(5), 2391-2400.

Albiman, M.M., Suleiman, N.N., Baka, H.O. (2015), The relationship between energy consumption, CO_2 emissions and economic growth in Tanzania. International Journal of Energy Sector Management, 9(3), 361-375.

Antonakakis, N., Chatziantoniou, I., Filis, G. (2017), Energy consumption, CO_2 emissions, and economic growth: An ethical dilemma. Renewable and Sustainable Energy Reviews, 68, 808-824.

Apergis, N., Payne, J.E. (2009), Energy consumption and economic growth: Evidence from the commonwealth of independent states. Energy Economics, 31(5), 641-647.

Apergis, N., Payne, J.E. (2010a), Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. Energy Policy, 38(1), 656-660.

Apergis, N., Payne, J.E. (2010b), The emissions, energy consumption, and growth nexus: Evidence from the commonwealth of independent states. Energy Policy, 38(1), 650-655.

Arellano, M., Bond, S. (1991), Some tests of specification for panel data: Monte carlo evidence and an application to employment equations. The Review of Economic Studies, 58(2), 277.

Arellano, M., Bover, O. (1995), Another look at the instrumental variable estimation of error-components models. Journal of Econometrics, 68(1), 29-51.

Asiedu, E. (2002), On the determinants of foreign direct investment to developing countries: Is Africa different? World Development, 30(1), 107-119.

Asongu, S., El Montasser, G., Toumi, H. (2016), Testing the relationships between energy consumption, CO2 emissions, and economic growth in 24 African countries: A panel ARDL approach. Environmental Science and Pollution Research, 23(7), 6563-6573.

Awodumi, O.B., Adewuyi, A.O. (2020), The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. Energy Strategy Reviews, 27, 100434.

Azeakpono, E.F., Lloyd, A. (2020), Renewable energy consumption and economic growth in Nigeria: Any causal relationship? The Business and Management Review, 11(1), 59-76.

Azubuike, N.C., Ikiensikimama, S.S., Osokogwu, U. (2025), Modelling the impact of total energy consumption on economic growth and carbon emissions in Sub-Saharan Africa. Energy Strategy Reviews, 61, 101840.

Bardhan, P. (1995), The Contributions of Endogenous Growth Theory to the Analysis of Development Problems: An Assessment. Ch. 46. London: Palgrave Macmillan. p2983-2998.

Barro, R.J. (1999), Human capital and growth in cross-country regressions. Swedish Economic Policy Review, 6(2), 237-277.

Baum, C.F., Schaffer, M.E., Stillman, S. (2003), Instrumental variables and GMM: Estimation and testing. The Stata Journal: Promoting Communications on Statistics and Stata, 3(1), 1-31.

Baz, K., Cheng, J., Xu, D., Abbas, K., Ali, I., Ali, H., Fang, C. (2021), Asymmetric impact of fossil fuel and renewable energy consumption on economic growth: A nonlinear technique. Energy, 226, 120357.

Beckmann, J., Czudaj, R. (2017), Capital flows and GDP in emerging economies and the role of global spillovers. Journal of Economic Behavior and Organization, 142, 140-163.

Bekun, F.V., Emir, F., Sarkodie, S.A. (2019), Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. Science of the Total Environment, 655, 759-765.

Bekun, F.V., Fumey, M.P., Staniewski, M.W., Sun, L., Agboola, P.O. (2025), Energy intensive growth and the transition pathways: Insights into the role of renewable energy and open market conditions in developing countries. Energy, 322, 135192.

Bélaïd, F., Youssef, M. (2017), Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: Assessing the evidence from Algeria. Energy Policy, 102, 277-287.

Belloumi, M. (2009), Energy consumption and GDP in Tunisia: Cointegration and causality analysis. Energy Policy, 37(7), 2745-2753.

Berndt, E.R., Wood, D.O. (1975), Technology, prices, and the derived demand for energy. The Review of Economics and Statistics, 57(3), 259.

