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Impact of Carbon Emissions on Sustainable Development of Selected Sub-Saharan African Countries

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Abstract

This paper examined the impact of carbon emissions on sustainable development in selected Sub-Saharan African countries, namely South Africa, Nigeria, Angola, Ghana, and Kenya, over the period 1999 to 2025. The paper adopted a longitudinal research design, while the analysis was estimated using the panel fully modified ordinary least squares technique. The findings revealed that industrial process carbon emissions had a negative but statistically insignificant impact on sustainable development, implying that although industrial emission increases tended to correspond with lower human development outcomes, the influence was not strong enough to establish a definite long-run impact across the selected countries. This showed that the industrial sector had not consistently translated carbon-intensive production into broad-based improvements in welfare. In contrast, transport carbon emissions had a positive and statistically significant impact on sustainable development, indicating that rising emissions from transport were associated with improvements in human development. The implication was that mobility, market access, and transport-linked economic activities are still playing an important role in supporting education, healthcare access, income generation, and overall welfare, though through carbon-intensive systems. Similarly, building carbon emissions exerted a positive and statistically significant impact on sustainable development, suggesting that expansion in housing, commercial infrastructure, and energy use in the built environment contributed meaningfully to human development. This implied that better shelter, urban services, and electrification were enhancing welfare, even though these gains were accompanied by higher emissions. The paper recommended that the selected countries should pursue cleaner industrialization through stricter emissions standards and green industrial financing, decarbonize transport systems through mass transit investment and cleaner vehicle policies. They should also enforce energy-efficient building regulations to reduce the carbon intensity of urban development while sustaining improvements in human welfare.

Keywords: *Carbon emissions, Sustainable development, Human Development Index, Industrial process carbon emissions, Transport carbon emissions*

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Background to the Study

The rising challenge of carbon emissions represents one of the most pressing global environmental crises of the twenty-first century, fundamentally threatening the capacity of nations to achieve sustainable development outcomes. At the global scale, anthropogenic carbon dioxide emissions have demonstrated a persistent upward trajectory, with total CO_2 emissions from fossil fuels and industry reaching approximately 37.4 gigatonnes in 2023 according to the Global Carbon Project, reflecting a continuation of trends that have characterized industrial economies since the mid-twentieth century (Friedlingstein *et al.,* 2024). This global emission burden originates from diverse sources including energy generation, industrial manufacturing, transportation systems, and built environment operations, each contributing distinct emission profiles that vary substantially across geographic regions and development contexts. While high-income nations historically account for the largest cumulative emissions, emerging and developing economies increasingly contribute to annual emission flows as they pursue industrialization and economic transformation pathways (Peters *et al.,* 2024).

Within the Sub-Saharan African context, carbon emissions present a complex and heterogeneous picture across the five selected countries of South Africa, Nigeria, Angola, Ghana, and Kenya, each exhibiting distinct emission trajectories shaped by their unique economic structures, resource endowments, and development priorities. South Africa stands as the region's largest emitter, with total emissions from the three sectors under examination reaching approximately 89.06 million tonnes of CO_2 equivalent in 2023, driven predominantly by its coal-dependent energy infrastructure and significant industrial base (Akpolat & Bakırtaş, 2024). The South African emission profile reveals building and energy-related emissions of 23.68 Mt CO_2e, industrial process emissions of 15.86 Mt CO_2e, and transport emissions of 49.41 Mt CO_2e in 2023, reflecting the country's status as a middle-income economy with substantial manufacturing and mining sectors.

Nigeria, Africa's most populous nation and one of the largest economies by GDP, recorded combined sectoral emissions of approximately 78.32 Mt CO_2e in 2023, with transport emissions constituting the dominant share at 57.86 Mt CO_2e, followed by industrial process emissions at 15.63 Mt CO_2e and building emissions at 4.83 Mt CO_2e (World Bank, 2025). The Nigerian emission trajectory demonstrates accelerating growth particularly in transport and industrial sectors, increasing from approximately 25.90 Mt CO_2e in 1999 to the 2023 level, mirroring the country's rapid urbanization and motorization trends despite persistent infrastructural challenges. Angola's emission profile reflects its petroleum-dependent economy and post-conflict reconstruction trajectory, with total sectoral emissions rising from 2.60 Mt CO_2e in 1999 to 17.74 Mt CO_2e in 2023, characterized by building emissions of 7.37 Mt CO_2e, industrial emissions of 1.87 Mt CO_2e, and transport emissions of 8.50 Mt CO_2e in the most recent year (World Bank, 2025). Ghana and Kenya, as smaller economies in the sample, exhibit more modest absolute emission levels yet demonstrate concerning growth trends, with Ghana recording 12.44 Mt CO_2e in 2023 across the three sectors and Kenya recording 16.53 Mt CO_2e, both nations experiencing notable increases in transport and industrial emissions over the study period (World Bank, 2025).

In many African settings, building-sector emissions do not rise uniformly because they depend on electricity access, appliance use, construction standards, cooking fuels, and the energy mix supplying homes and offices. That helps explain why building-emission growth is strong in South Africa and Angola, more moderate in Kenya, and more volatile in Ghana and Nigeria. Taken together, the emissions profiles of the selected countries reveal that carbon emissions are embedded in everyday development processes, housing provision, mobility, industrialization, and urban expansion, rather than being solely a by-product of heavy industry.

Sustainable development represents a normative framework that seeks to balance economic advancement, social inclusion, and environmental stewardship, enabling current generations to meet their needs without compromising the capacity of future generations to meet their own needs. Within the international development architecture, the Human Development Index has emerged as the preeminent composite measure of sustainable development outcomes, integrating dimensions of health measured through life expectancy, education assessed via schooling indicators, and material living standards captured through gross national income per capita (Ezako, 2024). The HDI ranges from 0 to 1, with higher values indicating superior development achievements, and the measure has proven particularly valuable for tracking progress in developing regions where GDP alone provides an insufficient representation of wellbeing improvements and capability expansion (UNDP, 2025).

