Innovations

Exploring the Nexus between Economic Growth, Energy Access and Population Dynamics in Sub-Saharan Africa

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Abstract: *This study examines the dynamic relationships between economic growth, energy access, population growth, urbanization, and human capital in 46 Sub-Saharan African countries over the period 2000–2023. Employing the Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) approach alongside robustness checks with Random Effects (RE) and Panel Corrected Standard Errors (PCSE), the analysis reveals significant long-run and short-run effects of urbanization, population growth, and human capital on per capita income growth. Energy access exhibits a positive but statistically insignificant long-run impact on growth, with some countries showing significant short-term effects. The findings underscore the crucial role of enhancing human capital and managing demographic transitions to foster sustainable economic development in the region. Policy implications highlight the need for integrated strategies to expand energy infrastructure, improve education and health outcomes, and support urban planning for inclusive growth.*

Keywords: *Economic Growth, Energy Access, Population Dynamics, Human Capital, Sub-Saharan Africa*

1.0 Introduction

Sub-Saharan Africa (SSA) stands at a pivotal juncture in its development trajectory, characterized by rapid population growth, persistent energy deficits, and fluctuating economic performance. The region's population is projected to double by 2050, reaching approximately 2.1 billion people, with a significant proportion being youth under the age of 25 (Simkins, 2023). This demographic trend presents both opportunities and challenges, particularly in the context of economic growth and sustainable development.

Energy access remains a critical concern in SSA, with over 600 million people lacking access to electricity (Ogunbiyi, 2024). This energy deficit hampers industrialization, limits educational and health services, and constrains overall economic productivity. The International Energy Agency (IEA) emphasizes that achieving universal energy access by 2030 requires connecting 90 million people annually, a rate triple that of recent years (IEA, 2022).Energy access is a fundamental enabler of economic development. Reliable and affordable energy facilitates industrialization, supports education and healthcare services, and improves overall quality of life(UNCTAD, 2023). Yet, SSA has the lowest electrification rate globally, with significant disparities between urban and rural areas (Copinschi, 2022). The lack of energy access not only impedes economic activities but also exacerbates social inequalities

Over the past decade, Sub-Saharan African countries such as Nigeria, Kenya, Ghana, and South Africa have exhibited diverse trends in population growth and energy access, underscoring the intricate nexus between demographic change and infrastructure development. Nigeria, with an average annual population growth rate of approximately 2.4% between 2013 and 2023, continues to grapple with widespread energy poverty, as about 43% of its population, equating to over 85 million people, still lack access to electricity (YCharts, 2023; AP News, 2023). In contrast, Kenya has achieved remarkable improvements in electrification, increasing access from around 28% in 2013 to over 75% by 2020, supported by substantial investments in geothermal and renewable energy, even as its population growth rate declined from 2.47% to 1.98% over the same period (YCharts, 2023; World Bank, 2022). Similarly, Ghana's electrification rate rose from 64% to over 85%, coinciding with a gradual decline in population growth from 2.45% to 1.91%, driven by focused national energy strategies and donor-supported programs (YCharts, 2023; IEA, 2022). South Africa, while maintaining a stable population growth rate of about 1.3%, already boasts a high electrification rate exceeding 85%, though challenges remain in ensuring energy reliability amid recurrent load shedding, prompting greater interest in solar and off-grid energy solutions (YCharts, 2023; Financial Times, 2023). These contrasting developments highlight the importance of aligning population policies with infrastructure investments to sustainably bridge energy gaps and support inclusive economic growth across the region.

Economic growth in SSA has been uneven, with some countries experiencing robust expansion while others face stagnation due to various factors, including political instability, inadequate infrastructure, and limited access to energy. The World Bank projects a regional growth rate of 3% in 2024, up from 2.4% in 2023, with expectations of acceleration to 4% in 2025–26 (WB, 2020). However, this growth is insufficient to keep pace with the region's burgeoning population, leading to concerns about the sustainability of economic development.

Over the past decade (2013–2023), Sub-Saharan Africa has exhibited varied economic growth trajectories, with countries like Ethiopia, Kenya, Ghana, and Nigeria presenting notable trends. Ethiopia has led the region with an average annual GDP growth rate of approximately 7.5%, driven by public infrastructure investments and an aggressive industrialization agenda, although recent years have seen a slowdown due to political and external pressures (World Bank, 2024). Kenya has maintained a relatively stable average growth rate of around 5.0%, buoyed by its diversified economy and resilient service and agricultural sectors, rebounding strongly after the COVID-19-induced slowdown in 2020. Ghana, similarly averaging around 5.0% growth, has leveraged its oil and gas sector for economic expansion, though fiscal constraints and external shocks have caused periodic setbacks. Nigeria, Africa's largest economy, has experienced more erratic growth, averaging just 2.3% annually, largely influenced by oil price volatility, security issues, and structural economic weaknesses. These disparities reflect the complex interplay of sectoral strengths, policy choices, and vulnerability to global shocks across the region (World Bank, 2024; Macro Trends, 2024).