Bhattacharya, M., Paramati, S.R., Ozturk, I., Bhattacharya, S. (2016), The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. Applied Energy, 162, 733-741.

Biala, M.I., Aromasodun, O.M., Shitu, A.M. (2025), Energy-growth nexus: A systematic review of empirical evidence and policy implications. African Journal of Environmental Sciences and Renewable Energy, 18(1), 178-197.

Bloom, D., Canning, D. (2004), Global Demographic Change: Dimensions and Economic Significance. NBER Working Paper Series.

Blundell, R., Bond, S. (1998), Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115-143.

Bond, S., Hoeffler, A., Temple, J. (2001), GMM Estimation and Empirical Growth Models (3048). Available from: https://ssrn.com/abstract=290522

Borensztein, E., De Gregorio, J., Lee, J.W. (1998), How does foreign direct investment affect economic growth? Journal of International Economics, 45(1), 115-135.

Caporale, G.M., Pittis, N. (1999), Unit root testing using covariates: Some theory and evidence. Oxford Bulletin of Economics and Statistics, 61(4), 583-595.

Chudik, A., Pesaran, M.H. (2015), Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Econometrics, 188(2), 393-420.

Chukwunonso Bosah, P., Li, S., Kwaku Minua Ampofo, G., Akwasi Asante, D., Wang, Z. (2020), The nexus between electricity consumption, economic growth, and CO_2 emission: An asymmetric analysis using nonlinear ARDL and nonparametric causality approach. Energies, 13(5), 1258.

Dimnwobi, S.K., Madichie, C.V., Ekesiobi, C., Asongu, S.A. (2022), Financial development and renewable energy consumption in Nigeria. Renewable Energy, 192, 668-677.

Ebohon, O.J. (1996), Energy, economic growth and causality in developing countries. Energy Policy, 24(5), 447-453.

Effiong, M.O., Hosu, Y.S. (2025), Energy use and economic growth nexus in central Africa: A longitudinal analysis (1990-2023). International Journal of Energy Economics and Policy, 15(2), 164-170.

Engle, R.F., Granger, C.W.J. (1987), Co-integration and error correction: Representation, estimation, and testing. Econometrica, 55(2), 251.

Esso, J. (2010), Threshold cointegration and causality relationship between energy use and growth in seven African countries. Energy Economics, 32(6), 1383-1391.

Ezenwa, N., Nwatu, V., Gershon, O. (2021), Renewable energy consumption shocks on co2 emissions and economic growth of Nigeria. IOP Conference Series: Earth and Environmental Science, 665(1), 012013.

Fan, J., Liao, Y., Yao, J. (2015), Power enhancement in high-dimensional cross-sectional tests. Econometrica, 83(4), 1497-1541.

Fossong, D., Dickson, T.N., Mofor, G.Z. (2021), An empirical analysis of the modulating effect between oil and non-oil revenue in explaining economic growth in Cameroon. Euro Economica, 1, 102-115.

Ganda, F. (2019), Carbon emissions, diverse energy usage and economic growth in South Africa: Investigating existence of the environmental kuznets curve (EKC). Environmental Progress and Sustainable Energy, 38(1), 30-46.

Global Footprint Network. (2023), Carbon Footprint-Open Data. Global Footprint Network. Available from: https://data.footprintnetwork.org

Goshit, G.G., Sunday, B.S. (2022), Impact of renewable energy consumption on economic growth in Nigeria: Fresh evidence from a non-linear ARDL approach. Environmental Science and Pollution Research, 5, 153-168.

Granger, C.W.J. (1981), Some properties of time series data and their use in econometric model specification. Journal of Econometrics, 16(1), 121-130.

Gujarati, D.N., Porter, D.C. (2009), Basic Econometrics. 5th ed. Columbus: McGraw-Hill/Irwin.

Gyimah, J., Yao, X., Tachega, M.A., Sam Hayford, I., Opoku-Mensah, E. (2022), Renewable energy consumption and economic growth: New evidence from Ghana. Energy, 248, 123559.