The current reality, however, shows that sustainable development in many Sub-Saharan African countries remains below this ideal. Although HDI levels in the selected countries have improved over time, the pace and level of progress remain uneven and, in several cases, insufficient relative to the scale of development needs. Available data showed that South Africa's HDI increased from 0.619 in 1999 to 0.749 in 2025, Ghana's from 0.481 to 0.634, Kenya's from 0.498 to 0.630, Angola's from 0.391 to 0.618, and Nigeria's from 0.429 to 0.566. These figures indicate progress, but they also reveal that, by 2025, four of the five countries still remained below 0.65, while Nigeria remained below 0.60, suggesting that significant human-development deficits persist. This is consistent with broader evidence that Sub-Saharan Africa continues to face slower and more fragile human-development progress than many other regions because of structural poverty, macroeconomic vulnerability, weak social protection, infrastructure deficits, climate shocks, and unequal access to essential services (International Monetary Fund [IMF], 2025; Zaghdoude *et al.,* 2026). Thus, while progress has occurred, the region has not yet achieved the level of sustainable development that would be expected if economic transformation were fully translating into human well-being.

Over time, governments and development institutions have introduced several measures aimed at improving sustainable development outcomes in these countries. These include poverty-reduction strategies, national development plans, social investment programmes, health and education spending, infrastructure expansion, climate adaptation frameworks, and broader commitments to the Sustainable Development Goals. However, despite these measures, the problem persists, because progress in sustainable development has remained

slower, more uneven, and more vulnerable than expected. It is of interest in this paper to conduct a rigorous empirical analysis examining how carbon emissions from industrial processes, transport systems, and building energy consumption have affected sustainable development measured through the Human Development Index in five selected Sub-Saharan African countries including South Africa, Nigeria, Angola, Ghana, and Kenya over the period from 1999 to 2025.

Literature Review

Conceptual Review

Carbon Emissions

Carbon emissions represented anthropogenic releases of carbon dioxide into the atmosphere resulting from human economic activities, constituting the primary driver of contemporary climate change and environmental degradation globally. Zhang et al. (2024) conceptualized carbon emissions as greenhouse gas releases originating from fossil fuel combustion and industrial processes that accumulate in the atmosphere and intensify radiative forcing, thereby elevating global temperatures and disrupting ecological systems. Adebayo and Kirikkaleli (2023) defined carbon emissions as measurable quantities of CO_2 discharged through energy consumption, manufacturing operations, and land use transformations that contributed directly to anthropogenic climate change and associated environmental challenges. Industrial process carbon emissions were conceptualized as CO_2 releases inherent to manufacturing chemical reactions and mineral transformations, distinct from combustion emissions, arising from production activities including cement calcination, steel manufacturing, and petrochemical processing (Rahman & Zhang, 2023). Sarkodie and Owusu (2024) characterized industrial process emissions as non-energy carbon releases occurring during raw material conversion in industries such as cement, lime, glass, and ammonia production where chemical decomposition generated CO_2 as an unavoidable byproduct of material transformation.

Transport carbon emissions encompassed CO_2 discharged from mobile sources including road vehicles, aviation, shipping, and rail systems through petroleum product combustion for passenger and freight movement (Liu et al., 2023). Nathaniel and Adeleye (2024) defined transport emissions as carbon releases from gasoline, diesel, and jet fuel combustion in motorized vehicles serving mobility and logistics functions within economic systems. Building carbon emissions referred to CO_2 generated from energy consumption in residential, commercial, and institutional structures for heating, cooling, lighting, and appliance operation (Chen & Wang, 2025). Usman and Balsalobre-Lorente (2023) conceptualized building emissions as energy-related carbon releases from electricity use and direct fuel combustion within constructed environments serving human habitation and commercial activities. For this study, carbon emissions were operationalized as measurable anthropogenic CO_2 releases from industrial manufacturing processes, transportation systems, and building energy consumption that contributed to atmospheric greenhouse gas concentrations and potentially affected sustainable development outcomes in Sub-Saharan African countries.

Sustainable Development (Human Development Index)

Sustainable development represented a holistic developmental paradigm integrating economic prosperity, social equity, and environmental sustainability to meet present generation needs without compromising future generation capacities to satisfy their requirements. Hickel *et al.* (2024) conceptualized sustainable development as transformative processes balancing material advancement, ecological preservation, and social justice whereby societies achieved wellbeing improvements within planetary boundaries while ensuring intergenerational equity and resource availability. Asongu and Odhiambo (2024) defined sustainable development as multidimensional progress encompassing economic growth, human capability expansion, and environmental stewardship that enabled populations to achieve dignified lives while maintaining ecosystem integrity for posterity. The Human Development Index constituted a composite index synthesizing three fundamental dimensions of human wellbeing including health measured through life expectancy at birth, education assessed via mean and expected years of schooling, and living standards captured through gross national income per capita (UNDP, 2024). Mensah *et al.* (2023) characterized the HDI as a summary measure of average achievement in key human development dimensions that transcended purely economic indicators by incorporating health and education outcomes reflecting broader capability development and opportunity expansion. Vo *et al.* (2024) conceptualized the HDI as a normalized composite index ranging from zero to one that aggregated longevity, knowledge, and decent living standard indicators to provide comprehensive assessment of societal development beyond income-centric frameworks.

Sahoo and Sethi (2023) defined human development index as an evaluative tool measuring countries' progress toward enabling populations to live long, healthy, educated lives with adequate resources for dignified existence and meaningful participation in community life. Globally, sustainable development measured through HDI reflected nations' capacities to translate economic resources into tangible improvements in population health, educational attainment, and material wellbeing (Ngouhouo *et al.,* 2024). For this study, sustainable development was operationalized as comprehensive human welfare advancement measured through the Human Development Index, capturing aggregated achievements in health longevity, educational access and attainment, and income-based living standards that collectively reflected populations' capabilities to pursue valued life objectives within Sub-Saharan African countries.

Theoretical Underpinning

The theoretical underpinning for this study rooted in the Environmental Kuznets Curve theory propounded by economists Gene Grossman and Alan Krueger in 1991 and subsequently expanded by Theodore Panayotou in 1993, which posited an inverted U-shaped relationship between economic development and environmental degradation. The Environmental Kuznets Curve theory suggested that carbon emissions and environmental damage initially increased during early stages of economic growth as nations pursued industrialization through resource-intensive production methods and pollution-generating manufacturing activities, but eventually declined after economies reached certain income

thresholds where societies accumulated sufficient wealth to invest in cleaner technologies, strengthen environmental institutions, and demonstrate greater willingness to pay for environmental protection (Grossman & Krueger, 1991; Panayotou, 1993). Stern (2004) argued that the theory explained environmental transitions through multiple mechanisms including structural economic transformation from agriculture through industry toward services, technological innovation that enhanced resource efficiency and reduced emission intensity, rising environmental awareness among wealthier populations, and institutional capacity development that enabled effective environmental regulation.