The intricate relationship between energy access, population dynamics, and economic growth in Sub-Saharan Africa (SSA) is central to the region's development prospects. On one hand, access to affordable, reliable, and modern energy services facilitates industrial development, enhances productivity, supports education and healthcare delivery, and ultimately promotes economic transformation (IEA, 2022a). However, SSA continues to experience the lowest electrification rates globally, particularly in rural areas, where over 600 million people still lack access to electricity (World Bank, 2024). This energy deficit undermines growth potential and limits opportunities for poverty alleviation. Simultaneously, SSA's population is growing rapidly, projected to double by 2050, with high fertility rates and declining mortality rates creating a youth-dominated demographic profile (Moosa, 2023). While this demographic shift presents potential for a demographic dividend, it also intensifies pressure on energy infrastructure, public services, and employment systems (Onabanjo, 2024).

In countries like Nigeria and the Democratic Republic of Congo, energy supply is not only inadequate but also unreliable, often resulting in prolonged outages and high costs for alternative sources like diesel generators. Such conditions hamper the growth of small and medium enterprises and discourage foreign investment, both of which are crucial for sustained economic growth (IEA, 2022b). Furthermore, the expansion of urban areas, driven by population growth, creates new demand for energy infrastructure, housing, and public services, amplifying the challenge of achieving inclusive development. Without strategic interventions, the gap between energy demand and supply will continue to widen, risking a reversal of recent developmental gains (Kassi et al., 2023).

Importantly, while economic growth in SSA has shown pockets of resilience, such as in Ethiopia, Rwanda, and Ghana, which have seen average GDP growth rates above 5% over the past decade, it has not been inclusive or sustainable in many contexts (World Bank, 2024). Growth has often been uneven, vulnerable to commodity price shocks, and insufficient to absorb the expanding labour force. The mismatch between population growth and job creation has led to rising unemployment and informality, especially among youth and women.

Despite numerous development initiatives and foreign investments, the challenge remains that policies often target one dimension of development, energy, population, or growth, in isolation. However, these dimensions are deeply interconnected. For instance, improving energy access can reduce household reliance on biomass, improving health outcomes and freeing time for education or employment. Similarly, managing population growth through investments in education and reproductive health can reduce dependency ratios and increase per capita Copinschi, 2022). In this light, integrated policy frameworks that address the energy-population-growth nexus are essential.

Understanding the interplay between energy access, population dynamics, and economic growth is not only academically valuable but also policy-critical. Evidence from both national and regional studies shows that this nexus plays a decisive role in determining SSA's development outcomes (Kassi et al., 2023). Hence, a holistic approach that considers synergies and trade-offs among these variables can significantly enhance the effectiveness of development strategies in SSA. This study contributes to this discourse by empirically exploring these inter linkages, aiming to inform policy design that is inclusive, sustainable, and context-sensitive.

The Sustainable Development Goals (SDGs) emphasize the interconnectedness of energy access (SDG 7), economic growth (SDG 8), and sustainable urban development (SDG 11), which are especially critical for Sub-Saharan Africa (SSA). Despite global progress, SSA faces significant challenges in achieving these goals due to its rapid population growth, urbanization, and infrastructural deficits. Over 600 million people in the region lack electricity, and nearly 900 million rely on biomass for cooking, limiting productivity, health outcomes, and educational attainment (IEA, 2022; World Bank, 2023). Simultaneously, urban populations are expanding rapidly, often into informal settlements lacking basic services, which strains infrastructure and exacerbates environmental and social issues (UN-Habitat, 2022). Economic growth, though modest in some countries, remains vulnerable to global shocks, commodity dependence, and governance issues (IMF, 2023). Thus, integrating energy development with urban planning, population policy, and economic diversification is essential. Decentralized renewable energy systems and targeted investments in human capital and infrastructure offer viable pathways to sustainable development (IRENA, 2021; Blimpo and Cosgrove-Davies, 2019). Addressing this nexus holistically is vital for SSA to achieve inclusive growth and long-term resilience.