Gyimah-Brempong, K., Paddison, O., Mitiku, W. (2006), Higher education and economic growth in Africa. The Journal of Development Studies, 42(3), 509-529.

Hansen, L.P. (1982), Large sample properties of generalized method of moments estimators. Econometrica, 50(4), 1029.

Howitt, P. (2018), Endogenous growth theory. In: The New Palgrave Dictionary of Economics. United Kingdom: Palgrave Macmillan. p3632-3636.

IEA. (2019), Africa Energy Outlook 2019: Africa's Energy Future Matters for the World. International Energy Agency. Available from: https://www.iea.org/reports/africa-energy-outlook-2019

IEA. (2021), World Energy Balances: Energy Balances for 156 Countries and 35 Regional Aggregates. International Energy Agency. Available from: https://www.iea.org/data-and-statistics/data-product/world-energy-balances

IEA. (2022a), International Energy Agency: Africa Energy Outlook 2022, Special Report. International Energy Agency. p1-250. Available from: https://www.iea.org/reports/africa-energy-outlook-2022

IEA. (2022b), World Energy Outlook 2022. International Energy Agency. Available from: https://www.iea.org/reports/world-energy-outlook-2022

Ilesanmi, K.D., Tewari, D.D. (2017), Energy consumption, human capital investment and economic growth in South Africa: A vector error correction model analysis. OPEC Energy Review, 41(1), 55-70.

Im, K.S., Pesaran, M.H., Shin, Y. (2003), Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115(1), 53-74.

İnal, V., Addi, H.M., Çakmak, E.E., Torusdağ, M., Çalışkan, M. (2022), The nexus between renewable energy, CO_2 emissions, and economic growth: Empirical evidence from African oil-producing countries. Energy Reports, 8, 1634-1643.

Isa, Z., Al Sayed, A.R.M., Kun, S.S. (2015), Review paper on economic growth-aggregate energy consumption nexus. International Journal of Energy Economics and Policy, 5(2), 385-401.

Ivanovski, K., Hailemariam, A., Smyth, R. (2021), The effect of renewable and non-renewable energy consumption on economic growth: Non-parametric evidence. Journal of Cleaner Production, 286, 124956.

Joshua, J. (2015), Neoclassical and endogenous growth models. In: The Contribution of Human Capital Towards Economic Growth in China. United Kingdom: Palgrave Macmillan. p10-25.

Justice, G., Seth, P., George, N., Philip, A.S., Isaac, S.H. (2021), Do globalization and economic development promote renewable energy use in Ghana? International Journal of Advanced Engineering Research and Science, 8(4), 109-116.

Kahsai, M.S., Nondo, C., Schaeffer, P.V., Gebremedhin, T.G. (2012), Income level and the energy consumption-GDP nexus: Evidence from Sub-Saharan Africa. Energy Economics, 34(3), 739-746.

Kais, S., Ben Mbarek, M. (2017), Dynamic relationship between CO_2 emissions, energy consumption and economic growth in three North African countries. International Journal of Sustainable Energy, 36(9), 840-854.

Kao, C. (1999), Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1-44.

Karekezi, S. (2002), Renewables in Africa-meeting the energy needs of the poor. Energy Policy, 30(11-12), 1059-1069.

Kaygusuz, K. (2012), Energy for sustainable development: A case of developing countries. Renewable and Sustainable Energy Reviews, 16(2), 1116-1126.

Kebede, E., Kagochi, J., Jolly, C.M. (2010), Energy consumption and economic development in Sub-Sahara Africa. Energy Economics, 32(3), 532-537.

Kennedy, P. (2008), A Guide to Econometrics. 6th ed. United States: Blackwell Publishing.

Khobai, H., Le Roux, P. (2018), Does renewable energy consumption drive economic growth: Evidence from granger-causality technique. International Journal of Energy Economics and Policy, 8, 205-212.

Khoshnevis Yazdi, S., Ghorchi Beygi, E. (2018), The dynamic impact of renewable energy consumption and financial development on CO_2 emissions: For selected African countries. Energy Sources, Part B: Economics, Planning, and Policy, 13(1), 13-20.