The significance of this theory in the study lay in its portrayal of how sustainable development measured through human development index potentially interacted with carbon emissions from industrial processes, transport systems, and building energy consumption, suggesting that relationships between emissions and development outcomes might vary systematically across development stages represented by the five selected Sub-Saharan African countries at different income levels and industrialization phases. However, Stern (2004) and Arrow *et al.* (1995) remained unconvinced by the limited empirical support for Environmental Kuznets Curve patterns particularly regarding carbon dioxide emissions as opposed to local pollutants, noting methodological weaknesses including model specification errors, omitted variable bias, and the fundamental difference that global pollutants created collective action problems preventing automatic improvement even at high income levels. This created further arguments by contemporary scholars including Barbier (2024) and Dasgupta *et al.* (2002) who challenged the theory's universal applicability to developing countries facing different technological options, international trade structures, and global environmental constraints compared to historical industrializers, potentially precluding automatic environmental improvement pathways.

Empirical Review

Recent empirical literature had increasingly treated sustainable development as a balance between improvements in human well-being and the containment of environmental harm, with many studies operationalising the outcome variable through the Human Development Index, socio-economic development indicators, or coordinated development frameworks linking HDI and environmental quality. Across this body of evidence, carbon emissions were repeatedly found to complicate development gains by worsening environmental quality, even were income, infrastructure, or industrial expansion improved living standards.

Most recently, Zaghdoud *et al.* (2026) examined 14 Arab countries from 2000 to 2020 to determine how governance and public health spending shaped quality of life under environmental and macroeconomic pressures. The study was in the domain of sustainability and development policy, and it proxied sustainable development with quality of life measured by life expectancy, while carbon emissions were measured through CO2 emissions. The authors used fixed effects with panel corrected standard errors in order to address heteroskedasticity and cross-sectional dependence. Their results indicated that carbon emissions had a small but statistically significant positive coefficient in the quality-of-life

equation, suggesting that in the sampled Arab economies higher emissions were associated with slight improvements in life expectancy. However, the authors interpreted this as a reflection of structural and policy weaknesses rather than genuine sustainable welfare gains, especially in rent dependent systems where growth had not fully translated into broad based wellbeing. The study was useful because it extended the sustainable development discussion beyond HDI to a more direct welfare measure. However, it relied on a one-dimensional proxy of sustainable development, and the positive emissions coefficient required cautious interpretation since it could capture oil-based affluence more than sustainability itself.

Using time-series evidence from Kazakhstan, Dildebayeva *et al.* (2025) evaluated the impact of oil prices, CO2 emissions, and renewable energy consumption on socio-economic development over 1992 to 2021 through a nonlinear autoregressive distributed lag model. Their domain of study was Kazakhstan, and sustainable development was proxied by GDP per capita and the Human Development Index, while carbon emissions were measured through CO2 emissions. The findings showed that CO2 emissions had a negative effect on HDI in both the short run and the long run, whereas the remaining indicators were reported to support socio-economic development in the long run. This study was useful because it explicitly captured asymmetry and temporal dynamics, which many linear models overlooked. However, its single-country design constrained external validity, especially for economies with different production structures. In addition, the use of only two socio-economic development measures meant that broader sustainability dimensions, such as ecological resilience, social inclusion, or institutional quality, were left outside the analysis.

Fakhri *et al.* (2024) focused on the Kingdom of Saudi Arabia and other developed countries, drawing on a sample of eight countries and employing the autoregressive distributed lag model to examine the effects of CO2 emissions on the Human Development Index. Their empirical domain was cross-country, with special attention to oil-rich and advanced economies, and the study framed sustainable development through HDI while carbon emissions were represented by CO2 emissions. The results showed that, in the long run, the relationship in several cases converged toward what the authors described as human development through polluting growth. Specifically, the USA, the UK, and Morocco were reported to fit that pattern, while hegemonic and rentier economies such as the USA, UK, Norway, and Saudi Arabia were said to remain within old polluting development models. This made the paper particularly useful for showing that development gains could coexist with persistent emissions. Even so, the sample size of eight countries was narrow for broad generalisation, and the study's concentration on long-run ARDL evidence left less room for institutional, distributional, and non-CO2 environmental dimensions of sustainable development.

A broader cross-country perspective was offered by Xu *et al.* (2024), who examined 151 countries from 1990 to 2019 in an empirical study of carbon dioxide emissions, material footprints, and human development. Using a modified coupling coordination degree model and an improved decoupling index model, they assessed how CO2 emissions per capita and

material footprints interacted with HDI across development levels and energy endowment structures. Their findings indicated that global CO2 emissions per capita had been slowly declining, with very high HDI countries remaining the main contributors, and that worldwide differences in CO2 emissions per unit of HDI variation were narrowing. They also found temporary absolute decoupling in very high and low HDI countries, whereas medium HDI countries still displayed significant coupling, and some high-HDI fossil-energy-exporting countries showed recoupling tendencies. The strength of the study lay in its very large international coverage and dynamic decoupling perspectives. Nevertheless, its emphasis on coupling patterns made causal interpretation weaker than in conventional regression frameworks, and the use of highly aggregated national data may have masked important within-country sustainability disparities.

Rahman and Sultana (2024) examined 60 countries drawn from low-, lower-middle-, and upper-middle-income groups over the period 2002 to 2019, and studied the relationship between human development and environmental quality with carbon emissions as the environmental proxy. Their methods combined generalized method of moments, fixed effects, and random effects estimators, while long-run relationships were explored through FMOLS and DOLS. In this study, the domain was low-income and developing countries, sustainable development was represented by HDI, and the carbon-related measure was CO2 emissions. The results showed a significant positive association between improvements in human-development status and increased CO2 emissions, implying a trade-off between development progress and environmental quality in the sampled countries. They further showed that renewable energy, rule of law, and control of corruption mitigated emissions, whereas regulatory quality could worsen environmental outcomes. The study was methodologically rich, yet its model still treated CO2 as the sole environmental-quality indicator, which narrowed sustainability measurement. Also, because the panel was limited to 2002 to 2019 and used country-level averages, it could not capture recent shocks or subnational inequalities in human development and emissions.

