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# Financial Inclusion on the Nexus between Environmental Quality and Energy Consumption in Low-Income Sub-Saharan Africa

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**ABSTRACT**

This study investigates how financial inclusion affects the connection between energy use and environmental quality in 20 low-income sub-Saharan African nations. The study employs annual secondary data from 1991 to 2022 with the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) technique, which considers time dynamic, cross-sectional heterogeneity and cross-sectional dependence. The findings suggest that energy use significantly increases carbon emissions over the short- and long-terms, although financial inclusion has a positive yet statistically insignificant short-term effect on environmental quality. Furthermore, there is a positive correlation found between carbon emissions and real GDP and gross capital investment (GCI), which suggests that industrial expansion has occurred in African nations. Moreover, the study emphasizes how important financial inclusion is to sub-Saharan Africa's environmental quality. The policy recommendations urge policymakers in Sub-Saharan Africa to prioritize initiatives that enhance financial inclusion, promote green financing, support sustainable energy practices, strengthen environmental regulations, incorporate environmental considerations into economic policies, and foster regional cooperation for environmental management.

**Keywords:** Financial Inclusion, Environmental Quality, Energy Consumption, Sub-Saharan Africa, CS-ARDL Estimator
**JEL Classifications:** C33, Q43, Q56, O13, G21

## 1. INTRODUCTION

Sub-Saharan Africa faces a multifaceted challenge characterised by a growing demand for energy, limited access to financial services, and escalating environmental concerns. Insufficient energy infrastructure, coupled with a significant portion of the population excluded from formal financial systems, poses obstacles to sustainable development (Mabinuori et al., 2023). The region's reliance on traditional and non-renewable energy sources contributes to environmental degradation and hinders progress toward attaining sustainable development goals 7 and 9. The lack of widespread access to modern, clean energy technologies further exacerbates this issue. High levels of carbon emissions have frequently been linked to economic expansion in environmental economics literature. The desire to hasten growth and industrialization is associated with an increase in the amount of $CO_2$ emissions that are frequently produced and released into the atmosphere, particularly during production activities. Furthermore, the rising requirement for food production and shelter brought on by growing density of population can be linked to this rise in $CO_2$ emissions. In order to accommodate the growing population, environmental degradation activities such as logging and a general loss of ecological diversity is forced, leading to environmental degradation (Asafu-Adjaye, 2003). This is because increased economic productivity mostly fueled by non-sustainable sources of energy such as coal, fossil fuels, and nuclear energy—requires a growth in GDP. As developing economies strive to catch up with and converge with industrialised economies, they employ polluting energy sources which are more affordable to power rising economic activities. This puts them at risk of environmental degradation, especially for energy-dependent African nations (Omojolaibi et al., 2016; Mesagan and Olunkwa, 2020).

Furthermore, a significant segment of the populace does not have access to official financial institutions, which restricts their ability to make investments in sustainable practices and clean energy solutions. The low rate of financial inclusion in the region can be seen in the 43% of adults who own a bank account (Makoni, 2014; Demirgüç-Kunt and Levine, 2018; Park and Mercado 2015).

Consequently, financial exclusion of the marginalised population and the unsustainable usage of energy resources contribute to deforestation, air and water pollution, and climate change. Understanding how these factors intersect is essential for devising effective strategies that simultaneously address energy poverty, enhance financial inclusion, and promote environmental sustainability. Environmental degradation is widespread in the region despite its enormous potential for renewable energy and plenty of natural resources. As the Sustainable Development Goals (SDGs) expiration year approaches, this has been a major source of concern for many stakeholders in the region. The extraction and sale of these natural resources boost energy consumption and provide the people and governments of these African countries with reliable streams of income and foreign cash. Resource-rich economies frequently have to decide whether to increase or decrease their use of natural resources while keeping in mind the environmental impact of their choices (Afolabi, 2023).

Therefore, this study is motivated by the need to provide more insights on the environmental effects of such rapid growth in energy use and high degree of financial exclusion for evidence based policy-making, development interventions, and economic strategies to foster more sustainable inclusive future for the region.

This study's main goal is to investigate how, in Sub-Saharan African (SSA) nations, financial inclusion influences the link between environmental quality and energy use. The specific objectives are to evaluate the link between energy consumption and environmental quality, and to examine the impact of financial inclusion on this nexus in the low-income SSA countries.