Kouakou, A.K. (2011), Economic growth and electricity consumption in Cote d'Ivoire: Evidence from time series analysis. Energy Policy, 39(6), 3638-3644.

Kraft, J., Kraft, A. (1978), On the relationship between energy and GNP. The Journal of Energy and Development, 3(2), 401-403.

Kripfganz, S., Schwarz, C. (2019), Estimation of linear dynamic panel data models with time-invariant regressors. Journal of Applied Econometrics, 34(4), 526-546.

Kutner, M.H., Nachtsheim, C.J., Neter, J. (2004), Applied Linear Regression Models. 4th ed. United States: McGraw-Hill/Irwin.

Le, H.P., Ozturk, I. (2020), The impacts of globalization, financial development, government expenditures, and institutional quality on CO_2 emissions in the presence of environmental Kuznets curve. Environmental Science and Pollution Research, 27(18), 22680-22697.

Lin, B., Ankrah, I. (2019), On Nigeria's renewable energy program: Examining the effectiveness, substitution potential, and the impact on national output. Energy, 167, 1181-1193.

Lucas, R.E. (1988), On the mechanics of economic development. Journal of Monetary Economics, 22(1), 3-42.

Mahadevan, R., Asafu-Adjaye, J. (2007), Energy consumption, economic growth and prices: A reassessment using panel VECM for developed and developing countries. Energy Policy, 35(4), 2481-2490.

Maji, I.K., Sulaiman, C., Abdul-Rahim, A.S. (2019), Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa. Energy Reports, 5, 384-392.

Mensah, J.T. (2014), Carbon emissions, energy consumption and output: A threshold analysis on the causal dynamics in emerging African economies. Energy Policy, 70, 172-182.

Mutumba, G., Odong, T., Bagire, V. (2024), Modelling Renewable Energy

Consumption and Economic Growth in Uganda. International Journal For Multidisciplinary Research.

Mutumba, G.S., Odongo, T., Okurut, F.N., Bagire, V., Senyonga, L. (2022), Renewable and non-renewable energy consumption and economic growth in Uganda. SN Business and Economics, 2(7), 63.

Namahoro, J.P., Wu, Q., Xiao, H., Zhou, N. (2021), The impact of renewable energy, economic and population growth on CO_2 emissions in the East African Region: Evidence from common correlated effect means group and asymmetric analysis. Energies, 14(2), 312.

Narayan, P.K., Smyth, R. (2008), Energy consumption and real GDP in G7 countries: New evidence from panel cointegration with structural breaks. Energy Economics, 30(5), 2331-2341.

Nathwani, J., Kammen, D.M. (2019), Affordable energy for humanity: A global movement to support universal clean energy access. Proceedings of the IEEE, 107(9), 1780-1789.

Nyasha, S., Odhiambo, N.M. (2022), Energy consumption and economic growth in Zambia: A disaggregated approach. Journal of Economic Policy and Management Issues, 1(1), 1-11.

Odhiambo, N.M. (2009), Energy consumption and economic growth nexus in Tanzania: An ARDL bounds testing approach. Energy Policy, 37(2), 617-622.

Odhiambo, N.M. (2010), Energy consumption, prices and economic growth in three SSA countries: A comparative study. Energy Policy, 38(5), 2463-2469.

Okun, A.M. (1962), Potential GNP: Its measurement and significance. The Business and Economic Statistics Section, 1962, 98-104.

Omri, A. (2013), CO_2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. Energy Economics, 40, 657-664.

Omri, A., Nguyen, D.K., Rault, C. (2014), Causal interactions between CO2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. Economic Modelling, 42, 382-389.

Ouedraogo, N.S. (2013), Energy consumption and economic growth: Evidence from the economic community of West African States (ECOWAS), Energy Economics, 36, 637-647.

Ozturk, I. (2010), A literature survey on energy-growth nexus. Energy Policy, 38(1), 340-349.