Ezako (2024) examined the nexus among human development, carbon emissions, official development assistance, and governance in 56 developing countries over the period 2005 to 2019. The study was situated in the domain of development economics and sustainable development, and it adopted the Human Development Index as the proxy for sustainable development, while carbon emissions were measured by CO2 emissions. Methodologically, the author employed the cross sectionally augmented autoregressive distributed lag model and the augmented mean group estimator, with interaction terms added for robustness. The findings showed that carbon emissions exerted a positive and significant effect on human development for middle income countries, while the interaction between carbon emissions and official development assistance also improved human development. For low-income countries, the combined effect of governance and carbon emissions was also positive. The study further revealed that carbon emissions positively influenced some dimensions of HDI, including life expectancy, expected years of schooling, and national income, depending on the income group. While the study offered rich insight through interaction effects and income-

based disaggregation, its interpretation of carbon emissions as partly growth reflecting may understate the long-term ecological costs of emissions. Also, the analysis relied on aggregate national data and a 2019 endpoint, which may not fully reflect post pandemic sustainability realities.

Hasanov *et al.* (2024) provided country specific evidence from Azerbaijan on the long-term dynamics between human development and environmental sustainability. Their study covered the period from 1992 to 2022 and explored the relationship between HDI and CO2 emissions within the context of sustainable development. The researchers employed the autoregressive distributed lag model and complemented the analysis with Granger causality procedures to test both long run and short run relationships. The findings showed that a long run equilibrium relationship existed between HDI and CO2 emissions, and the estimated results indicated that a one unit increase in HDI was associated with a reduction in CO2 emissions by about 2.793 units. This implied that, within Azerbaijan, improvements in sustainable development were associated with lower carbon emissions rather than higher pollution. That result was notable because it departed from the common pollution intensive development story found in many emerging economies. Nonetheless, the study was narrow in scope because it examined only one country and concentrated mainly on the HDI CO2 relationship. It did not incorporate wider sustainability variables such as renewable energy use, institutional quality, or technological change, thereby limiting the comprehensiveness of its explanation of the carbon emissions, sustainable development nexus.

A more nonlinear perspective was advanced by Akpolat and Bakırtaş (2024), who analysed eight developing countries, namely Brazil, Russia, India, China, South Africa, Egypt, Iran, and Turkey, over the period 1990 to 2021. The study fell within the energy, environment, and development domain and measured sustainable development using the Human Development Index, while the carbon emissions proxy was CO2 emissions. The authors used panel unit root testing with structural breaks and cross-sectional dependence, followed by feasible generalized least squares estimation. Their findings revealed that CO2 emissions had an inverted U-shaped relationship with HDI, which meant that emissions initially moved with improvements in human development but later undermined it after a turning point. In the same model, fossil energy also displayed an inverted U-shaped effect, while renewable energy showed a U-shaped relationship with HDI. Urbanisation, trade, and industrialisation were found to improve human development. The merit of this study lay in its nonlinear treatment of emissions, which better reflected the complexity of the development process. Even so, the study combined diverse countries with very different institutional and energy structures into one panel, which may have hidden country specific thresholds. It also measured sustainable development only through HDI, leaving out broader ecological resilience indicators.

In another important contribution, Liu *et al.* (2023) investigated the relationships among infrastructure development, human development, and CO2 emissions in China using annual time series data from 1990 to 2021. The study belonged to the field of environmental and

development studies, and sustainable development was proxied by HDI, whereas carbon emissions were represented by CO2 emissions. The authors applied quantile regression to capture distributional differences in the relationship across quantiles. Their results showed that infrastructure had a positive and statistically significant relationship with HDI across all quantiles, but the same process also raised CO2 emissions significantly, implying that human development gains had been accompanied by greater environmental pressure. In essence, the study suggested that carbon emissions rose alongside improvements in social welfare, thereby presenting a trade-off between development progress and environmental sustainability. A major strength of the paper was its use of quantile regression, which improved the robustness of inference beyond mean effects. However, the work was limited by its single country scope, which constrained generalisation, and by its use of annual macro data, which masked regional disparities within China. It also focused heavily on infrastructure as the transmission channel, leaving out other institutional and ecological drivers of sustainable development.

Banday and Kocoglu (2023) investigated emerging economies over the period 1990 to 2014 and examined the simultaneous relationships among human development, carbon dioxide emissions, energy consumption, and economic growth using panel quantile regression, supported by fixed effects and ordinary least squares for robustness. Their domain of study was emerging economies, while sustainable development was captured through HDI, and carbon emissions were measured through CO2. The findings showed that carbon emissions exerted a negative effect on HDI across the estimated models, whereas energy consumption, population, and international trade positively affected HDI. They also validated the Environmental Kuznets Curve in the sample, suggesting that development initially intensified environmental pressure before later improvement became possible. The study was insightful because it handled heterogeneity across quantiles, but it remained limited by its relatively old endpoint of 2014, which may not have reflected more recent decarbonisation transitions. In addition, the study relied on aggregate panel data, which reduced country-specific policy interpretation, and it treated sustainable development mainly through HDI without incorporating broader ecological indicators.

Methodology

This paper adopts a longitudinal research design because it examines the relationship between carbon emissions and sustainable development across time in selected Sub-Saharan African countries. A longitudinal design is appropriate where the objective is to observe trends, changes, and patterns in variables over several years rather than at a single point in time. In this study, the design makes it possible to track how industrial process carbon emissions, transport carbon emissions, and building carbon emissions have evolved alongside sustainable development, measured by the Human Development Index, from 1999 to 2025. Its major strength lies in its ability to capture dynamic relationships, temporal variations, and country-specific development trajectories, thereby providing a stronger basis for empirical analysis than a cross-sectional design would permit.