Although substantial research has explored the relationships between energy access and economic growth in Sub-Saharan Africa (SSA), significant gaps remain, particularly regarding the role of population dynamics in shaping this nexus. Many studies, such as those by van Ruijven et al., 2012) addressed how demographic trends, including population growth, are often underrepresented in energy-economic development models in SSA. Similarly, the work of Narayan and Narayan (2010) critiqued the use of static models and emphasizes the importance of accounting for both short-run and long-run relationships in panel data analysis, highlighting the necessity of dynamic models such as PMG or ARDL frameworks that incorporate cointegration. Furthermore, demographic variables such as population growth, youth bulges, and urban expansion which significantly affect energy supply and demand—are underrepresented in empirical models, despite growing recognition from global development bodies like the UNDP (2020) and IEA (2022). Existing research also often relies on outdated datasets (e.g., Alam et al., 2011) or lacks regional granularity, limiting their applicability in addressing post-COVID-19 development realities. Moreover, policy recommendations in prior studies tend to be fragmented or too generalized, as seen in IRENA (2021) and Blimpo and Cosgrove-Davies (2019), offering limited guidance on how to harmonize energy, economic, and demographic policies. This calls for a more integrated and dynamic approach that utilizes updated panel methodologies and current datasets to understand the complex interdependencies shaping SSA's sustainable development pathway.

This study is organized into seven distinct sections. Section Two offers a review of relevant empirical literature, while Section Three outlines the theoretical framework underpinning the research. Section Four details the methodology and model specification, followed by Section Five, which describes the nature and sources of data employed. Section Six presents the empirical results along with their analysis, and finally, Section Seven concludes the study with key findings and policy recommendations.

2.0 Review of Empirical Literatures

Jayawardhana et al (2025) investigated the relationship between the elderly population and economic growth in 25 North and South American countries using annual data from 1961 to 2021. Employing Granger causality testing across the entire conditional distribution and wavelet coherence analysis, the study finds mixed causality patterns. Unidirectional causality from GDP to the elderly population is observed in countries like Bolivia and Colombia, while the reverse holds for Costa Rica and Honduras. No significant causality is found in other countries. Wavelet coherence reveals that in North America, economic growth positively influenced the elderly population in the early 21st century, whereas in South America, a negative influence persisted. The study underscores the importance of recognizing temporal and regional variations in demographic-economic relationships. It recommends dynamic and tailored policy responses. A key critique is the lack of analysis on socio-political or healthcare variables that may mediate this relationship.

Lilik et al (2025) investigates CO_2 emissions in ASEAN countries between 1990 and 2021 using the STIRPAT model and the Common Correlated Effects Mean Group (CCEMG) method to assess the impact of population, wealth, and technology. Results reveal that economic growth, population increase, and energy intensity drive rising CO_2 emissions, while renewable and nuclear energy usage helps reduce them. Both FMOLS and DOLS tests confirm that greater reliance on clean energy sources effectively mitigates emissions. The study recommends policies aimed at diversifying the energy mix, enhancing energy efficiency, and rethinking development strategies. It emphasizes the need for structural shifts in energy and economic systems. However, it may benefit from deeper national-level policy analysis across ASEAN members to better tailor recommendations.

Ma and Wang (2025) explored the nexus between renewable energy, green employment, and sustainable economic growth in BRICS countries from 2000 to 2023. Utilizing the Autoregressive Distributed Lag (ARDL) model, the research captures both short- and long-term effects of renewable energy adoption. The findings indicate that renewable energy significantly enhances green job creation and contributes positively to environmentally sustainable economic growth across BRICS nations. In the short run, renewable investments generate immediate economic benefits, while in the long run, they support enduring employment and carbon reduction. A feedback mechanism is identified, where growth in green jobs stimulates further renewable energy adoption. The study recommends that BRICS governments increase investment in renewable energy infrastructure and green workforce development. However, it could be strengthened by addressing potential institutional and financial barriers to renewable energy transitions across different BRICS contexts.

Ganda and Panicker 2025) examined the non-linear effects of energy access on carbon emissions in 45 Sub-Saharan African countries from 2000 to 2019 using a fixed-panel double-threshold regression model. It finds that in the early phases, foreign direct investment (FDI) helps reduce carbon emissions, but this effect weakens and reverses in later stages. Similarly, primary energy consumption initially has a moderate positive effect on emissions, which becomes stronger as access to electricity increases. Economic growth is positively associated with environmental quality, while the impact of information and communication technology (ICT) on emissions is marginally positive and statistically insignificant. The d-H causality test shows bi-directional relationships between economic growth and emissions, energy use and environmental quality, and ICT and emissions. The study suggests policymakers should craft strategies that promote clean energy access, environmentally responsible ICT use, and green FDI to ensure sustainable development. A potential critique is the limited treatment of governance quality and regional policy heterogeneity in explaining these dynamics.