## 2. LITERATURE REVIEW

According to the "pollution haven hypothesis" (Copeland and Taylor, 2004), countries or enterprises that produce a lot of pollution may migrate there in the case of free trade. The fundamental concept is straightforward: by raising the price of necessary inputs, environmental regulations reduce jurisdictions' comparative advantage in commodities produced in ways that cause pollution. According to the pollution haven theory, exports are impacted by environmental rules, but the inverse may also be true: exports may have an impact on regulations. Trade may enhance voters' support for stringent environmental rules if trade raises incomes and environmental quality is viewed as a standard good. Alternately, the increasing pollution brought on by commerce can lead to a rise in local demand for stringent environmental laws.

The idea was to treat environmental quality like any other item and assume an unequal distribution of wealth. According to this concept, multinational companies move their highly polluting sectors to nations with less stringent environmental regulations so they are not required to pay as much for regulatory compliance back home (Eskeland and Harrison, 2003; Copeland and Taylor, 2004). Consequently, developing nations have heightened levels of environmental contamination and become hotspots for pollution. In contrast, the pollution haven theory posits that multinational enterprises export state-of-the-art technologies to developing and host nations with the aim of disseminating their environmentally friendly innovations.

According to Cole 2004; Grossman and Krueger 1991; Shafik, 1994; Soytas et al., 2007, the EKC is an important subject in the research on the link between growth and the environment. Kuznets first proposed the theory in 1955, which holds that economic disparity will rise as nations become richer and then begin to diminish after we reach a particular phase of growth, sometimes known as a turning point.

Several environmental degradation indices and per capita income were proposed to be correlated by the environmental Kuznets curve. The concept of the EKC is hinged upon the influence of the switch in production from rural agriculture to urban industry. When industrial activity intensifies, pollution increases. As income levels rise, the industrial-heavy industry is gradually replaced by a production that is more cutting-edge and customer-focused. It is expected that this modification will eventually lead to a decrease in pollution by offsetting the increase in pollution. According to Stern (2004), this suggests that pollution and environmental degradation increase during the early stages of economic expansion, but the pattern shifts at a certain wealth per capita level (which will vary depending on the indicator). This suggests that environmental quality would rise during periods of rapid economic growth.

The EKC theory has a variety of facets. Scale impact describes how environmental harm initially increases as economies grow. Increased output alone causes higher pollution levels to accompany economic growth. Increased input leads to increased output, which increases the consumption of natural resources and the amount of pollution. According to Grossman and Krueger (1991), the pollution is anticipated to rise according to economic growth. The shape of the EKC raises the possibility of additional scale-resisting devices. These elements work together to slow down environmental damage as economies grow. The effects of global trade, the composition effect, the technology effect, the increased demand for clean air, and the tightening of laws are mentioned as the factors anticipated to offset the scale effect and eventually entirely offset it.

Using the dynamic Generalised Method of Moments estimator, Jinapor et al. (2023) examine the data collected from 20 sub-Saharan African nations (2000–2020). They discover that although renewable energy has beneficial effects, overall energy usage deteriorates environmental circumstances. It has been demonstrated that energy efficiency both directly and indirectly reduces pollution. When utilised alongside energy consumption, it also considerably reduces emissions of greenhouse gases, such as carbon and nitrous oxides.

Olaoye et al. (2024) look into how energy use and environmental quality are related in Sub-Saharan Africa (SSA), taking international trade into account. The study concludes that energy use has a detrimental impact on environmental quality, particularly in middle-income countries (MICs).

Diallo (2024) uses an upgraded Green Solow model with a defactored instrumental variables method to investigate the effects of renewable energy usage on environmental quality in nations in Sub-Saharan Africa. The study concludes that using renewable energy greatly lowers $CO_2$ emissions while also improving environmental quality.

In 45 sub-Saharan African nations, Acheampong and Dzator (2020) examine the link between institutional quality and carbon emissions between 2000 and 2015. According to their findings, institutions typically have little impact on reducing carbon emissions. Nevertheless, the results show that institutions are important in lowering carbon emissions when the sample is divided into categories according to institutional origin.

A novel paradigm is presented by Liu et al. (2022) to evaluate the effects of financial inclusion on environmental quality in Sub-Saharan African nations between 2004 and 2020. The study concludes that financial inclusion raises carbon emissions using the CS-ARDL method. Additionally, while advancements in education improve the quality of the environment, economic expansion increases $CO_2$ emissions. The environment is badly impacted by the depletion of natural resources, and remittances increase carbon emissions.

