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Environmental Regulatory Standards, Energy Consumption, and Environmental Quality in Lower Middle-Income Sub-Saharan Africa: The Role of Structural Breaks

Olugbenga O. Olaoye[1]*, Ebenezer Bowale[1], Olabanji O. Ewetan[2]

[1]Covenant University, Nigeria, [2]Research Fellow Centre for Economic Policy and Development Research, Covenant University, Nigeria. *Email: olugbenga.olaoyepgs@stu.cu.edu.ng

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ABSTRACT

The primary objective of this paper is to investigate how environmental regulations in Sub-Saharan African (SSA) countries influence the nexus between energy use and environmental quality, and in particular, to ascertain the degree to which structural breaks impact the nexus. The study covered eighteen (18) middle-income (MIC) countries in sub-Saharan Africa. The research uses yearly secondary data from 1991 to 2022, and relies on the Cross Sectional Autoregressive Distributed Lag (CS-ARDL) as the estimating technique to achieve the study's objectives. Findings indicate that structural reforms and policy shifts significantly enhance environmental quality. While economic growth positively affects environmental quality, the adverse initial impacts of regulatory changes and capital investments underscore the need for integrating climate resilience into national security strategies to sustain environmental quality in order to create a stable environment for economic activities.

Keywords: Environmental Quality, Energy Consumption, Regulatory Standards, Structural Breaks, Sub-Saharan Africa
JEL Classifications: Q50, Q53, O13, C23, Q58

1. INTRODUCTION

Development of the human race, industrialization, use of resources, and technical advancement are the foundations for economic growth (Rasheed et al., 2022). As a result of the environmental degradation and the depletion of natural resources, creating a sustainable world is one of the most important goals (Song et al., 2019). Therefore, reducing the effects of global warming is critical to addressing environmental issues and fostering economic growth. Whenever economic activity rises, the primary goal of environmental sustainability is to reduce emissions of greenhouse gases (GHG), including carbon dioxide emissions. The primary impediments to utilizing an environmentally friendly system, such as renewable household systems, and preserving the environment are financial in nature (Ewetan et al., 2020; Baulch et al., 2016).

According to Eregha and Mesagan (2017), economic activities are the primary causes of excessive levels of carbon emissions. The kind and number of products and services an economy creates and consumes determines how fast it will grow. There is a constant inclination to produce and market in order to make a living. The standard of living in a society as a whole heavily depends on the nature of the commodities and services made available to the populace. The fight for environmental quality has recently seen a substantial uptick in both emerging and developed countries due to the detrimental consequences of environmental pollution on human wellness, food availability, both natural and physical capital, as well as the preservation of land and water and climate change. The claim that economic activity and environmental quality are directly related has also been advanced by Mesagan and Olunkwa (2020); Padhan et al. (2019); and Kahia et al. (2019). This demonstrates how policies intended to promote economic expansion are simultaneously linked to an increase in carbon emissions, which has an impact on the state of the environment. This is because economies use energy sources like coal, gas, and fossil fuels, which are perceived to be less expensive to consume yet have negative environmental effects, in an effort to promote economic expansion.

Similar to this, Salahuddin and Gow (2019) offered an alternative line of reasoning, contending that there is not enough proof to argue for green initiatives that aim to reduce harmful emissions and improve environmental quality, regardless of whether there is a positive or negative connection between economic expansion and environmental quality. It becomes crucial, in particular, to comprehend the relationship between environmental quality and economic growth. In this context, Abdouli and Hammami (2017) provided evidence of both a causal flow from growth towards the environment and a unidirectional causal association between environmental quality and growth. The research suggests that when economic activity, including production, distribution, and trade, increases, degrade the environment's quality because economic activity is accompanied by biodiversity loss, deforestation for the construction of industries and manufacturing facilities, and carbon emissions from the usage of heavy energy. This demonstrates how more stringent environmental regulations aimed at enhancing environmental quality can limit the freedom of economic activity, which subsequently slows growth.

Several African countries, especially Nigeria, Angola, Algeria, Tunisia, Egypt, and South Africa, have an abundance of natural energy resources, including coal, crude oil, gas, solar, hydro, biogas, and wind. The abundance of these energy resources—especially oil—in African nations provides the primary energy supply for the continent, promoting economic growth in addition to being a source of revenue for these countries. The majority of countries, most notably Nigeria, encourage the usage of fossil fuels by giving out exorbitant amounts of subsidies (Adejumo, 2019). While the evidence is clear that using energy to fuel economic growth has effects on the environment and that African countries are quickly rising to the top of the environmental quality rankings, campaign that inspired 33 African nations, or around 60% of them, to sign the Paris Agreement in 2015 to reduce greenhouse gas (GHG) emissions to 2%. In accordance with the principles of Agenda 2063, the African Union (AU) has established a target for 2063: Using renewable energy to promote environmentally friendly development and growth. This objective aligns with the campaign for environmental quality.