Gahlot and Garg (2025) conducted a bibliometric analysis of 409 scholarly articles from Scopus spanning 2003 to 2023 using science mapping techniques. The research aimed to categorize existing literature on energy consumption and economic growth, highlighting key themes and identifying gaps. Methodologically, the study relied on bibliometric tools to systematically track research trends and thematic concentrations. The findings show that most prior works focus on the general relationship between energy use and economic growth, with little attention given to disaggregated energy sources like fossil fuels and renewables. It also found a lack of studies on the interplay among CO_2 emissions, energy use, and GDP growth, especially within Asian contexts. Additionally, crucial factors such as urbanization, globalization, public expenditure, and financial development have been largely overlooked. The study recommends more granular research into specific energy types and socio-economic variables influencing energy-growth dynamics. It is particularly relevant for policymakers aiming to address energy challenges with targeted strategies. However, the study's reliance on secondary bibliometric data, without empirical validation of the identified gaps, limits its depth of policy inference.

Dilanchiev et al (2024) explored the relationship between renewable energy consumption, economic growth, and CO_2 emissions in South Caucasus countries using panel data analysis. It employs second-generation unit root and cointegration tests to account for cross-sectional dependence, followed by panel causality and panel VAR techniques. The findings show a bidirectional causality between economic growth and renewable energy, supporting the feedback hypothesis. Additionally, unidirectional causality runs from CO_2 to renewable energy and from growth to CO_2 emissions. A positive shock in renewable energy boosts growth while reducing CO_2 emissions, suggesting its dual economic and environmental benefits. The study offers practical implications for policymakers and stakeholders. However, its findings are region-specific and may not apply broadly. A key critique is its limited consideration of socio-economic and technological factors, which could enrich the analysis.

Wang et al (2024) investigated the impact of China's proposed Global Energy Internet (EI) initiative on green development efficiency (GDE), employing regional data to assess variations in its effectiveness. The findings reveal that the EI significantly improves GDE, particularly in areas already exhibiting high levels of green efficiency. Regionally, the southern and northern energy transmission channels benefit more from the EI than the central corridor, with power-importing regions experiencing the most pronounced effects. The EI contributes to GDE by promoting upgrades in energy consumption and industrial structures. These results underscore the EI's role in accelerating the clean energy transition and supporting sustainable development. The study offers critical insights for policymakers and global stakeholders tackling energy crises and regional green transitions. However, a more detailed analysis of implementation barriers or regional disparities would enhance its applicability.

Tule et al (2024) examined the impact of renewable energy, ICT, and globalization on economic growth in sub-Saharan Africa from 2005 to 2022 using the Pooled Mean Group (PMG) ARDL model alongside robustness tests. The results reveal that both renewable energy and ICT exert a negative and significant influence on economic growth in the long run, suggesting current implementation strategies may be inefficient or inadequate. Conversely, globalization shows a positive and significant long-run effect, emphasizing its role in driving economic development. The study recommends enhanced infrastructure, incentives to attract private investment in renewable energy, and funding for locally developed technology to improve energy access, especially in rural regions. While the findings offer relevant policy insights, the negative effect of ICT and renewable energy warrants deeper investigation into usage efficiency and institutional factors.

Shiqi et al (2024) explored the relationship between inclusive growth and environmental sustainability within the framework of the Sustainable Development Goals (SDGs), emphasizing equality of opportunity, prosperity sharing, climate adaptation, and macroeconomic stability. Using the Kao cointegration test, the study finds long-run positive feedback relationships among variables such as CO_2 emissions, GDP per capita, renewable energy, tourism, water and sanitation, and electricity access. Fully Modified Ordinary Least Squares (FMOLS) results show that a 1% increase in inclusive growth raises CO_2 emissions by 0.342% to 0.258%, while energy consumption per capita increases CO_2 emissions by up to 1.343%. Conversely, expanding tourism's share in exports reduces emissions, highlighting its mitigating role. Canonical Cointe grating Regression (CCR) confirms similar effects. While the study offers valuable insights into the growth-environment nexus, it could benefit from integrating dynamic policy variables to reflect real-time responsiveness to SDG goals.