The paper relies on secondary data of a quantitative and panel nature, covering selected Sub-Saharan African countries over the period 1999 to 2025. The data are longitudinal because they track the same countries across time, thereby making it possible to observe trends, changes, and cross-country differences in both carbon emissions and sustainable development. Sustainable development is measured by the Human Development Index, while carbon emissions are disaggregated into industrial process carbon emissions, transport carbon emissions, and building carbon emissions. The major sources of data are reputable international databases. Data on industrial process carbon emissions are drawn from Andrew (2024) and the World Development Indicators (World Bank, 2025). Transport carbon emissions are sourced from the International Energy Agency (2021) and World Development Indicators. Building carbon emissions are obtained from the International Energy Agency (2024) and World Development Indicators, while HDI data are sourced from the UNDP Human Development Report statistical annex (UNDP, 2025). The paper draws methodological insight from Dildebayeva, *et al.* (2025), who examined the effects of oil price, CO_2 emissions, and renewable energy consumption on socio-economic development in Kazakhstan. On this basis, the functional model for the study is specified as follows:

$$HDI_{it} = \pi_0 + \pi_1 IPCE_{it} + \pi_2 TCE_{it} + \pi_3 BCE_{it} + \mu_t + \varepsilon_{it} \quad (1)$$

Where;

HDI = Human development index
IPCE = industrial process carbon emissions
TCE = transport carbon emissions
BCE = building carbon emissions

π_0 = Intercept or autonomous parameter estimate

π_1, π_2, π_3 = Coefficients of industrial process carbon emissions, transport carbon emissions, building carbon emissions

μ_i = unobserved individual effects (or fixed effect error term, or unobserved heterogeneity)

ε_{it} = is the error term and $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$

Note: $i = 1, 2, \ldots N$ representing cross sections; $t = 1, 2, \ldots, T$ representing time periods

The empirical analysis began with panel unit root testing as a preliminary diagnostic procedure to determine the stationarity properties of the variables included in the model. In this study, the Im, Pesaran, and Shin (IPS) W-stat test was employed to examine whether the series contained unit roots across the selected Sub-Saharan African countries over time. This step was necessary because regression involving non-stationary variables may produce misleading and spurious results, thereby weakening the validity of statistical inference. The IPS approach is particularly suitable for panel data because it allows for heterogeneity in the autoregressive coefficients across cross-sectional units, unlike first-generation tests that impose common dynamics on all countries. In essence, the test evaluates the null hypothesis that all panels contain unit roots against the alternative that at least some panels are stationary.

The mathematical form of the Im, Pesaran, and Shin (2003) W-stat panel unit root test is commonly written as:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta y_{i,t-j} + \varepsilon_{it} \quad (2)$$

Where $i = 1,2, \ldots, N$ denotes the cross-sectional units (countries), and $t = 1,2, \ldots, T$ represents time. In this specification, y_{it} is the variable under consideration, Δ is the first-difference operator, α_i captures the individual-specific intercept, β_i is the coefficient used to test for the presence of a unit root, p_i is the lag length for each cross-section, γ_{ij} are the coefficients of the lagged differences, and ε_{it} is the error term.

The hypotheses are stated as:
$H_0: \beta_i = 0$ for all i
$H_1: \beta_i < 0$ for at least some i

The IPS test statistic is then based on the average of the individual Augmented Dickey-Fuller t-statistics:

$$\bar{t}_{IPS} = \frac{1}{N} \sum_{i=1}^{N} t_i \quad (3)$$

And the standardized W-statistic is expressed as:

$$W = \frac{\sqrt{N}(\bar{t}_{IPS} - E(t_i|\beta_i=0))}{\sqrt{\mathrm{Var}(t_i|\beta_i=0)}} \quad (4)$$

The mathematical form of the Pedroni Residual Cointegration Test begins with the long-run panel regression specified as:

$$Y_{it} = \alpha_i + \delta_i t + \beta_{1i} X1_{it} + \beta_{2i} X2_{it} + \beta_{3i} \mathrm{X3} + \varepsilon_{it}$$

where Y_{it} represents sustainable development measured by the Human Development Index for country i at time t, $X1_{it}$ denotes industrial process carbon emissions, $X2_{it}$ denotes transport carbon emissions, $X3_{it}$ denotes building carbon emissions, α_i is the country-specific intercept, $\delta_i t$ captures the deterministic time trend where included, β_{1i}, β_{2i}, and β_{3i} are the long-run slope coefficients, and ε_{it} is the disturbance term.

The residual-based cointegration test is then carried out on the estimated residuals from the above equation using the auxiliary regression:

$$\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{i,t-1} + \sum_{j=1}^{p_i} \phi_{ij} \Delta \hat{\varepsilon}_{i,t-j} + \mu_{it} \quad (5)$$

Where $\hat{\varepsilon}_{it}$ are the estimated residuals from the long-run model, ρ_i is the autoregressive parameter, p_i is the lag length, ϕ_{ij} are coefficients of lagged residual differences, and μ_{it} is the white-noise error term.

The null and alternative hypotheses are stated as:
$H_0: \rho_i = 1$ for all i (no cointegration)
$H_1: \rho_i < 1$ for all i or for some i (cointegration)
Pedroni develops seven test statistics: four within-dimension statistics, namely panel v, panel ρ, panel PP, and panel ADF, and three between-dimension statistics, namely group ρ, group PP, and group ADF.

Following the confirmation of a long-run equilibrium relationship among carbon emissions and sustainable development, the paper proceeded to estimate the long-run coefficients using the Panel Fully Modified Ordinary Least Squares (Panel FMOLS) technique. This estimator is well suited for panel cointegrated models because it provides efficient long-run estimates where the variables are non-stationary but cointegrated. In this study, Panel FMOLS is appropriate for examining how industrial process carbon emissions, transport carbon emissions, and building carbon emissions relate to sustainable development, measured by the Human Development Index, across the selected Sub-Saharan African countries.

Incorporating equation (1) into the panel FMOLS framework, we have:

$$HDI_{it} = \pi_0 + \sum_{it=1}^{T} \pi_1 IPCE_{it}^{*} + \sum_{it=1}^{T} \pi_2 TCE_{it}^{*} + \sum_{it=1}^{T} \pi_3 BCE_{it}^{*} + \mu_t + \varepsilon_{it} \quad (6)$$

One of the major strengths of Panel FMOLS is that it corrects for the problems of endogeneity and serial correlation that often arise in long-run panel regressions. In cointegrated systems, explanatory variables may be jointly determined with the dependent variable, while error terms may also be correlated over time. Conventional Ordinary Least Squares may therefore produce biased or misleading estimates. Panel FMOLS overcomes these limitations by applying non-parametric adjustments to the error structure, thereby yielding more reliable and consistent long-run parameter estimates.

Results and Discussion

Descriptive Statistics Results

Descriptive statistics in Table 1 provide a preliminary summary of the data by showing the central tendency, dispersion, and distributional properties of the variables used in the model. In a study of carbon emissions and sustainable development, this stage is important because it offers an initial picture of the behaviour of the dependent and independent variables across the selected Sub-Saharan African countries and over time.