Kar and Bali Swain (2023) look at the link between energy scarcity and financial inclusion in 27 Sub-Saharan African nations between 2004 and 2021. The study indicates that financial inclusion considerably lowers energy insecurity. Furthermore, there exists a positive correlation between GDP per capita and energy access, whereas there is a negative link between energy access and oil prices and energy intensity.

Hussain et al. (2023) use the STIRPAT framework to examine the effects of financial inclusion on carbon emissions in 102 countries between 2004 and 2020. The study finds that financial inclusion, particularly in emerging nations, has a nonlinear connection with carbon emissions, first reducing, then increasing, and finally decreasing.

In 67 developing nations, Ababio et al. (2023) investigate how financial inclusion might encourage the use of renewable energy sources and environmental sustainability. Using a number of econometric models, the findings show that financial inclusion increases environmental sustainability and has a favourable impact on the use of renewable energy.

## 3. THEORETICAL FRAMEWORK

To capture the influence of energy consumption (ENC) on environmental quality, the study adopts and extends the simplified EKC theory, according to Ulucak and Bilgili, (2018). The link between energy use and environmental quality can be influenced by financial inclusion. Financial inclusion may facilitate the adoption of cleaner technologies and improve energy efficiency. We introduce financial inclusion into the model as both a direct effect and an interaction effect with energy use.

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

Where; EQ represents environmental quality, Y represents income per capita, and β0, β1, β2 are the parameters.

In order to quantify how energy use affects the quality of the environment, we extend the EKC theory;

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

Financial inclusion can influence the link between energy consumption and environmental quality. Financial inclusion may facilitate the adoption of cleaner technologies and improve energy efficiency. We introduce financial inclusion into the model as both a direct effect and an interaction effect with energy consumption.

$$EQ=\beta_0+\beta_1 Y+\beta_2 Y^2+\beta_3 ENC+\beta_4 FIN\_INC+\beta_5 ENC*FIN\_INC \quad (3)$$

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

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

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 financial inclusion. The sign and magnitude of $\beta_5$ indicate the moderating effect: If $\beta_5 < 0$, financial inclusion mitigates the adverse impact of energy use on the environment. If $\beta_5 > 0$, financial inclusion exacerbates the adverse impact.

## 4. RESEARCH DESIGN

### 4.1. Data Sources and Measurement

Due to data limitations, the study only included 20 of the 46 SSA countries that classified as low-income countries (LICs). According to World Economic Outlook, 2019, World Bank, 2021/2022, low-income economies are those with per capita gross national incomes of $995 or less in the years 2015–2017. 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), financial inclusion (FIN_INC) and regulatory quality (REQ) were sourced from World Development Indicators (2022). The data on energy use interaction with financial inclusion was generated by the study.

### 4.2. Model Specification

The link between $CO_2$ emissions and per capita income is an inverted U-shaped one: when per capita income increases, emissions per person climb to a particular level until starting to drop (Dinda, 2004; Müller-Fürstenberger and Wagner 2007; Kaika and Zervas 2013).

### 4.2.1. Objective one

To achieve this objective this study adapts and modifies the empirical model of Afolabi (2023) as follows:

$$EQ=f(ENC,RGDP,REQ,GCI) \quad (5)$$

Where EQ, ENC, RGDP, REQ and GCI denote total environmental quality (proxied by $CO_2$), energy consumption (proxied by what?), 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. Equation (5), an implicit function, is thus represented explicitly as;

$$lnEQ_{i,t} = \beta_0 + \beta_1 lnENC_{i,t} + \beta_2 ln\,R\,GDP_{i,t} + \beta_3 REQ_{i,t} + \beta_4 lnG\,CI_{i,t} + \varepsilon_{i,t} \quad (6)$$

where i represents a cross-section of countries; t stands for the years 1991 to 2022; $\beta_0$ is the intercept; $\beta_1$-$\beta_4$ are each variable's elasticities; and ε is the noise (error).