According to the Environmental Kuznets Curve's hypothesis, when economic expansion accelerates and the amount of carbon emissions from industrial effluents released by businesses rises, this growth is followed by rising levels of environmental pollution. As the economy, however, approaches its growth goal, pollution control measures are put in place, and further economic expansion is accompanied with decreased pollution of the environment and improvement of the environment (Ajide and Mesagan, 2022; Tabash et al., 2022). However, in recent times, scholars such as Anwar et al. (2022) and Evans and Mesagan (2022) have shifted their focus from the need for expansion of output to other factors, such as trends concerning energy use, volumes of trade, income, investment in capital, and financial progress. There has been advocacy for deepening and strengthening regulatory standards to lessen the growing ecological hazards around the world (Destek & Sinha, 2020; Bowale, 2019).

Therefore, an investigation of the environmental effects of such rapid growth in energy use aims to provide deeper insights for evidence based policy-making, guiding development interventions, and formulating economic strategies to foster more sustainable inclusive economies. The middle-income countries are the economies with per capita gross national income between $1,136 and $4,465 according to the World Bank 2021/22 country income group classification. Consequently, the primary objective of this paper is to investigate how environmental regulations in Sub-Saharan African (SSA) nations impact the relationship between energy use and environmental quality. To be more precise, the goals are to ascertain how regulatory quality influences the connection between energy use and environmental quality in the chosen SSA countries and how much structural breaks impact the connection between energy usage and environmental quality in those countries.

2. LITERATURE REVIEW

The Porter Hypothesis contends that regulations requiring high environmental compliance may increase industry competitiveness through technical development (Thurow and Holt, 1997). Businesses want to make as much revenue as possible, therefore they will seize any opportunity to improve environmental performance that presents themselves. As a result, any legislation requiring enhanced environmental performance will have to be costly. In particular, Porter and Van der Linde (1995) contest the idea that pollution is only wasteful if it can be avoided for a lesser amount than what it costs a business to address it after it has been produced. They give examples of how technological developments in reaction to environmental regulations have brought costs down, creating win-win situations where environmental efficiency and financial viability have both increased.

The Porter Hypothesis (PH) outlines the mechanisms by which stringent environmental laws in the country of origin can, in fact, spur increased innovation and productivity, a net reduction in expenses, and bolster the competitive advantage of domestic businesses.

The "Treadmill of Production" environmental sociology theory distinguishes itself in comparison with different sociological theories that have expressly emphasised environmental danger and the continuation of modern, untenable economic practices (Gould, 2015). The treadmill of production theory is used to investigate how changes in the economy and environment interact. In spite of the fact that this pursuit of expansion causes enormous environmental damage, it demonstrates how industrialized economies are put on a never-ending treadmill of economic expansion with little increase in their well-being (Gould et al. 2015). As emphasized in his original formulation of the "treadmill" metaphor, corporations, the state, and labour are all committed to economic progress. This "ideology of growth" has dominated both capitalist and socialist societies in the 20th century. Consequently, "economic development" is seen as "the sole route to advancement in society, despite being reluctant" (Gould et al., 2004). Environmental concerns have inevitably developed as a result of the quest of economic growth, according to Schaiberg (2005), via the growth of industry and growing capital intensity. The important treadmill hypothesis looks at the social mechanisms associated with the creation and propagation of social surplus in order to offer "an explanation of the social roots of expanded production" Gould, et al., (2015).

Asongu et al.'s (2019) analysis of the conditional association between environmental quality and renewable energy in 40 African nations between 2002 and 2017 adds to the body of work. Their results, which make use of quantile and fixed effects regressions, continuously show that carbon dioxide (CO_2) emissions are decreased by renewable energy. Furthermore, when CO_2 levels rise, renewable energy's detrimental effects on CO_2 emissions become less pronounced. This suggests that in comparison with countries with lower emissions, those with higher CO_2 emissions have a less noticeable detrimental impact.

Olanrele and Awode (2022) investigate the dynamic relationship among energy consumption, foreign direct investment (FDI), and economic growth in Sub-Saharan Africa. Using data from 42 countries between 1991 and 2018 and applying the Generalized Method of Moments, they find that a 1% increase in energy consumption boosts economic growth by 1.3%, while economic growth increases energy consumption by 0.004%. Moreover, there is a statistically insignificant correlation between FDI and energy consumption, while a strong one-way causality exists among FDI and growth in the economy.

Panel auto-regression distributed lag (PARDL) is used by Riti et al. (2022) to investigate the connection among renewable energy, real GDP, greenhouse gas (GHG) emissions, and gross fixed capital formation in SSA countries from 1990 to 2018. The results indicate a significant long-term relationship among these variables. Renewable energy and gross fixed capital formation positively impact long-term growth, while renewable energy reduces GHG emissions. Long-term interactions involving GDP, renewable energy, and gross fixed capital formation are also identified by the study, with renewable energy having a unidirectional causal relationship with CO_2 emissions.