Ozturk, I., Acaravci, A. (2011), Electricity consumption and real GDP causality nexus: Evidence from ARDL bounds testing approach for 11 MENA countries. Applied Energy, 88(8), 2885-2892.

Pack, H. (1994), Endogenous growth theory: Intellectual appeal and empirical shortcomings. Journal of Economic Perspectives, 8(1), 55-72.

Payne, J.E. (2010), Survey of the international evidence on the causal relationship between energy consumption and growth. Journal of Economic Studies, 37(1), 53-95.

Pedroni, P. (2001), Fully modified OLS for heterogeneous cointegrated panels. In: Baltagi, B.H., Fomby, T.B., Hill, R.C., editors. Advances in Econometrics Nonstationary Panels, Panel Cointegration, and Dynamic Panels. Vol. 15. Leeds: Emerald Group Publishing Limited. p93-130.

Pedroni, P. (2004), Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric Theory, 20(3), 597-625.

Pesaran, M.H. (2007), A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics, 22(2), 265-312.

Pesaran, M.H. (2015), Testing weak cross-sectional dependence in large panels. Econometric Reviews, 34(6-10), 1089-1117.

Pesaran, M.H. (2021), General diagnostic tests for cross-sectional dependence in panels. Empirical Economics, 60(1), 13-50.

Pindyck, R.S., Rubinfeld, D.L. (1988), Econometric Models and Economic Forecasts. 3rd ed. United States: McGraw-Hill.

Ranjbar, O., Chang, T., Nel, E., Gupta, R. (2017), Energy consumption and economic growth nexus in South Africa: Asymmetric frequency domain approach. Energy Sources, Part B: Economics, Planning, and Policy, 12(1), 24-31.

Romer, P.M. (1986), Increasing returns and long-run growth. Journal of Political Economy, 94(5), 1002-1037.

Romer, P.M. (1990), Endogenous technological change. Journal of Political Economy, 98(5, Part 2), S71-S102.

Roodman, D. (2009a), A note on the theme of too many instruments. Oxford Bulletin of Economics and Statistics, 71(1), 135-158.

Roodman, D. (2009b), How to do Xtabond2: An Introduction to Difference and System GMM in Stata. The Stata Journal, 9(1), 86-136.

Sadorsky, P. (2011), Trade and energy consumption in the Middle East. Energy Economics, 33(5), 739-749.

Saidi, K., Omri, A. (2020), The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. Environmental Research, 186, 109567.

Sargan, J.D. (1958), The estimation of economic relationships using instrumental variables. Econometrica, 26(3), 393.

Sebri, M., Ben-Salha, O. (2014), On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: Fresh evidence from BRICS countries. Renewable and Sustainable Energy Reviews, 39, 14-23.

Shakouri, B., Khoshnevis Yazdi, S. (2017), Causality between renewable energy, energy consumption, and economic growth. Energy Sources, Part B: Economics, Planning, and Policy, 12(9), 838-845.

Smulders, S., De Nooij, M. (2003), The impact of energy conservation on technology and economic growth. Resource and Energy Economics, 25(1), 59-79.

Solow, R.M. (1956), A contribution to the theory of economic growth. The Quarterly Journal of Economics, 70(1), 65.

Stern, D.I. (1993), Energy and economic growth in the USA. Energy Economics, 15(2), 137-150.

Stern, D.I. (2004), Environmental Kuznets Curve. In: Encyclopedia of Energy. Netherlands: Elsevier. p517-525.

Stern, D.I. (2011), The role of energy in economic growth. Annals of the New York Academy of Sciences, 1219(1), 26-51.

Stern, D.I. (2018), The Environmental Kuznets Curve. In: Reference Module in Earth Systems and Environmental Sciences. Netherlands: Elsevier.

Sunde, T. (2020), Energy consumption and economic growth modelling in SADC countries: An application of the VAR Granger causality analysis. International Journal of Energy Technology and Policy, 16(1), 41.

Swan, T.W. (1956), Economic growth and capital accumulation. Economic Record, 32(2), 334-361.