Liu and Cai (2024) investigated the impact of energy-related foreign aid on green total factor productivity (GTFP) across 92 recipient countries from 2002 to 2019 using balanced panel data. It finds that energy aid significantly enhances GTFP, though the effects vary across sectors, indicating heterogeneity in aid effectiveness. The analysis also reveals that energy aid boosts GTFP indirectly by advancing financial development, optimizing the energy mix, and enhancing energy efficiency. Moreover, the presence of strong government institutions and high levels of human capital further strengthen this positive relationship. The study offers valuable insights into how energy aid can drive green growth and underscores the need for targeted, sector-specific aid strategies. However, it critiques prior literature for overlooking these nuanced sectoral dynamics and mechanisms.

Yunker (2024) analyzed the divergent population growth rates and economic outcomes in China and India from 1980 to 2020, highlighting China's more pronounced decline in population growth and sharper rise in per capita income. Leveraging the natural experiment created by their differing population control policies—China's stringent measures versus India's conventional approach—the research employs a basic economic growth model treating population growth as a key exogenous variable. The model's simulations closely replicate the actual economic trajectories of both countries, supporting the hypothesis that China's aggressive population control significantly contributed to its rapid economic growth. This work underscores the important link between demographic policy and economic performance, though it may oversimplify other factors such as technological advancement and institutional differences that also influence growth. The findings provide valuable insights into how population management can affect development trajectories in populous nations.

Onwe et al (2024) examined the determinants of food security in Nigeria from 1980 to 2022 using advanced econometric techniques, including Quantile Autoregressive Distributed Lag (QARDL) and Wavelet Coherence (WTC). Food security is measured by the food production index (FPI), while globalization, population growth, GDP, and inflation serve as explanatory variables. Findings reveal that globalization positively influences food security at lower quantiles in the short term but has negative effects at median and higher quantiles, and overall detrimental effects in the long run. GDP consistently exerts a positive impact on food security across all quantiles both short- and long-term. Population growth negatively affects food security at most quantiles in the short term. The study highlights complex, nonlinear relationships and underscores the need for targeted policies addressing globalization and population dynamics to enhance Nigeria's food security.

Minh et al (2023) investigated Vietnam's efforts to achieve net-zero carbon emissions by 2050 amidst rapid economic growth, urbanization, and coal-dependent industrialization. Using data from 1990 to 2018, the research applies the Environment Kuznets Curve (EKC) framework and autoregressive distributed lag bounds testing to explore long-run relationships among CO2 emissions, economic growth, foreign direct investment (FDI), renewable energy use, and urban population. Findings support the EKC hypothesis, showing CO2 emissions rise with economic growth until a threshold, after which emissions decline. Granger causality analysis reveals that FDI, urbanization, and renewable energy consumption significantly influence carbon emissions. The study highlights the complex balance Vietnam must navigate between development and environmental sustainability, offering critical insights for policymakers managing growth and emissions trade-offs.

3.0 Theoretical Framework

To underpin the investigation of the interrelationship between economic growth, energy access, and population dynamics in Sub-Saharan Africa, this study adopts a theoretical framework grounded in three interrelated theories: the Endogenous Growth Theory (Romer, 1986; 1990), the Demographic Transition Theory (Notestein, 1945), and the Energy Ladder Theory (Leach, 1992).

First, Endogenous Growth Theory, proposed by Paul Romer, emphasizes that economic growth is primarily driven by internal factors such as innovation, investment in human capital, and infrastructure—including energy infrastructure (Romer, 1986; 1990). In the Sub-Saharan African context, improved access to energy directly enhances productivity and facilitates industrial development, education, and healthcare, thereby stimulating sustained economic growth.

Second, the Demographic Transition Theory, originally posited by Frank W. Notestein in 1945, explains how population dynamics evolve alongside economic development. According to this theory, countries move from high birth and death rates to lower rates as they industrialize. This demographic shift influences labour supply, savings, consumption patterns, and the demand for energy. In Sub-Saharan Africa, where many countries are in the early or transitional stages of demographic change, the growing and youthful population poses both challenges and opportunities for energy demand and economic development.

Third, the Energy Ladder Theory, advanced by Gerald Leach in 1992, provides insight into household energy consumption patterns. It posits that as income levels rise; households shift from traditional biomass fuels to cleaner and more efficient energy sources. This transition, which hinges on both income growth and energy access, reflects broader socio-economic progress. For Sub-Saharan Africa, this theory highlights how improved access to modern energy not only supports economic development but also responds to the needs of a growing and urbanizing population.