Boakye-Mensah (2021) examines the impact of institutional quality and disaggregated energy usage on environmental quality using data from 26 sub-Saharan African nations (2002-2016) and the Generalised Method of Moments methodology. According to the findings, renewable energy enhances the environment while non-renewable energy deteriorates it. When renewable energy is used, environmental quality is improved via reduced tax burdens and improved government integrity. Better transparency in government and property rights mitigate the negative impacts of non-renewable energy use.

Ali et al. (2023) examines the nexus between economic growth, CO_2 emissions, and agriculture-value added using panel data from selected African countries (1997-2020) and applying the generalized method of moments. Their findings indicate that economic growth significantly contributes to environmental pollution, supported by the growth-led pollution hypothesis. However, agricultural production and labor reduce pollution, while the food price index, capital, and FDI promote it. The study also finds that economic growth enhances agricultural production when considering the interaction between GDP per capita and FDI.

Ssali et al. (2019) examine the connections between FDI, energy consumption, economic growth, and environmental contamination over a 34-year period (1980-2014) in six sub-Saharan African countries. They discover unidirectional linkage from energy usage to carbon dioxide emissions in the long run and bidirectional causality between energy use and CO_2 emissions in the short run using a variety of panel econometric methodologies. The Environmental Kuznets Curve hypothesis is supported by the fact that a 1% increase in energy use causes CO_2 emissions to rise by 49%, whereas a 1% increase in economic growth causes CO_2 emissions to climb by 16%.

Using static gravity models and the Panel GMM model, Bakari (2024) evaluates the effects of national investments and greenhouse gas emissions on growth in the economy in 48 sub-Saharan African nations (1990-2022). The findings demonstrate that local investment and carbon dioxide emissions have a substantial and favourable impact on the growth of the economy.

Nkemgha et al. (2024) examine the relationship between industrialization and environmental quality in 24 SSA countries (2000-2020) using the system GMM methodology. They find that industrialization, measured by industry and manufacturing value added, deteriorates environmental quality. However, stringent environmental policies can mitigate these negative effects. Additionally, the Environmental Kuznets Curve is noted, which shows that when economic development reaches specific policy thresholds, carbon dioxide emissions ultimately decrease rather than rising initially.

In 2020, the United Nations Environment Programme (UNEP) stated that the global temperature increase of more over 3°C remains expected, even with the short-term decrease in carbon emissions brought on by the COVID-19 epidemic. Remarkably, throughout 2020, the release of greenhouse gases other than carbon dioxide (CO_2), like nitrous oxide and methane, increased. The UNEP's Executive Director, Ms. Inger Andersen, has emphasised how urgent it is to reduce emissions. The goal of keeping the increase in temperature to 1.5°C by 2030 will not be possible with no such actions (UNEP, 2020). Global temperatures rising by 3°C might lead to extreme weather, weaken ecosystems, and destroy the ozone layer, all of which would be grave hazards to the continued existence of humans. Adopting environmentally friendly energy strategies in both production and consumption is essential to meeting long-term energy and climate targets (Kabeyi, and Olanrewaju, (2022).

The state of the environment is now a crucial factor in achieving sustainable development objectives. Several research works, such as those by Usman et al. (2022), Ali et al. (2021), Tenaw and Beyene (2021), Yahaya et al. (2020), Dagar et al. (2022), and Ali et al. (2021), have successfully emphasised the significance of tackling the degradation of the environment in various locations, especially emerging nations. But these studies have frequently failed to recognise the vital role that natural resources play in the environment.

3. THEORETICAL FRAMEWORK

To capture the impact of energy consumption (ENC) on environmental quality, we extend the simplified EKC model, according to Ulucak and Bilgili (2018). The link between energy use and environmental quality can be influenced by regulation policy.

$$EQ = \beta_0 + \beta_1 Y + \beta_1 Y^2 \quad (1)$$

Where; EQ represents environmental quality, Y represents income per capita, and $\beta 0$, $\beta 1$, $\beta 2$ are the parameters.

To capture the impact of energy consumption on environmental quality, we extend the EKC model;

$$EQ = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 ENU \quad (2)$$

The link between environmental quality and energy usage can be influenced by regulatory quality. We introduce regulatory policy into the model as both a direct effect and an interaction effect with energy consumption.

$$EQ = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 ENU + \beta_4 REQ + \beta_5 ENC\_REQ \quad (3)$$

To understand the moderating effect of regulatory policy, consider the partial derivative of environmental quality with respect to energy consumption:

$$\frac{\partial EQ}{\partial ENC} = \beta_3 + \beta_5 REQ \quad (4)$$

Here; $\beta 3$ represents the direct effect of ENC on environmental quality, $\beta 5$ represents how the effect of ENC on environmental quality changes with REQ. The sign and magnitude of $\beta 5$ indicate the moderating effect: If $\beta 5 < 0$, regulatory quality mitigates the adverse impact of energy use on the environment. If $\beta 5 > 0$, regulatory quality exacerbates the adverse impact.