Tamba, J.G., Nsouandélé, J.L., Fopah Lélé, A., Sapnken, F.E. (2017), Electricity consumption and economic growth: Evidence from Cameroon. Energy Sources, Part B: Economics, Planning, and Policy, 12(11), 1007-1014.

Tiba, S., Belaid, F. (2021), Modeling the nexus between sustainable development and renewable energy: The African perspectives. Journal of Economic Surveys, 35(1), 307-329.

Tiwari, A.K., Apergis, N., Olayeni, O.R. (2015), Renewable and nonrenewable energy production and economic growth in sub-Saharan Africa: A hidden cointegration analysis. Applied Economics, 47(9), 861-882.

Tugcu, C.T., Topcu, M. (2018), Total, renewable and non-renewable energy consumption and economic growth: Revisiting the issue with an asymmetric point of view. Energy, 152, 64-74.

Udemba, E.N. (2020), A sustainable study of economic growth and development amidst ecological footprint: New insight from Nigerian Perspective. Science of the Total Environment, 732, 139270.

Ullah, O., Rahman, Z.U., Guo, A., Zeb, A. (2024), Disaggregated public spending, income inequality and its effect on economic growth: Empirical evidence from developing countries. Journal of the Knowledge Economy, 15(4), 20823-20850.

Umeji, G., Agu, A., Eleanya, E., Ezeh, M., Nwabugwu, O., Obumnene, M. (2023), Renewable energy consumption and economic growth in Nigeria. African Journal of Social Sciences and Humanities Research, 6, 34-48.

United Nations. (2015), The 2030 Agenda for Sustainable Development. United Nations Environment Programme Sustainable Development Summit, New York. Available from: https://sdgs.un.org/2030agenda

Uzokwe, A.E., Onyije, I. (2020), Renewable and non-renewable energy consumption and economic growth- a case of Nigeria. International Journal of Economics and Management Studies, 7(1), 1-8.

Wolde-Rufael, Y. (2005), Energy demand and economic growth: The African experience. Journal of Policy Modeling, 27(8), 891-903.

Wolde-Rufael, Y. (2006), Electricity consumption and economic growth: A time series experience for 17 African countries. Energy Policy, 34(10), 1106-1114.

Wolde-Rufael, Y. (2009), Energy consumption and economic growth: The experience of African countries revisited. Energy Economics, 31(2), 217-224.

World Bank. (2023), World Development Indicators. World Bank, Washington, DC. Available from: https://datatopics.worldbank.org/world-development-indicators

Yang, L., Bashiru Danwana, S., Issahaku, F.Y. (2022), Achieving environmental sustainability in Africa: The role of renewable energy consumption, natural resources, and government effectiveness-evidence from symmetric and asymmetric ARDL models. International Journal of Environmental Research and Public Health, 19(13), 8038.

Zerbo, E. (2015), CO_2 emissions, growth, energy consumption and foreign trade in Sub-Sahara African countries. Working Paper hal-01110769, Hal Open Access.

APPENDIX

Appendix 1: Survey of energy–growth–emission causality evidence in Sub-Saharan Africa