### 4.2.2. Objective two

Empirical model (5) provides a rich method of modeling the impact of financial inclusion 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 financial inclusion and energy use as one of the explanatory factors in the model.

$$EQ=f(ENC, Fin\_Inc, RGDP, REQ, GCI) \quad (7)$$

$$ln\,EQ_{i,t} = \beta_0 + \beta_1 ENC_{i,t} + \beta_2 ln\,Fin\_Inc_{i,t} + \beta_3 ln\,E\,NC_{i,t} * Fin\_Inc_{i,t} + \beta_4 ln\,R\,GDP_{i,t} + \beta_5 REQ_{i,t} + \beta_6 ln\,G\,CI_{i,t} + \varepsilon_{i,t} \quad (8)$$

where FIN_INC denotes the degree of financial inclusion; ENC*FIN_INC is the interactive term of energy consumption and financial inclusion; and all other factors stay the same as earlier defined. The total impact of energy consumption which includes the marginal influence of financial inclusion on the quality of environment is arrived at by taking partial derivatives of equation (6):

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

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 financial inclusion offers energy-inefficient technologies. However, if$\beta_1 < 0$ and $\beta_3 > 0$, it implies that using energy-efficient technologies due to financial inclusiveness would make energy consumption to enhance environmental quality (EQ). Meanwhile, if $\beta_1 > 0$ and $\beta_3 > 0$, then energy consumption and financial inclusion complementarily promote environmental quality (EQ). Lastly, if $\beta_1 < 0$ and $\beta_1 < 0$, 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 financial inclusion enhance environmental quality (EQ) but if $\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} < 0$, both energy use and financial inclusion reduce the quality of environment in the sampled SSA countries.

## 4.3. Estimation Technique

The unique Cross Sectional Autoregressive Distributed Lag (CS-ARDL) estimating technique by Chudik et al. (2016) is the primary analytical method employed in this thesis. Using the panel ARDL-PMG estimator, the validity of the CS-ARDL estimates is evaluated.

$$\Delta y_{it} = w_i + \delta_i (y_{i,t-1} - \theta_i^{'} x_{i,t-1}) + \sum_{j-1}^{p-1} \phi_{ij} \Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (10)$$

here $y_{it}$ is environmental quality for economy i at time t; $\alpha_{ij}$ represents a matrix of the regressors (factors); $\theta_i^{'}$ is a connection between $y_{it}$ and $x_{it}$; in the long-run equilibrium, $\delta_i$ is the error correction term; $\phi_{ij}$ and $\alpha_{ij}$ 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.

Equation (10) can be changed to be stated as its CS-ARDL equivalent, which is:

$$\Delta y_{it} = \mu_i + \delta_i (y_{i,t-1} - \theta_i^{'} x_{i,t-1} + \delta_i^{-1} n_i \overline{y_t} + \delta_i^{-1} \varphi_i^{'} \overline{x_t}) + \sum_{j-1}^{p-1} \phi_{ij} \Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij} \Delta x_{i,t-j} + \sum_{j-0}^{p-1} \tau_{ik} \Delta \overline{y}_{t-j} + \sum_{j-0}^{q-1} \Delta_{ik} \varphi \overline{x}_{t-j} + \varepsilon_{it} \quad (11)$$

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

Prior to using these estimators, we conducted certain tests. This includes the cross-sectional dependence (CD) test, slope homogeneity test, panel unit root test, and panel cointegration test. A CD test must be carried out in an effort to prevent imprecise and biased estimates in panel data analysis caused by variations in spatiotemporal features and geographical effects (Afolabi, 2023; Majeed et al., 2022). When Pesaran (2004) originally introduced the CD test, it was stated as:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left( \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho ij \right) \quad (12)$$

here, T, N and $\rho_{ij}$ stand respectively for time, panel data sample, and correlation parameter. The alternative hypothesis contradicts the null hypothesis of the CD test, which claims that there is CD in the sampled nations.

The estimations could be inconsistent if slope heterogeneity is ignored (Afolabi, 2023; Zuo et al., 2022). As such, this work employs the slope homogeneity test Pesaran and Yamagata (2008). This is how its test statistic is stated:

$$\widetilde{\Delta_{SH}} = (N)^{\frac{1}{2}}(2K)^{-\frac{1}{2}}(\frac{1}{N}\tilde{S} - k) \quad (13)$$

$$\widetilde{\Delta_{ASH}} = (N)^{\frac{1}{2}}(\frac{2k(T-k-1)}{T+1})^{-\frac{1}{2}}(\frac{1}{N}\tilde{S} - k) \quad (14)$$

Where $\widehat{\Delta}$ SH and $\widehat{\Delta}$ ASH are delta tilde and adjusted delta tilde, respectively. The alternative hypothesis of the slope homogeneity test indicates that the gradients are not homogeneous in the cross-sections, contrary to the null hypothesis.