4. RESEARCH DESIGN

4.1. Data Sources and Measurement

The investigation covered eighteen middle-income (MIC) nations in sub-Saharan Africa. Countries classified as middle-income have gross national product per capita of more than \$995 (World Economic Outlook, 2019, World Bank, 2021; 2022). The research makes use of yearly secondary data covering the years 1991-2022. Data on environmental quality (EQ), real gross domestic product (RGDP) energy consumption (ENC), gross capital investment (GCI), and regulatory quality (REQ) were sourced from World Development Indicators (2021). The data on energy use interaction with regulatory quality was generated by the study Table 1 displays the variables' descriptions and sources:

4.2. Model Specification

As per Dinda (2004), Müller-Fürstenberger and Wagner (2007), Kaika and Zervas (2013), carbon dioxide emissions and per capita income have an inverted U-shaped connection, with emissions rising to a certain amount before starting to fall.

Objective one seeks to examine the role of structural shift in the nexus between energy use and environmental quality in SSA The empirical model to achieve this objective is as specified:

$$EQ = f(ENU, RGDP, DB) \quad (5)$$

$$\ln EQ_{i,t} = \beta_0 + \beta_1 lnENU_{i,t} + \beta_2 \ln RGDP_{i,t} + \sum_{r=1}^{k} D_r B_{rt} + \varepsilon_{i,t} \quad (6)$$

Where EQ, ENU, RGDP, REQ and GCI denote total environmental quality (proxied by CO_2), energy consumption (proxied by carbon emission per kt), real GDP (a proxy for economic growth), regulatory quality and gross capital investment, respectively. The determinants are all expressed in logarithms (rep by the prefix "ln") except the REQ which is in percentile. Thus, elasticity is used to express how the independent variables affect the quality of the environment, and i represents a cross-section of countries; t stands for the years 1991 to 2022; β_0 is the intercept; β_1 - β_4 are each variable's elasticities; $\sum_{r=1}^{k} D_r B_{rt}$ where B_{rt} is a dummy variable for each of the breaks defined as B_{rt} = 1 for $t \geq T_{B_r}$, otherwise B_{rt} = 0, and ε is the noise (error).

Objective Two investigated how the quality of environmental regulatory policy among the selected SSA economies affects the nexus between energy use and the quality of environment. Empirical model (7) provides a rich method of modeling the moderating impact of regulatory policies on the link between energy use and the quality of the environment in SSA, thereby captured the conditional impacts. The conditional effect is represented by including the proxy of regulatory and energy use as one of the explanatory factors in the model.

$$EQ = f(ENU, RGDP, REQ, GCI) \quad (7)$$

$$ln\ EQ_{i,t} = \beta_0 + \beta_1 ENU_{i,t} + \beta_2 ln\ ENU_{i,t} REQ_{i,t} + \beta_3 ln\ RGDP_{i,t} + \beta_4 REQ_{i,t} + \beta_5 ln\ GCI_{i,t} + + \varepsilon_{i,t} \quad (8)$$

Where ENC_REQ is the interactive term of energy consumption and regulatory quality; and all other factors stay the same as earlier defined. The total impact of energy consumption which includes the marginal influence of regulatory policy on the quality of environment is arrived at by taking partial derivatives of equation (8):

$$\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} = \beta_1 + \beta_3 REQ_{i,t} \quad (9)$$

The sign and magnitude of this equation should be considered while interpreting it. Considering the sign, if $\beta_1 > 0$ and $\beta_3 < 0$, energy consumption deteriorates environmental quality (ECF) only when regulatory policy leads to energy-inefficient technologies. However, if $\beta_1 < 0$ and $\beta_3 > 0$, it implies that using energy-efficient technologies due to regulatory quality would make energy consumption to enhance environmental quality (EQ). Meanwhile, if $\beta_1 > 0$ and $\beta_3 > 0$, then energy consumption and regulatory policy complementarily promote environmental quality (EQ). Lastly, if $\beta_1 < 0$ and $\beta_3 < 0$, the nexus of energy consumption-environmental quality (EQ) has amplifying influence in diminishing environmental quality. Considering the magnitude, if $\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} > 0$, energy consumption together with regulatory policy enhance environmental quality (EQ) but if $\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} < 0$, both energy use and regulatory policy reduce the quality of environment in the sampled SSA countries.