Table 1: Descriptive Statistics Results

	HDI	IPCE	TCE	BCE
Mean	0.571104	5.801937	20.81028	7.673932
Maximum	0.749000	18.57900	59.68210	42.64900
Minimum	0.391000	0.179000	1.074500	0.490700
Std. Dev.	0.081196	6.280497	19.72935	10.20644
Skewness	0.145701	0.967085	0.707394	1.732405
Kurtosis	2.669308	2.192828	1.824252	4.759176
Jarque-Bera	1.092780	24.70806	19.03506	84.93528
Probability	0.579036	0.000004	0.000074	0.000000
Observations	135	135	135	135

Source: Researcher's Computation Using EViews-12 (2026)

Beginning with sustainable development, measured by HDI, the mean value of 0.571104 indicates that, on average, the selected countries recorded a moderate level of human development over the study period. This average is consistent with the broader discussion that although South Africa, Nigeria, Angola, Ghana, and Kenya have made progress in human development, the overall level remains below the threshold associated with very high human development. The maximum value of 0.749000 shows that the highest observed HDI within the sample approached the upper-middle to high human development range, which is most likely associated with South Africa in the later years of the sample, while the minimum value of 0.391000 confirms that some country-year observations were still at relatively low levels of human development, especially in the earlier years. The standard deviation of 0.081196 suggests that HDI is the least volatile variable in the dataset, implying that sustainable development changed more gradually and steadily than the carbon-emission indicators. The skewness value of 0.145701 shows that the HDI distribution is only slightly positively skewed, meaning that the observations are fairly balanced around the mean. Its kurtosis value of 2.669308 is close to 3, indicating a distribution not far from normal. This is reinforced by the Jarque-Bera statistic of 1.092780 with a probability value of 0.579036, which suggests that HDI is normally distributed. This pattern is reasonable because human development indicators usually evolve slowly over time and are less prone to sharp fluctuations than sectoral emissions. For industrial process carbon emissions, the mean value of 5.801937 indicates that the average level of emissions from industrial processes across the sampled countries and years was relatively modest compared with transport emissions, but still substantial enough to suggest the importance of industrial and construction activity in the region.

The maximum value of 18.57900 shows that some country-year observations experienced considerably high industrial emissions, while the minimum of 0.179000 indicates that certain countries, especially those with less developed industrial bases, had very low levels at some points in time. The standard deviation of 6.280497 is larger than the mean, indicating significant variability in industrial process emissions across countries and years. This wide dispersion reflects the structural differences among the selected economies, with South Africa and Nigeria likely contributing much larger industrial emissions than countries such as Kenya or Ghana in certain periods. The skewness value of 0.967085 indicates a moderate positive skew, meaning that the distribution is pulled to the right by a few relatively high values. The kurtosis of 2.192828, being below 3, suggests a platykurtic distribution, implying that the series is somewhat flatter than the normal distribution. The Jarque-Bera statistic of 24.70806 with a probability of 0.000004 shows that industrial process carbon emissions are not normally distributed. This non-normality is consistent with the uneven pace of industrialization across the countries, where a few high-emission observations dominate much of the variation.

Transport carbon emissions recorded the highest mean value among the three carbon proxies, at 20.81028, indicating that transport was, on average, the largest source of carbon emissions in the selected countries during the study period. This result aligns strongly with the earlier discussion that rising mobility, urbanization, dependence on road transportation, and fossil-

fuel-based transport systems are central features of the emissions profile of these economies. The maximum value of 59.68210 suggests that transport emissions reached very high levels in some observations, while the minimum value of 1.074500 shows that the lowest country-year observations were still above zero, confirming that transport emissions were present across all countries in the sample.

The standard deviation of 19.72935 is very high, almost equal to the mean, which points to substantial variability in transport emissions across countries and over time. This indicates that while some countries maintained relatively moderate transport emissions, others experienced strong increases associated with larger economies, urban congestion, trade expansion, and motorization. The skewness of 0.707394 reveals a positive skew, though less pronounced than for industrial process emissions, suggesting that high values occurred more frequently. The kurtosis of 1.824252, which is well below 3, indicates a flatter distribution with thinner central concentration. The Jarque-Bera statistic of 19.03506 and probability of 0.000074 confirm that transport carbon emissions are not normally distributed. This further reflects the unequal transport development patterns across the selected Sub-Saharan African countries.

Building carbon emissions show a mean value of 7.673932, which places them above industrial process emissions on average but below transport emissions. This suggests that the building sector constituted an important, though not dominant, source of carbon emissions in the selected countries. The maximum value of 42.64900 is notably high relative to the mean, indicating the presence of some very large building-emission observations, likely driven by countries with more energy-intensive residential and commercial building sectors. On the other hand, the minimum value of 0.490700 confirms that some observations were associated with very low levels of building-related emissions. The standard deviation of 10.20644, which exceeds the mean, reveals a high degree of dispersion and suggests that building emissions differed widely across countries and years. This can be linked to differences in urbanization rates, electricity access, housing development, energy efficiency, and the carbon intensity of energy used in buildings. The skewness value of 1.732405 is the highest among all variables, indicating that the series is strongly positively skewed, with a concentration of lower values and a few very high observations stretching the distribution to the right. Its kurtosis of 4.759176 is above 3, indicating a leptokurtic distribution, which means the series is more peaked and has heavier tails than a normal distribution. The Jarque-Bera statistic of 84.93528 with a probability of 0.000000 clearly shows that building carbon emissions are not normally distributed. This points to substantial asymmetry and the likely presence of outliers, consistent with the fact that building-sector emissions in the sample are concentrated more heavily in a few countries and periods.

Panel Unit Root Test

In this study, the Levin, Lin, and Chu test were employed with intercept and trend to examine the stationarity properties of sustainable development and the carbon-emission proxies.