In summary, cross-sectional ARDL is informed by the need to analyze dynamic relationships in panel data, considering heterogeneity and potential structural breaks. While it offers advantages in terms of dynamic modeling and heterogeneity consideration, researchers should be mindful of data requirements, model complexity, and potential challenges in interpretation.

## 5. EMPIRICAL ANALYSIS AND DISCUSSION RESULTS

### 5.1. Results

Formal pre-estimation analysis and informal preliminary analysis are the two key steps of the traditional technique described in the literature that come before the estimation process. Within the framework of this research, the former comprises statistical summaries, descriptive analyses, and graphical displays of the data utilized. Checking for unit roots in the examined series is the next stage in the preliminary analysis procedure.

#### *5.1.1. Descriptive statistics*

Table 1 summarises the data by presenting descriptive statistics. 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$1.4 trillion in constant US dollars. Environmental quality (EQ) averages US$116.207 billion. Energy consumption per capita (ENC) averages 24.62 LICs. Financial Inclusion (FIN_INC) averages 13.42%. Gross Capital Investment averages US$20.91. Regulatory rank percentiles are 24.323%.

Regarding the statistical distribution, most variables appear positively skewed. Kurtosis statistics vary, with the majority of variables being leptokurtic, ENC showing platykurtic characteristics, and REQ being mesokurtic. At the 5% significance level, the Jarque-Bera test produces probability values <0.05, which indicates that the normal distribution hypothesis is rejected.

#### *5.1.2. 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 2, indicate modest correlations among the considered factors. Notably, real GDP exhibits the most robust association with carbon emissions the overall 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.

#### *5.1.3. Cross-sectional dependence*

Given the variability in the uniform characteristics among the countries included in the sample, it becomes imperative to assess cross-sectional dependence (CD) in panel analyses. Table 3 presents the findings of the Pesaran CD test, which indicates that the null hypothesis of no CD is rejected at 1% significance level. This implies that the dynamics of variables, such as environmental quality, energy consumption, real GDP, financial inclusion, gross capital investment, regulatory factors, and ENC_FIN_INC, may influence other nations within the sample. Consequently, it suggests a mutual reliance among low-income countries (LICs) in Sub-Saharan Africa (SSA). In essence, this outcome underscores the interconnectedness of LICs in the region.

#### *5.1.4. Analysis of the unit root*

Here, we provide the results of unit root tests, which are essential to the conventional inference process in order to differentiate between non-stationary and stationary variables. Three-unit root tests are used, such as Breitung unit-root test, Pesaran Panel Unit Root Test with Cross-sectional, and Pesaran's CADF test, to guarantee robustness and consistency. Two sets of requirements are applied to each test: one includes only the constant constraint, while the

**Table 1: Descriptive statistics**

| Variable | EQ | ENC | FIN INC | RGDP | GCI | REQ |
|---|---|---|---|---|---|---|
| Obs | 620 | 620 | 620 | 620 | 620 | 620 |
| Mean | 3641.652 | 24.62 | 13.42076 | 1.43E+10 | 20.907 | 24.323 |
| Std. Dev. | 4280.574 | 16.606 | 8.167292 | 1.90E+10 | 9.096 | 14.263 |
| Min | 0 | 1.64 | 1.474376 | 7.16E+08 | 1.525 | 0.472 |
| Max | 22131.5 | 74.688 | 84.05232 | 1.00E+11 | 60.156 | 73.932 |
| Skewness | 2.0274 | 0.8643 | 2.1427 | 2.6118 | 0.7328 | 0.531 |
| Kurtosis | 7.035 | 3.1274 | 13.9534 | 9.8035 | 3.9157 | 2.9393 |
| J-Bera | 2.20E+04 | 118.9*** | 1965 | 8922*** | 569.7*** | 61.13*** |

Source: Author's Computation (2024)

other includes both trend and constant restrictions. Interestingly, every test is run on the natural logarithm of the series, with the exception of the percentages for energy consumption (ENC) and financial inclusion (FIN_INC).

Following the CD test, stationarity tests utilizing suitable techniques are imperative. The results of the CIPS and CADF unit root techniques are shown in Table 4, which indicates that the three models' integration sequences differ. Some series are stable at (I(0)), but others require differencing to the first order (I(1)). This meets a need in order to use the CS-ARDL framework. 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.