Author(year)	Period	Country(s)	Methodology	Conclusions(results)
Total energy consumption and economic growth causality				
Akinlo (2008)	1980-2003	11 Sub-Saharan African countries	ARDL bounds test	EC~GDP(Cameroon, Ivory Coast, Nigeria, Kenya, Togo)
Odhiambo (2009)	1971-2006	Tanzania	ARDL bounds test	EC→GDP
Ebohon (1996)	1960-1984	Nigeria, Tanzania	Engle–Granger causality approach	EC↔GDP
Wolde-Rufael (2005)	1971-2001	19 African countries	ARDL bounds test	EC→GDP(Cameroon, Morocco, Nigeria) GDP→EC(Algeria, Congo DR, Egypt, Ghana, Ivory Coast) EC↔GDP(Gabon, Zambia); GDP~EC(Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia)
Wolde-Rufael (2009)	1971-2004	Algeria, Benin, South Africa	Toda and Yamamoto(1995) causality test	EC↔GDP
Esso (2010)	1970-2007	7 African countries	Threshold cointegration approach	EC↔GDP(Ivory Coast) GDP→EC(Congo and Ghana) EC~GDP(Cameroon, Nigeria, Kenya, South Africa)
Odhiambo (2010)	1971-2006	South Africa, Kenya, Congo RD	ARDL bounds test	EC→GDP(South Africa, Kenya) GDP→EC(Congo RD)
Ouedraogo (2013)	1980-2008	15 ECOWAS countries	Panel unit root, panel cointegration and Granger causality tests	EC↔GDP
Kebede etal. (2010)	1980-2004	20 Sub-Saharan African countries	Model for Analysis of Energy Demand(MAED)	GDP→EC
Mahadevan and Asafu-Adjaye (2007)	1971-2002	20 net energy importers and exporters	Panel error correction model	EC↔GDP(importers and exporter in developed countries). EC→GDP(developing countries)
Adewuyi and Awodumi (2017)	1980-2010	West African Countries	Simultaneous equation model estimated with three stage least squares(3SLS)	EC↔GDP(Nigeria, Burkina Faso, The Gambia, Mali and Togo) EC~GDP(remaining West African countries)
Ilesanmi and Tewari (2017)	1960-2015	South Africa	Vector Error Correction Model(VECM) framework	EC↔GDP
Sunde (2020)	1971-2015	9 Sub-Saharan African countries	Vector Autoregression(VAR) model	GDP→EC(Angola, Namibia, Democratic Rep. Congo); EC↔GDP(Botswana, Mauritius); EC~GDP(Mozambique, Zambia, Zimbabwe, South Africa)
Yang etal. (2022)	1980-2017	9 African countries	Nonlinear ARDL bounds test	GDP→EC(Burundi, Tanzania, Kenya) EC↔GDP(Ethiopia, Democratic Rep. Congo); EC~GDP(Rwanda, Uganda)
Nyasha and Odhiambo (2022)	1990-2013	Zambia	ARDL bounds test/Granger causality	GDP→EC
Mutumba etal. (2022)	1990-2015	Uganda	Granger Wald Causality	EC→GDP
Udemba, (2020)	1981-2018	Nigeria	Granger Casualty Test, ARDL	GDP→EC
Tamba etal. (2017)	1971-2013	Cameroon	ECM	EC↔GDP
Fossong etal. (2021)	1971-2016	Cameroon	ECM	EC→GDP
Renewable energy consumption and economic growth causality				
Tiwari etal. (2015)	1971-2011	12 Sub-Saharan African countries	Linear cointegration and the hidden cointegration methodology.	EC→GDP(Cameroon, Congo Rep., Gabon, Kenya, Zimbabwe, Congo Dem. Rep. and Cote d'Ivoire,) GDP→EC(Kenya and Sudan) EC~GDP(Ghana, Nigeria, Togo, Zambia)
Asongu etal. (2016)	1982-2011	24 African countries	Panel autoregressive distributed lag(ARDL)	EC, CE→GDP GDP, EC→CE CE, GDP→EC EC↔CE CE↔GDP
Gyimah etal. (2022)	1990-2015	Ghana	Granger causality and the mediation model	EC↔GDP
Adams etal. (2018)	1980-2012	30 Sub-Saharan African countries	Heterogeneous panel cointegration and panel-based error correction tests,	EC→GDP(REC & nREC)
Lin and Ankrah (2019)	1980-2015	Nigeria	Translog production function framework	EC~GDP(REC & nREC)

(Contd...)