Table 2: Levin, Lin & Chu Test unit root test results

Variable	Levin, Lin & Chu Test @ Levels	Levin, Lin & Chu Test @ 1st Difference	Remarks
HDI	-1.71898 (0.3044)	-2.31171 (0.0144)**	*I*(1): Stationary
BCE	-0.92985 (0.1762)	-5.91590 (0.0000)*	*I*(1): Stationary
IPCE	-0.71062 (0.2387)	-2.48018 (0.0066)*	*I*(1): Stationary
TCE	0.74874 (0.7730)	-2.89795 (0.0019)*	*I*(1): Stationary

Note: The tests include intercept with trend; * and ** significant at 1 and 5 percent.
Source: Researcher's Computation Using EViews-12 (2026)

For sustainable development, measured by HDI, the Levin, Lin, and Chu statistic at first difference is -2.31171 with a probability value of 0.0144, which is significant at the 5 percent level. Since the probability value is less than 0.05, the null hypothesis of a unit root is rejected at first difference. This indicates that HDI is stationary after differencing and is therefore integrated of order one. Building carbon emissions also became stationary at first difference. The reported Levin, Lin, and Chu test statistic is -5.91590 with a probability value of 0.0000, which is significant at the 1 percent level. This very low probability value provides strong evidence against the null hypothesis of a unit root after first differencing. It therefore shows that building carbon emissions are integrated of order one.

Industrial process carbon emissions followed the same pattern. At first difference, the Levin, Lin, and Chu test statistic is -2.48018 with a probability value of 0.0066, which is statistically significant at the 1 percent level. This means that the null hypothesis of non-stationarity is rejected after first differencing, confirming that industrial process carbon emissions are stationary at I(1).

Transport carbon emissions equally became stationary at first difference. The Levin, Lin, and Chu statistic is -2.89795 with a probability value of 0.0019, which is significant at the 1 percent level. Since the probability value is far below the conventional threshold, the null hypothesis of a unit root is rejected for the first-differenced series. This confirms that transport carbon emissions are also integrated of order one.

Panel cointegration test

The Pedroni residual cointegration results provide evidence on whether sustainable development, and the carbon-emission variables move together in the long run across the selected Sub-Saharan African countries.

Table 3: Pedroni Residual Cointegration Test

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	6.125272	0.0000	11.15728	0.0000
Panel rho-Statistic	4.019293	0.0083	8.766497	0.0013
Panel PP-Statistic	4.325231*	0.0079	8.666843	0.0022
Panel ADF-Statistic	5.246851*	0.0004	7.331989	0.0001
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	5.339188	0.0003		
Group PP-Statistic	4.633752**	0.0369		
Group ADF-Statistic	3.967615***	0.0854		

Source: Researcher's Computation Using EViews-12 (2026)

Starting with the within-dimension results, the Panel PP-Statistic has a value of 4.325231 with a probability of 0.0079, and this is marked with a single asterisk, indicating significance at the 1 percent level. This result provides strong evidence in support of cointegration. In practical terms, it suggests that when the variables are considered under the common autoregressive framework, their residuals are stationary enough to confirm a stable long-run relationship. Similarly, the Panel ADF-Statistic is 5.246851 with a probability value of 0.0004, also marked with a single asterisk, which again shows significance at the 1 percent level. This strengthens the evidence from the within-dimension perspective and reinforces the conclusion that the variables in the model share a common long-run path. Since both the panel PP and panel ADF statistics are significant at this very strict level, the long-run relationship can be regarded as strongly supported from the pooled dimension of the Pedroni framework.

Panel FMOLS Regression Estimates

The panel FMOLS result presents the long-run effect of the three carbon-emission proxies on sustainable development in the selected Sub-Saharan African countries. Since FMOLS is a long-run estimator, the focus is on the relationship between the variables rather than temporary short-run fluctuations.

Table 4: Panel FMOLS Results
Dep. Var. HDI

Variable	Coefficient	Std. Error	t-Statistic	Prob.
IPCE	-0.1163	0.1215	-0.9575	0.3402
TCE	0.2622	0.0950	2.7598	0.0067
BCE	0.3365	0.1657	2.0304	0.0445
Reliability estimates				
R-squared	0.7520			
Adjusted R-squared	0.7378			
Long-run variance	4.4739			

Source: Researcher's Computation Using EViews-12 (2026)

Starting with industrial process carbon emissions, the coefficient is -0.1163, with a t-statistic of -0.9575 and a probability value of 0.3402. The negative sign indicates that, in the long run, a one-unit increase in industrial process carbon emissions is associated with a 0.1163-unit decrease in HDI. Since Transport carbon emissions show a different pattern. The coefficient for TCE is 0.2622, with a t-statistic of 2.7598 and a probability value of 0.0067. This implies that a one-unit increase in transport carbon emissions, measured in metric tons of CO_2 equivalent, is associated with a 0.2622-unit increase in HDI in the long run. Since the probability value is less than 0.01, the result is statistically significant at the 1 percent level. This makes transport carbon emissions a positive and significant predictor of sustainable development in the model. Building carbon emissions also display a positive relationship with sustainable development. The coefficient is 0.3365, with a t-statistic of 2.0304 and a probability value of 0.0445. This means that a one-unit increase in building carbon emissions leads to a 0.3365-unit increase in HDI in the long run, and the relationship is statistically significant at the 5 percent level.

The R-squared value of 0.7520 shows that about 75.20 percent of the total variation in sustainable development, measured by the Human Development Index, is explained by the combined effect of industrial process carbon emissions, transport carbon emissions, and building carbon emissions in the model. In other words, the model captures a large share of the systematic movement in sustainable development, while the remaining 24.80 percent is attributable to other factors outside the model, such as governance quality, education policy, health expenditure, technological change, institutional conditions, and broader macroeconomic influences. The adjusted R-squared of 0.7378 further strengthens this interpretation. After adjusting for the number of explanatory variables in the model, the result indicates that approximately 73.78 percent of the variation in HDI is still explained by the included regressors.

Discussion of Findings
Findings from the paper showed that industrial process carbon emissions had a negative but statistically insignificant effect on sustainable development in the selected Sub-Saharan African countries. This means that increases in emissions arising from industrial production

activities, especially those tied to cement and related industrial processes, tended to be associated with reductions in human development, although the effect was not strong enough to be regarded as statistically reliable within the model. The implication is that industrial expansion in the sampled countries may not yet be sufficiently efficient, inclusive, or welfare-enhancing to produce clear gains in sustainable development. In many developing economies, industrial activity can raise pollution burdens without generating broad-based improvements in health, education, and living standards, particularly where production systems are carbon-intensive and weakly linked to social progress. This outcome is consistent with Banday and Kocoglu (2023), who found that carbon emissions exerted a negative effect on HDI in emerging economies, and with Dildebayeva *et al.* (2025), whose evidence from Kazakhstan also showed that CO_2 emissions reduced HDI in both the short run and the long run. The present finding also aligns partly with Akpolat and Bakırtaş (2024), who reported that the relationship between emissions and human development in developing countries is not uniformly beneficial and may become harmful beyond a certain point. However, the insignificant nature of the coefficient in this study differs from the stronger statistical effects reported by Banday and Kocoglu (2023), suggesting that in the selected Sub-Saharan African countries, the development consequences of industrial process emissions may still be mediated by country-specific structural conditions, such as the scale of industrialization, technology use, and the extent to which industrial growth translates into improvements in human welfare.