### *5.1.5. Analysis of homogeneity slope*

The homogeneity slope test is crucial in panel data analysis as it helps determine whether the relationships between variables are consistent across different groups or entities within the panel. Specifically, this test assesses whether the slope parameters of the regression model are uniform across all panel units. Overall, the homogeneity slope test is essential for ensuring the robustness and accuracy of panel data analysis results, ultimately enhancing the credibility of research findings and conclusions.

**Table 2: Correlation matrix**

| Variables | −1 | −2 | −3 | −4 | −5 | −6 |
|---|---|---|---|---|---|---|
| (1) ENC | 1 | | | | | |
| (2) FIN_INC | 0.081 | 1 | | | | |
| (3) RGDP | −0.154 | −0.097 | 1 | | | |
| (4) GCI | 0.138 | 0.035 | 0.145 | 1 | | |
| (5) REQ | 0.061 | −0.137 | −0.205 | 0.131 | 1 | |
| (6) ENC_FIN_INC | 0.726 | 0.675 | −0.174 | 0.133 | −0.05 | 1 |

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

**Table 3: Cross-sectional dependence**

| Variable | CD test | P-value | Corr | abs (corr) |
|---|---|---|---|---|
| LEQ | 44.15 | 0 | 0.05 | 0.229 |
| LENC | 15.36 | 0 | −0.62 | 0.341 |
| LFIN_INC | 29.72 | 0 | 0.057 | 0.263 |
| LRGDP | 63.23 | 0 | 0.318 | 0.53 |
| LGCI | 12.04 | 0 | 0.179 | 0.535 |
| REQ | 0.96 | −0.339 | 0.345 | 0.451 |
| LENC*FIN_INC | 30.96 | 0 | 0.229 | 0.387 |

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

Before proceeding with panel data estimation, it is imperative 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 and financial inclusion, undergo the slope homogeneity test. The null hypothesis that the slope parameters remain constant is rejected by the results shown in Table 5, which are obtained using the slope homogeneity test. This outcome vividly illustrates the variability in slopes among the sampled economies. Consequently, it is evident that Sub-Saharan African nations exhibit differences in their levels of energy consumption and environmental degradation, among other factors. Another implication of this finding is that these countries are not achieving convergence in their growth process because of their failure to achieve economic integration in the continent.

### *5.1.6. Analysis of cointegration*

The Westerlund (2007) second-generation test is frequently utilized to assess cointegration within panel data models, offering valuable insights into the long-term relationships among variables. This is shown in Table 6.

In Model A (without interactive term), the modified DF test yields a test statistic of 2.61 surpassing conventional significance levels, indicating robust evidence against the null hypothesis of no cointegration. The remarkably low P-value of 0.0001 further bolsters this conclusion, underscoring a high level of confidence in rejecting the null hypothesis. Conversely, the ADF test presents a test statistic of 1.878, below typical critical values, yet its associated P-value of 0.030 below the conventional thresholds of 0.05, suggesting 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 2.039 and P-value of 0.02. Similarly, the ADF test reinforces this conclusion, with a test statistic of 2.673 surpassing conventional critical values and a P-value of 0.003 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.

In brief, the cointegration analysis presented in Table 6 reveals evidence of cointegration across all three panels 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.

**Table 4: The combined first-and-second generation unit root tests**

| Variable | CADF | | CIPS | | Breitung | | Order of Int |
|---|---|---|---|---|---|---|---|
| | Level | First diff. | Level | First diff. | Level | First diff. | |
| LEQ | −1.01 | −5.33*** | NA | NA | | NA | I (1) |
| ENC | −1.52** | −5.33*** | −2.26** | −4.58*** | 0.267 | −9.74*** | I (1) |
| LFIN_INC | −2.71*** | −9.02*** | −3.51*** | −5.79*** | 0.13 | 9.74*** | I (1) |
| LRGDP | −1.84** | ??? | −2.01 | −4.39*** | 12.7 | −6.76*** | I (1) |
| LGCI | −4.26*** | −7.59*** | −2.91*** | −5.53*** | −3.88 | −12.18*** | I (1) |
| REQ | 0.78 | −6.49*** | −1.99 | −5.21*** | −1.69** | −16.99*** | I (0) |
| LENC*FIN_INC | −0.25 | −8.25*** | −3.19*** | −5.90*** | 0.69 | −8.04*** | I (1) |