4.3. Estimation Technique

To achieve our objective one, we employed ARDL model as specified in equation (10) to include endogenous structural breaks follows:

$$\Delta \ln EQ_{it} = \alpha + \sum_{i=1}^{p} \lambda_{1i} \Delta \ln EQ_{it-i} + \sum_{i=0}^{q} \lambda_{2i} \Delta \ln ENU_{it-i} + \sum_{i=0}^{r} \lambda_{3i} \Delta \ln RGDP_{it-i} + \varphi_1 \ln EQ_{It-1} + \varphi_2 \ln ENU_{it-1} + \varphi_3 \ln RGDP_{it-1} + \sum_{r=1}^{k} D_r B_{rt} + \varepsilon_t \quad (10)$$

The inclusion of the break(s), as demonstrated in equation (18), captures $\sum_{r=1}^{k} D_r B_{rt}$ where B_{rt} is a dummy variable for each of the breaks defined as $B_{rt} = 1$ for $t \geq T_{Br}$, otherwise $B_{rt} = 0$. The time period is represented by t; T_{Br} are the structural break dates where r = 1,2,3,…k and Dr is the coefficient of the break dummy. All the other parameters have been previously defined.

The unique Cross Sectional Autoregressive Distributed Lag (CS-ARDL) estimating technique created by Chudik et al. (2016) is employed to achieve objective two. Aspects of the Mean Group (MG) and Pool Mean Group (PMG) estimators can be incorporated into the CS-ARDL credited to Chudik and Pesaran's (2015) dynamic common correlated effects (DCCE) approach while accounting for cross-sectional dependence. It takes into consideration heterogeneous slopes, allows for small numbers of samples, concurrently analyzes both long- and short-run models, handles the problem of cross-sectional dependence, and assumes that parameters are expressed by similar characteristics. Additionally, it can be applied if the panel data is uneven and the series contains structural breaks.

Equations (11) in the panel ARDL version are expressed as;

$$\Delta y_{it} = w_i + \delta_i (y_{i,t-1} - \theta_i' x_{i,t-1}) + \sum_{j-1}^{p-1} \phi_{ij} \Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (11)$$

Table 1: Data descriptions and sources

Symbol	Variable	Measurement	Source
EQ	Environmental Quality	Carbon emissions (CO2) in kt.	WDI (2022)
RGDP	Real Gross Domestic Product	GDP (US$ Billion 2015 constant prices)	WDI (2022)
ENC	Energy Consumption	Fossil fuel energy consumed per capita (EN)	WDI (2022)
GCI	Gross Capital Investment	Gross capital formation (US$)	WDI (2022)
REQ	Regulatory Quality	Quality of regulations (in Percentile Rank)	WDI (2022)

Source: Author's Compilation (2024)

Where y_{it} is environmental quality for economy i at time t; α_{ij} represents a matrix of the regressors (factors); θ_i' is a connection between y_{it} and x_{it}; in the long-run equilibrium, δ_i is the error correction term; ϕ_{ij} and α_{ij} show the connection between y_{it} and x_{it} in the short-run; and the items in the parentheses denotes in the long-run link.

Chudik et al. (2016) created the CS-ARDL model by adding cross-sectional averages to the dependent and explanatory variables, which accounts for gradient asymmetry and cross-sectional relationships. Equation (10) can be changed to be stated as its CS-ARDL equivalent, which is:

$$\Delta y_{it} = \mu_i + \delta_i (y_{i,t-1} - \theta_i' x_{i,t-1} + \delta_i^{-1} n_i \overline{y_t} + \delta_i^{-1} \varphi_i' \overline{x_t}) + \sum_{j-1}^{p-1} \phi_{ij} \Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij} \Delta x_{i,t-j} + \sum_{j-0}^{p-1} \tau_{ik} \Delta \bar{y}_{t-j} + \sum_{j-0}^{q-1} \Delta_{ik} \varphi \bar{x}_{t-j} + \varepsilon_{it} \quad (12)$$

Where $\overline{y_t}$ and $\overline{x_t}$ are the cross-sectional averages of the cause-and-effect factors, respectively.

We first carried out some basic testing before applying the CS-ARDL and PMG. These include the panel unit root test, slope homogeneity test, cross-sectional dependence (CD) test, and panel cointegration test.

5. EMPIRICAL ANALYSIS AND DISCUSSION OF RESULTS

5.1. Descriptive Statistics

The Table 2, which presents descriptive statistics, provides a summary of the overall sample. For every variable, it displays important metrics including the mean, maximum, lowest, and standard deviation. Furthermore, the table uses skewness and kurtosis statistics to evaluate the distributional properties of the variables. Using the Jarque-Bera test statistic, distribution normality is examined in more detail.

In terms of average values, the gross domestic product (RGDP) stands at an average of US$7.63 trillion. Environmental quality (EQ) averages 51087kt. Energy consumption per capita (ENC)

Table 2: Descriptive statistics

Overall sample countries								
Variable	**Obs**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Skewness**	**Kurtosis**	**J-Bera**
EQ	558	51087.936	90370.134	806.3	448298.1	2.7320	10.4415	2.2e+04
ENU	558	58.793	30.2	6.736	99.978	−0.17393	1.6092	118.9***
RGDP	558	7.63E+10	1.05E+11	1.89E+09	5.19E+11	2.1252	7.1539	8922***
GCI	558	24.102	8.902	6.924	79.401	1.4960	7.7596	569.7***
REQ	558	38.442	20.713	0.476	86.058	0.0960	2.2064	61.13***

Source: Author's Computation (2024)
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

averages 58.79. Gross Capital Investment averages US$24.10. And regulatory rank percentiles are 38.44%.