These theories intersect powerfully within the study's framework. Economic growth (Endogenous Growth Theory) increases demand for modern energy (Energy Ladder Theory), while population dynamics (Demographic Transition Theory) shape both energy demand and economic structure. Together, they offer a comprehensive lens through which to explore how energy access, population shifts, and economic growth interact in Sub-Saharan Africa, providing crucial theoretical grounding for evidence-based policy design.

4.0 Methodology and Model Specification

4.1 Methodology

This study adopts a quantitative research approach, employing a panel data econometric analysis to investigate the relationship between economic growth, energy access, and population dynamics in Sub-Saharan Africa (SSA). The panel comprises

multiple SSA countries over the period 2000 to 2023. The design allows for controlling both temporal and cross-sectional variations, increasing the robustness of findings.
Variables of interest include the dependent variable: Economic Growth (GDPPC), measured as real GDP per capita (constant 2015 USD). The independent variables include: Energy Access (ENAC), constructed as the composite of Access to electricity and Access to clean fuel and technologies, Population Growth (POPG), measured as annual population growth rate (%), while the control variables include: Urbanization (URB), measured as urban population as % of total population, and Human Capital Index (HCI), constructed as a composite of secondary school enrollment rate, Life expectancy at birth, total (years) and Immunization, DPT (% of children ages 12-23 months).
The inclusion of Human Capital Index (HCI), foreign direct investment (FDI), and urbanization as control variables is essential for accurately examining the relationship between economic growth, energy access, and population dynamics in Sub-Saharan Africa. HCI, constructed from secondary school enrolment, life expectancy at birth, and immunization rates, which captures the quality of the labour force and overall human development, which directly influences productivity and economic resilience. FDI reflects external investment flows that can enhance infrastructure, promote technology transfer, and expand energy access. Urbanization, meanwhile, represents structural transformation and population concentration, often driving higher energy demand and influencing the efficiency of energy distribution and economic activities. Together, these variables help account for broader socio-economic dynamics that shape the core nexus under investigation.

4.2 Model Specification

To examine both short-run and long-run relationships, the Pooled Mean Group (PMG) Autoregressive Distributed Lag (ARDL) model was employed, following Pesaran, Shin, and Smith (1999). This method is suitable when data is panel-stationary at I(0) and I(1) but not I(2), and allows for heterogeneity in short-run dynamics while assuming long-run homogeneity.
The basic model for the work is specified as:

$$GDPpc_{it} = \propto_i + \beta_1 ENAC_{it} + \beta_2 POPG_{it} + \beta_3 URB_{it} + \beta_4 HCI_{it} + \varepsilon_{it} \quad (4.1)$$

Where the variables are as defined in 4.1
$\propto_i$ = Country-specific fixed effects
ε_{it} = Error term

4.3 Process of Human Capital Index (HCI) Construction

To capture the level of human capital across countries, three widely available indicators are selected: Immunization coverage for DPT (% of children ages 12–23 months), primary school enrollment (as a proxy for educational attainment), and life expectancy at birth (as a proxy for health status)(Kaufman and Rousseeuw, 2005; Liu et al. (2003). These indicators represent critical dimensions of human capital, health and education. Given the differing measurement units, each indicator is normalized using the min-max method to scale values between 0 and 1, ensuring comparability. The normalization formula is:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where X′ is the normalized value, and Xmin and Xmax represent the observed minimum and maximum values, respectively. Each indicator is then assigned equal weight (33.33%) to reflect their balanced importance (Vafaei et al.,2018; Mhlangaand Lall, 2022). The composite Human Capital Index for country i in year t is calculated as:

$HCI_{it} = \frac{1}{3}(DPT3'_{it} + PSENR'_{it} + LEB'_{it})$

HCI_{it} = Human Capital Index

$DPT3'_{it}$ = Normalized Immunization, DPT (% of children ages 12-23 months)

$PSENR'_{it}$ = Normalized Primary school enrolment

LEB'_{it} = Normalized life expectancy at birth

The resulting HCI ranges from 0 to 1, where:

i. Values closer to 1 indicate higher levels of human capital, characterized by better educational attainment and longer life expectancy.
ii. Values closer to 0 reflect lower human capital, often associated with poor access to education and health services.

Panel PMG-ARDL framework

$$\Delta GDPpc_{it} = \theta(GDPPC_{it-1} - \gamma_1 ENAC_{it-1} - \gamma_2 POPG_{it-1} - \gamma_3 URB_{it-1} - \gamma_4 HCI_{it-1}) + \sum_{j=1}^{p} \varphi_{1j}\, \Delta GDPPC_{it-j} \ldots + \cdots + \mu_i + \varepsilon_{it}$$

Where the variables are as defined in 4.1.