Appendix 1: *(Continued)*

Author (year)	Period	Country(s)	Methodology	Conclusions(results)
Renewable energy consumption and economic growth causality				
Justice etal. (2021)	1990-2015	Ghana	GMM & FMOLS	EC~GDP
Mutumba etal. (2024)	1982-2018	Uganda	VECM	EC→GDP
Mutumba etal. (2022)	1990-2015		Granger Wald Causality	GDP→EC
Uzokwe and Onyije (2020)	1984-2015	Nigeria	ARDL, VAR	EC→GDP
Goshit and Sunday (2022)	1990-2019		Toda Yamamoto Test	EC→GDP
Umeji etal. (2023)	1990-2020		Toda Yamamoto Test	EC→GDP
Dimnwobi etal. (2022)	1981-2019		ARDL	GDP→EC
Azeakpono and Lloyd (2020)	1990-2016		Granger Causality Test	EC~GDP
Khobai and Le Roux (2018)	1990-2014	South Africa	VECM	EC→GDP
Sebri and Ben-Salha (2014)	1971-2010		VECM	EC↔GDP
Interplay between total energy consumption, economic growth and carbon emission				
Ezenwa etal. (2021)	1990-2015	Nigeria	vector error correction model(VECM)	REC, nREC↔GDP nREC→CE(nREC increase CE)
Ganda (2019)	1980-2014	South Africa	Environmental Kuznets curve(EKC)	REC, nREC→GDP REC→CE(REC lowers CE)
Bekun etal. (2019)	1960-2016	South Africa	Cointegration approach, Bounds test and critical values and approximate *P*values.	EC→GDP EC↔GDP(long run) EC→CE
Maji etal. (2019)	1995-2014	15 West African countries	Panel dynamic ordinary least squares(DOLS)	GDP→REC(REC retards GDP growth)
Awodumi and Adewuyi (2020)	1980-2015	Top oil producing economies in Africa	Non-linear autoregressive distributed lag(NARDL)	REC→CE(REC lowers CE) GDP→REC(REC retards GDP growth in Nigeria) nREC→CE(nREC increase CE)
Tiba and Belaid (2021)	1990-2014	25 African economies	Simultaneous equation mode	REC→CE(REC lowers CE) REC→GDP
İnal etal. (2022)	1990-2014	11 Oil-producing African countries	Bootstrap panel LM cointegration, the AMG estimator and country-based Kónya panel causality test.	nREC~GDP GDP→CE(Algeria, Equatorial Guinea, and Egypt)
Chukwunonso Bosah etal. (2020)	1971-2014	9 African economies	Non-Linear Granger Causality Test	nREC→CE(Congo, Republic of the, Kenya, Nigeria, Zambia) nREC↔CE(Democratic Rep. Congo)
Mensah (2014)	1970-2010	Ghana and Nigeria	Toda and Yamamoto Granger causality	nREC→CE(Ghana, Nigeria)
Zerbo (2015)	1971-2010		Toda and Yamamoto Granger causality	nREC→CE(Togo, South Africa, Gabon)
Namahoro etal. (2021)	1980-2016	7 African countries	Non-Linear ARDL	GDP→REC(Ethiopia, Burundi, Kenya, Sudan, Uganda). REC~GDP(Rwanda, Tanzania,) REC→CE Kindly provide these author details in the reference list(Ethiopia, Kenya, Tanzania) CE→REC(Rwanda, Sudan, Uganda)
Khoshnevis Yazdi and Ghorchi Beygi (2018)	1985-2015	Selected African countries	Granger Causality Test	REC→CE(Côte d'Ivoire, Senegal, Zambia, Tanzania); REC↔CE(Angola, Sudan); CE→REC(Benin, Mozambique, Mauritius, Nigeria, Zimbabwe, Democratic Rep. Congo) GDP→CE(Ghana, Tanzania, Zimbabwe, Senegal, Kenya) CE→GDP(Angola, Cameroon, Gabon Mauritius, Mozambique, Nigeria, Democratic Rep. Congo) GDP↔CE(Benin, Burundi, Zambia)

→, ↔, and~indicate unidirectional, bidirectional and neutral cointegration respectively, EC: Energy consumption, REC: Renewable energy consumption, nREC: Non-renewable energy consumption, CE: Carbon emission, GDP: Gross domestic product growth