Regarding the statistical distribution, most variables appear positively skewed, except for ENC, which displays negative skewness. Kurtosis statistics vary, with the majority of variables being leptokurtic, ENU showing platykurtic characteristics, and REQ being mesokurtic. The Jarque-Bera test yields probability values below 0.05, indicating rejection of the hypothesis of normal distribution at the 5% significance level.

5.2. Correlation Analysis

We assessed both strength and direction of correlations between the relevant predictors using a correlation test. The degree of association prompts an investigation into the presence of multicollinearity. The correlation test outcomes, as depicted in Table 3, indicate modest correlations among the considered factors. Notably, real GDP exhibits the most robust association with carbon emissions across the dataset. These findings suggest the absence of multicollinearity within the model, with no notably strong correlations among the variables. Hence, the incorporation of all independent variables into the empirical model does not raise concerns regarding multicollinearity.

5.3. Cross-Sectional Dependence

Panel analyses need the evaluation of cross-sectional dependence (CD) due to the variation in uniform features among the sample countries. Table 4 presents the findings of the Pesaran CD test, which show that at the 1% significance level, the null hypothesis of no CD cannot be accepted. This suggests that other countries in the sample may be impacted by the dynamics of variables like energy consumption, environmental quality, real GDP, financial inclusion, gross capital investment, regulatory considerations, and ENU_REQ. As such, it implies a mutual dependence among Sub-Saharan African (SSA) middle-income nations (MICs). This result, in essence, emphasizes how interrelated the Sub-Saharan African region is.

5.4. Analysis of the Unit Root

Overall, testing for unit roots in panel data analysis and times series is fundamental for identifying potential cointegration relationships. Both first- and second-generation panel unit root tests are commonly utilized in panel data analysis to assess stationarity. However, Perron (1989) highlighted the importance of accounting for existing structural breaks, as neglecting them can introduce bias and undermine the capacity to reject false unit root null hypotheses.

Table 3: Correlation matrix

Variables	−1	−2	−3	−4	−5	−6
(1) ENU	1					
(3) RGDP	0.172	0.221	1			
(4) GCI	−0.145	−0.191	−0.113	1		
(5) REQ	0.239	0.602	−0.136	−0.202	1	
(6) ENC_REQ	0.626	0.979	0.265	−0.167	0.54	1

Source: Author's Computation using STATA 15 (2024)
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

Table 4: Cross-sectional dependence

Variable	CD test	P-value
LEQ	50.05	0.000
LENU	17.86	0.000
LRGDP	59.30	0.000
LGCI	1.58	0.114
REQ	0.790	0.429
LENC_REQ	18.60	0.000

Source: Author's Computation using STATA 15 (2024)
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

To extend the unit root test to accommodate structural breaks, we adopt the xtb unitroot method proposed by Karavias and Tzavalis (2014). This approach allows for the inclusion of structural breaks in panel data analysis, enhancing the robustness of the analysis.

Table 5 presents the results of the combined structural break and second-generation unit root tests conducted using the xtbunitroot method, and CIPS/Breitung respective. The table displays the series names, break dates, and critical values. Based on the reported test statistics, we find no significant evidence to reject the presence of breaks in the unit root for any of the series. This suggests that structural breaks may indeed be present in the data series under consideration. The CIPS unit root techniques adept at handling CD concerns, are introduced by Pesaran (2007). While LGCI and REQ achieve stationarity at (I[0]), others necessitate first-order differencing (I[1]). Additionally, the Breitung unit root test is employed to corroborate these findings. The identification of variable stability raises the prospect of cointegration, prompting the need for a cointegration test to explore this potential further.

5.5. Analysis of Homogeneity Slope

Before proceeding with panel data estimation, it is crucial to ascertain the status of slope parameters to prevent inconsistent estimators. Both Model A, which lacks an interactive term, and Model B, which includes an interactive term of energy consumption

Table 5: The combined structural break and second-generation unit root tests

Variable	???		CIPS		Breitung		Order of integers
	Break date	Values	Level	First difference	Level	First difference	
LEQ	2002	0.5205**	−1.25	−5.29**	NA	NA	I (1)
ENU	1995	1.503***	−2.44	−5.69**	0.53	−11.79***	I (1)
LRGDP	2020	24.839***	−2.33**	−4.44***	12.55	−9.06***	I (1)
LGCI	2020	6.174***	−2.31**	−5.64***	−2.32***	−10.79***	I (0)
REQ	1995	0.007***	−1.98	−5.86***	−2.12***	−17.02***	I (0)
LENU_REQ	2020	12.517***	−2.94***	−5.75***	0.46	−3.92***	I (1)