θ = s the error-correction speed of adjustment parameter, expected to be negative and significant.

γ_k = are the long-run coefficients representing the equilibrium relationship.

φ_{1j} = are the short-run dynamic coefficients for lagged differences.

μ_i = captures country-specific fixed effects.

ε_{it} = idiosyncratic error term

5.0 Nature and Sources of data

This study relies on secondary data sourced primarily from the World Bank's World Development Indicators (WDI), drawing from harmonized multi-year household panel datasets. The dataset spans a 24-year period and encompasses 46 countries across the Sub-Saharan African region. Countries included in the analysis are: Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Djibouti, Eritrea, Eswatini, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Equatorial Guinea, Lesotho, Madagascar, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

6.0 Presentation and Analysis of Results

6.1 Unit Root Test results

The unit root test results (Table 6.1) indicate that GDP per capita (GDPPC) and energy access (ENAC) are non-stationary at level but become stationary after first differencing, implying they are integrated of order one, I(1). Conversely, population growth (Popg), urbanization (Urbp), and the Human Capital Index (HCI) are stationary at level, indicating they are integrated of order zero, I(0). These findings justify the use of an estimation technique, such as the PMG-ARDL model, that can accommodate variables integrated of mixed orders, I(0) and I(1), without requiring all variables to be of the same order.

Table 6.1: Unit root test result

	At Level				At First Difference				
Variables	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square	Order of Int
GDPPC	0.1957	1.0000	0.9048	0.9707	0.0000	0.0000	0.0000	0.0000	I(1)
Popg	0.0000	0.0000	0.0000	0.2479					I(0)
Urbp	0.0000	0.1025	0.0000	0.0000					I(0)
HCI	0.0000	0.0000	0.0000	0.0000					I(0)
ENAC	0.0203	1.0000	0.9998	0.0122	0.0000	0.0000	0.0000	0.0000	I(1)

Source: Authors - generated

6.2 Pooled Mean Group Estimate

Long-run coefficients (Table 6.2)

i. **Energy Access (LNENAC):** The coefficient (0.057) is positive but statistically insignificant (p = 0.5204), indicating that in the long run, energy access has a positive but weak and not statistically confirmed effect on economic growth (GDP per capita) in Sub-Saharan Africa. Although energy access did not show a significant long-run effect here, it aligns with the works of Deka et al (2023) and Gyimah et al (2023). However, sustained investments in expanding and modernizing energy infrastructure remain important to support other growth drivers.

ii. **Urbanization (LNURBP):** The coefficient (1.590) is positive and highly significant ($p < 0.001$), suggesting that urbanization strongly drives economic growth in the long run. This highlights that the expansion of urban populations is a key contributor to GDP growth. The significant role of urbanization supports findings by Glaeser (2011) that urban growth stimulates productivity through agglomeration effects. Policymakers should focus on planned urban infrastructure development, housing, and services to maximize the benefits of urban population expansion.

iii. **Population Growth (POPG):** Positive and significant (0.262, $p < 0.001$), indicating that population growth positively influences economic growth, possibly through expanding labor markets and consumer bases. The positive effect of population growth on GDP suggests that a growing labour force can contribute to economic expansion, consistent with Becker's (1993) human capital theory. However, this also implies a need for policies that improve employment opportunities and skill development to fully leverage demographic dividends.

iv. **Human Capital Index (HCI):** The largest positive and highly significant coefficient (2.034, $p < 0.001$) indicates that improvements in education, health, and overall human capital development strongly enhance economic growth in the region.The strong positive impact of human capital aligns with studies by Barro (2001) and Psacharopoulos and Patrinos (2018), emphasizing investments in education and health as fundamental for sustainable economic growth. Sub-Saharan African countries should prioritize expanding access to quality education and healthcare services to harness this growth potential.

Table 6.2: PMG-ARDL Model

Dependent Variable: D(LNGDPPC)				
Method: ARDL				
Long Run Equation				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNENAC	0.057067	0.08874	0.643082	0.5204
LNURBP	1.590177	0.328815	4.836083	0.0000
POPG	0.262148	0.059114	4.434645	0.0000
HCI	2.034276	0.289747	7.020879	0.0000
Short Run Equation				
COINTEQ01	-0.05433	0.017457	-3.11238	0.0019
D(LNENAC)	0.461723	0.494933	0.932901	0.3511
D(LNURBP)	0.481027	4.269734	0.11266	0.9103
D(POPG)	0.004355	0.01783	0.24422	0.8071
D(HCI)	0.183221	0.079953	2.291616	0.0222
C	0.136353	0.096133	1.418386	0.1565