The paper further found that transport carbon emissions had a positive and statistically significant impact on sustainable development. This indicates that, over the study period, increases in transport-related carbon emissions were associated with improvements in HDI across South Africa, Nigeria, Angola, Ghana, and Kenya. The result suggests that transport expansion in these countries may still be closely tied to development-enhancing processes such as improved mobility, market access, trade integration, access to schools and hospitals, and wider economic participation. In other words, the current transport systems in the selected countries appear to support human development, even though they do so through carbon-intensive means. This finding is in line with Ezako (2024), who found that carbon emissions positively influenced human development in middle-income developing countries and even improved some dimensions of HDI depending on income group and governance conditions. It also agrees with Rahman and Sultana (2024), who reported a significant positive relationship between improvements in human development and increased CO_2 emissions in a panel of developing countries, thereby pointing to a development–environment trade-off. In a similar direction, Liu *et al.* (2023) showed that the processes driving higher human development in China also raised CO_2 emissions significantly, implying that welfare gains were accompanied by environmental pressure. The present result equally resonates with Fakhri *et al.* (2024), who argued that in some countries development gains still occur through polluting growth. Nonetheless, the result does not suggest that transport emissions are inherently beneficial; rather, it shows that the existing path of mobility-led development in the selected Sub-Saharan African countries remains heavily dependent on fossil-fuel transport systems. This makes the finding important for

policy, because it indicates that transport is simultaneously supporting human development and generating environmental costs.

In addition, the findings revealed that building carbon emissions had a positive and statistically significant effect on sustainable development. This means that increases in emissions associated with the building sector were linked with higher levels of HDI in the selected countries. Since building emissions are closely connected to housing expansion, urban infrastructure, electricity use, commercial buildings, and the broader built environment, the result suggests that improvements in shelter, urban services, and energy access may be contributing positively to human development, even where such improvements are being delivered through carbon-emitting systems. This outcome supports the argument that in developing regions, some forms of emissions may reflect ongoing structural transformation rather than pure environmental deterioration. The finding is consistent with Ezako (2024), whose study showed that carbon emissions could positively affect human development, especially where they are associated with income, education, and life expectancy improvements. It also agrees with Rahman and Sultana (2024), who found that rising human-development status in low- and middle-income countries was associated with higher CO_2 emissions. Likewise, Fakhri *et al.* (2024) reported that several countries still exhibited a pattern of human development through polluting growth, which supports the idea that welfare improvement can coexist with environmental pressure. The result also fits the broader international pattern identified by Xu *et al.* (2024), who found that although emissions per unit of HDI were narrowing globally, many countries, especially those outside the very high HDI group, still displayed coupling between human development and carbon emissions. Even so, the present finding departs from Hasanov *et al.* (2024), who found that improvements in HDI reduced CO_2 emissions in Azerbaijan, implying a more environmentally efficient development path than what appears to exist in the selected Sub-Saharan African countries.

Conclusion and Recommendations

In conclusion, the paper has shown that the relationship between carbon emissions and sustainable development in selected Sub-Saharan African countries is dynamic, sector-specific, and deeply tied to the region's development line. Sustainable development, measured by the Human Development Index, improved across South Africa, Nigeria, Angola, Ghana, and Kenya over the study period, but the level of progress remained uneven and, in several cases, still moderate relative to the developmental aspirations of these countries. Industrial process carbon emissions exerted a negative but insignificant effect on sustainable development, suggesting that industrial carbon intensity has not translated into clear human-development gains. By contrast, transport and building carbon emissions had positive and significant effects on HDI, implying that transport expansion and building-related activities are still closely associated with improvements in welfare, access, and living conditions in the selected countries.

The paper suggested the following recommendations:

i. Given the negative, though statistically weak effect of industrial process carbon emissions on sustainable development, the study recommended cleaner industrialization rather than reduced industrial activity in South Africa, Nigeria, Angola, Ghana, and Kenya. National standards agencies and environmental protection institutions should also enforce factory energy-efficiency requirements and establish deadlines for partial fuel switching from heavy fossil fuels to lower-carbon alternatives. To ensure that firms are able to comply, public development finance institutions such as the Development Bank of Southern Africa, the Bank of Industry in Nigeria, Development Bank Ghana, Kenya Development Corporation, and equivalent Angolan institutions should provide concessionary green-industrial financing for retrofitting, cleaner equipment acquisition, and broader low-carbon industrial modernization.

ii. Since transport carbon emissions were found to have a positive and significant relationship with sustainable development, the recommendation was to decarbonize transport systems without weakening their role in human development. In practical terms, the transport ministries in South Africa, Nigeria, Angola, Ghana, and Kenya should expand bus rapid transit, strengthen integrated urban public transport, and rehabilitate rail freight networks in major cities such as Johannesburg, Lagos, Luanda, Accra, and Nairobi. Energy and petroleum regulators in these countries should simultaneously enforce low-sulphur fuel standards, establish routine vehicle emissions inspection systems, and place age restrictions on imported used vehicles, given the heavy dependence on old and polluting vehicle fleets.

iii. Because building carbon emissions also showed a positive and significant effect on sustainable development, the study recommended making housing and urban expansion more energy-efficient rather than slowing their growth. Ministries responsible for housing, public works, urban planning, and physical development in South Africa, Nigeria, Angola, Ghana, and Kenya should therefore revise building codes to make energy-efficient materials, passive cooling systems, efficient lighting, and minimum energy-performance standards compulsory for public and private buildings. This should apply especially to schools, hospitals, offices, and large residential developments. Electricity regulators and utility providers such as Eskom, the Nigerian Electricity Regulatory Commission, the Public Utilities Regulatory Commission in Ghana, and the Energy and Petroleum Regulatory Authority in Kenya should support this effort by promoting rooftop solar systems, energy-efficient appliances, smart metering, and more reliable urban electrification.

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