Source: Author's Computation (2024) Stationary at 1% (*), 5% (**) and 10% (***)
By applying the xtbunitroot test and the suitable Critical values at the 1% and 5% level of significance, the break points and dates as well as the stationarity feature of the series are ascertained
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

Table 6: Testing for slope heterogeneity

Statistics	Model A		Model B	
	SH	ASH	SH	ASH
Value	22.078	24.585	17.163	19.163
Prob	0.000	0.000	0.000	0.000

Source: Author's Computation using STATA 15 (2024)

Table 7: Cointegration test

Statistics	Mode A		Mode B	
	t-statistics	P-value	t-statistics	P-value
Mod_DF	2.0771	0.0189	2.3141	0.0103
DF	3.5622	0.0087	1.2482	0.106
ADF	4.7335	0.0316	1.4482	0.038
Unadj Mod_DF	4.7774	0.00185	0.9039	0.183
Unadj DF	−0.8274	0.204	−0.3566	0.3607

Source: Author's Computation using STATA 15 (2024)

and financial inclusion, undergo the slope homogeneity test. The results presented in Table 6, derived from the slope homogeneity test proposed by Pesaran and Yamagata (2008), reject the null hypothesis that the slope parameters remain uniform across the three panels. This outcome vividly illustrates the variability in slopes among the sampled nations. Consequently, it is evident that Sub-Saharan African nations exhibit differences in their levels of energy consumption and environmental degradation (CO_2), among other factors.

5.6. Analysis of Cointegration

In brief, the cointegration analysis is presented in Table 7 reveals evidence of cointegration across countries for both Models A and B. This indicates a long-term relationship among the variables, suggesting that environmental quality, energy consumption, real GDP, and gross capital investments co-move over time.

In Model A (without interactive term), the modified DF test yields a test statistic of 3.07, surpassing conventional significance levels, indicating robust evidence against the null hypothesis of no cointegration. Conversely, the ADF test presents a test statistic of 4.73, below typical critical values, suggesting statistically significance.

In Model B (with interactive term), consistent with Model A, the modified DF test again yields compelling evidence against the null hypothesis, with a test statistic of 2.31 and a P = 0.010. Similarly, the ADF test reinforces this conclusion, with a test statistic of 1.44 surpassing conventional critical values and a P = 0.033 indicating significance below the 0.05 threshold. Collectively, both the modified DF and ADF tests provide robust evidence of cointegration among the variables, implying a sustained long-term relationship between them.

Table 8: Bai-Perron (1998) multiple structural break date test results

	MICS	
Breaks	1	2
Index	10	16
Date	2000	2006

6. DISCUSSION OF EMPIRICAL RESULTS

6.1. The Structural Break on the Link between Environmental Quality and Energy Usage

The findings of the unit root test in Table 6 show that there are significant structural variations across the series in addition to highlighting the sensitivity of the chosen African economies to both internal and external structural shocks. The accuracy of the estimations could be jeopardised if this component of the examination of the link between energy use and environmental quality is overlooked, especially in situations that are crucial. It is important to remember, too, that each series' results from the structural break date unit root test are unique and are displayed in Table 6. To identify a consistent break date(s) for regression purposes, we further utilize xtbreak, which facilitates the estimation and testing of multiple structural breaks in time series and panel data, drawing on methods by Bai and Perron (1998) and Ditzen et al. (2021) as demonstrated in Table 8.

Examining the empirical results presented in Table 9, the coefficient of 1.01 for the structural break (BD) in the context of environmental quality (EQ) suggests that for every 1% increase in the structural break variable, the environmental quality index increases by 1.01 units. The empirical result indicates that structural breaks have a significant and positive effect on environmental quality. This finding underscores the importance of structural reforms and policy shifts in enhancing environmental sustainability. Policymakers should leverage these insights to design and implement strategies that promote long-term environmental benefits through well-managed structural changes

Table 9: Estimates from CS-ARDL on the influence of structural breaks on the intersection of energy consumption and environmental quality

D.LEQ	Coefficient	Standard error	Z	P>z
ECT	−1.484***	0.048	−31.19	0.000
Short Run Est.				
D.LEQ	−0.484***	0.048	−10.17	0.000
ENU	0.151	0.098	1.54	0.123
LRGDP	−0.295	0.211	−1.4	0.16
REQ	0.22**	0.187	1.17	0.024
LGCI	0.003	0.108	0.03	0.977
BD	1.031***	0.11	9.41	0.000
Long Run Est.				
BD	0.712***	0.089	7.99	0.000
ENU	0.102	0.066	1.55	0.121
LGCI	0.002	0.07	0.03	0.978
REQ	0.202**	0.175	1.16	0.047
LRGDP	−0.187	0.136	−1.37	0.17

Source: Author's Computation using STATA 15 (2024)
*P<0.1, **P<0.05, ***P<0.01
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