Source: Authors – generated

Short-run dynamics (Table 6.2)

- The error-correction term (COINTEQ01) is negative and significant (-0.054, p = 0.0019), confirming the existence of a stable long-run relationship and that deviations from equilibrium are corrected at about 5.4% per period.
- Changes in energy access (D(LNENAC)), urbanization (D(LNURBP)), and population growth (D(POPG)) are insignificant in the short run, suggesting their immediate impact on economic growth is limited.
- Changes in human capital (D(HCI)) have a positive and significant short-term effect on economic growth (0.183, p = 0.0222), showing that improvements in health and education can produce immediate economic benefits.

6.3 Robustness Checks

i. Random Effect Model

To ensure the reliability and validity of the estimated long-run relationships derived from the Pooled Mean Group (PMG) estimation, this study conducted robustness checks using the Fixed Effects (FE) and Random Effects (RE) models. The Hausman specification test indicated that the RE model is more appropriate than the FE estimator, thereby justifying its use for robustness validation.

Table 6.3: Random Effect Model (Robustness check)

Dependent Variable: LNGDPPC				
Method: Panel EGLS (Cross-section random effects)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.761428	0.366288	26.6496	0.0000
LNENAC	0.146585	0.015955	9.187436	0.0000
LNURBP	0.376007	0.062776	5.989677	0.0000
POPG	0.017292	0.008274	2.089865	0.0369
HCI	0.47872	0.073813	6.485565	0.0000
R-squared	0.420827			
Adjusted R-squared	0.418694			
F-statistic	197.2718			
Prob(F-statistic)	0.0000			

Source: Authors - generated

The RE estimation results demonstrate consistency with the PMG outcomes, particularly in the significance and direction of the coefficients for energy access (LNENAC), urbanization (LNURBP), and human capital (HCI). All three variables exhibited positive and statistically significant relationships with economic growth (GDP per capita), aligning with the PMG model's long-run coefficients. Although population growth

(POPG) was significant in the RE model, the magnitude was smaller than in the PMG estimates.

ii. **Panel-Corrected Standard Errors (PCSE) Model**

To further enhance robustness, the RE model was re-estimated using Panel-Corrected Standard Errors (PCSE) with Period Seemingly Unrelated Regression (SUR) according to Beck and Katz (1995). This approach accounts for panel-specific heteroskedasticity, contemporaneous correlation, and serial correlation—conditions often present in macroeconomic panel data. The results from this specification reinforced the robustness of the PMG findings. Specifically, LNENAC and HCI remained statistically significant and positively related to economic growth, with coefficient magnitudes comparable to the initial RE model. Urbanization retained a positive effect, though marginally significant at the 10% level. However, population growth lost significance under the PCSE specification, indicating sensitivity to model assumptions.

Table 6.4: PCSE Model (Robustness check)

Dependent Variable: LNGDPPC				
Method: Panel EGLS (Cross-section random effects)				
Period SUR (PCSE) standard errors & covariance (d.f. corrected)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.761428	0.736979	13.24518	0.0000
LNENAC	0.146585	0.051098	2.868692	0.0042
LNURBP	0.376007	0.209827	1.791983	0.0734
POPG	0.017292	0.020262	0.853425	0.3936
HCI	0.47872	0.207214	2.310275	0.0211
R-squared	0.420827			
Adjusted R-squared	0.418694			
F-statistic	197.2718			
Prob (F-statistic)	0.0000			

Source: Authors - generated

Overall, the consistency in sign and statistical significance across PMG, RE, and RE-PCSE models, especially for energy access and human capital, confirms the robustness of the study's core findings. This reinforces the policy relevance of expanding energy infrastructure and investing in human capital development as reliable levers for promoting long-term economic growth in Sub-Saharan Africa.

7.0 Conclusion and Policy Recommendations

The study reveals that urbanization, population growth, and particularly human capital significantly drive economic growth in Sub-Saharan Africa, underscoring the vital role of investments in education, healthcare, and immunization in enhancing productivity. Although energy access shows a positive impact on growth, its significance varies across countries, highlighting the need to improve and diversify energy infrastructure, especially through renewable sources. To sustain and accelerate economic progress, policymakers should adopt integrated development strategies that simultaneously enhance human capital, manage demographic changes, expand energy access, and improve urban planning. Addressing these interconnected factors holistically will foster inclusive and sustainable growth, ensuring that population dynamics and urbanization are managed effectively while boosting the region's economic resilience and long-term development prospects.

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