Table 10: Estimates from CS-ARDL on the impact of regulations on the relationship between energy use and environmental quality

D.LEQ	Coefficient	Standard error	Z	P>z
ECT	−1.343***	0.041	−32.8	0.000
Short Run Est.				
D.LEQ	−0.343***	0.041	−8.37	0.000
ENU	−0.015**	0.044	−0.34	0.032
ENU_REQ	0.001	0.001	0.98	0.326
LRGDP	0.32	0.249	1.29	0.198
REQ	−0.052	0.097	−0.54	0.592
LGCI	−0.017	0.05	−0.34	0.732
Long Run Est.				
ENU	−0.011**	0.032	−0.34	0.033
ENU_REQ	0.001	0.001	0.93	0.353
LGCI	−0.011*	0.037	−0.29	0.069
LRGDP	0.206	0.161	1.28	0.202
REQ	−0.031	0.072	−0.43	0.664

Source: Author's Computation using STATA 15 (2024)
*P<0.1, **P<0.05, ***P<0.01
EQ: Environmental quality, RGDP: Real gross domestic product, GCI: Gross capital investment, REQ: Regulatory quality

In other words, our observation regarding the likelihood of declining environmental quality when a structural break is introduced indicates that sub-Sahara African economies should continue their energy consumption endeavors, but within the framework of policy shocks or initiatives aimed at mitigating environmental degradation associated with this relationship. However, the fundamental structural factors inside the economies may determine how effective such policy reforms are in alleviating environmental degradation. The implication of this finding is that regulatory quality can be enhanced through strong policy intervention to mitigate environmental degradation.

6.2. The Role of Regulatory Quality on the Nexus between Environmental Quality and Energy Consumption

As depicts in Table 10, the link between energy consumption and environmental quality can be moderated by regulatory policy, as evidenced by the fact that a 1% increase in energy use causes a 0.015% short-term drop in environmental quality. This suggests that greater energy use initially degrades the environment. The positive coefficient for the interaction term suggests that regulatory quality helps mitigate the negative impact of energy use on environmental quality. Specifically, for every 1% increase in both energy use and regulatory quality, environmental quality improves by 0.001%. Additionally, a 1% increase in real GDP leads to a 0.32% increase in environmental quality, indicating that economic growth positively impacts environmental quality in the short run. Interestingly, a 1% increase in regulatory quality on its own results in a 0.05% decrease in environmental quality in the short run. This might indicate initial implementation challenges or transitional costs associated with regulatory changes. Furthermore, a 1% increase in gross capital investment leads to a 0.02% decrease in environmental quality, possibly due to the short-term environmental costs of new industrial or infrastructural projects.

In the long run, a 1% increase in energy use leads to a 0.011% decrease in environmental quality, demonstrating a persistent but slightly reduced negative impact compared to the short run. The positive coefficient remains, indicating that regulatory quality continues to mitigate the adverse effects of energy use on environmental quality over time. A 1% increase in real GDP results in a 0.21% improvement in environmental quality in the long run, although the positive impact is slightly reduced compared to the short run. Over the long run, a 1% increase in regulatory quality leads to a 0.03% decrease in environmental quality, suggesting that while the negative impact of regulatory quality diminishes, it still persists to some extent.

7. CONCLUSION AND RECOMMENDATIONS

The analysis reveals several critical findings regarding the dynamics between economic variables, environmental quality, and energy in sub-Saharan Africa. The average gross domestic product (RGDP) stands at US$7.63 trillion, while environmental quality (EQ) averages 51,087 kt. Energy use per capita (ENU) averages 58.79 units, with gross capital investment averaging US$24.10 billion. Regulatory rank percentiles are at 38.44%.

Structural breaks show a substantial and positive influence on environmental quality, suggesting that policy reforms and structural changes are crucial for enhancing environmental sustainability. Policymakers can leverage this insight to design strategies that promote long-term environmental benefits through well-managed structural changes. This indicates that energy use should continue within the framework of policy initiatives aimed at mitigating environmental degradation. However, the effectiveness of such policies may depend on the underlying economic fundamentals.

In the short run, higher energy use harms the environment. However, regulatory quality helps mitigate this negative impact of energy use on the environmental quality. Similarly, in the long run, increase in energy use results in decrease in environmental quality, indicating a persistent but reduced negative impact compared to the short run. Regulatory quality continues to mitigate these adverse effects over time, although this positive impact is slightly reduced compared to the short run. While structural reforms and policy shifts are essential for improving environmental quality in sub-Saharan Africa, the interplay between regulatory quality and energy consumption requires careful consideration. There is urgent need to integrate climate resilience into national security strategies, promoting investments that address both security and environmental sustainability. Governments should prioritize investments in climate-resilient infrastructure, and renewable energy to mitigate the negative impacts of climate change on environmental quality. In addition, serious consideration should be given to improving the quality of governance through effective regulatory frameworks to sustain environmental quality.

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