Source: Author's Computation (2024) Stationary at 1% (*), 5% (**) and 10% (***)

**Table 5: Testing for slope heterogeneity**

| Statistics | Model A | | Model B | |
|---|---|---|---|---|
| | SH | ASH | SH | ASH |
| Value | 27.967 | 24.585 | 21.995 | 25.542 |
| Prob | 0.000 | 0.000 | 0.001 | 0.001 |

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

**Table 6: Cointegration test**

| Statistics | Mode A | | Mode B | |
|---|---|---|---|---|
| | t‑statistics | P‑value | t‑statistics | P‑value |
| Mod_DF | 2.6125 | 0.0045 | 2.0399 | 0.0207 |
| DF | 2.4526 | 0.0071 | 2.0175 | 0.0218 |
| ADF | 1.8786 | 0.0302 | 2.6729 | 0.0038 |
| Unadj Mod_DF | 2.4672 | 0.0068 | 1.847 | 0.0324 |
| Unadj DF | 2.249 | 0.0123 | 1.7913 | 0.0366 |

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

**Table 7: CS‑ARDL estimates on environmental quality and energy consumption relationship**

| D.LEQ | Coef. | Std. Err. | Z | P>z |
|---|---|---|---|---|
| ECT | −1.253*** | 0.059 | −21.24 | 0.001 |
| | | Short Run Est. | | |
| LEQ (‑1) | −0.253*** | 0.059 | −4.29 | 0.001 |
| ENC | 0.015** | 0.008 | 2.05 | 0.04 |
| LRGDP | −0.008 | 0.168 | −0.05 | 0.962 |
| REQ | 0.105* | 0.058 | 1.81 | 0.071 |
| LGCI | 0.019 | 0.037 | 0.5 | 0.615 |
| | | Long Run Est. | | |
| ENC | 0.011** | 0.005 | 2.07 | 0.039 |
| LGCI | 0.02 | 0.033 | 0.63 | 0.531 |
| REQ | 0.1* | 0.054 | 1.86 | 0.063 |
| LRGDP | −0.054* | 0.159 | −0.34 | 0.736 |

Source: Author's Computation using Stata 15 (2024). Note: *P<0.1, **P<0.05, ***P<0.01

## 6. DISCUSSION

The environmental quality–energy consumption model, as outlined in Equation (3.32) of section Three, is estimated with the variables expressed in logarithmic form. This decision aligns with the recommendation made by Cole et al. (1997), who argued in favor of estimating models using logarithmic transformations. Recent studies, such as Acheampong (2019) and Bouznit and Pablo-Romero (2016), have also followed this approach when estimating the $CO_2$–energy consumption model. Therefore, the empirical estimates presented in this study are based on the log-linear version of the $CO_2$–energy consumption model.

### 6.1. Environmental Quality and Energy Consumption Relationship

Table 7 presents the findings of the analysis conducted in the low-income countries (LICs). The results show that energy use has a long-term and short-term negative statistically significant influence on carbon emissions. This negative effect implies that environmental degradation occurs in these countries as a result of increased energy use. This suggests that rising demand for energy for home and industrial uses raises carbon emissions, which in turn causes short- and long-term environmental harm and has serious ramifications for the economy of the Sub-Saharan countries.

Furthermore, the analysis reveals positive elasticities between carbon emissions ($CO_2$) and real GDP (RGDP), as well as gross capital investment (GCI), in the selected African countries, indicating a growth in industrial activity. This empirical evidence aligns with previous studies by Baz et al. (2020), Faruq Umar (2019), Adejumo (2020), and Salahuddin and Gow (2019), which found that energy consumption promotes improved industrial performance but also causes environmental degradation in Pakistan, Africa, Nigeria, and Qatar, respectively.

Similarly, there is evidence of positive correlation but insignificant link between gross capital investment (GCI) and environmental quality in LICs in the short- and-long terms. This demonstrates how Sub-Saharan Africa's growing investment expenditure contributes to environmental deterioration. This confirms the conclusion made by Mesagan and Olunkwa (2020) that capital investment in Algeria, Nigeria, and Morocco greatly increases carbon emissions. This implies that capital investment significantly drives environmental degradation in the continent. However, the finding shows that degradation of the environment in SSA, is a trade-off for the pursuit of economic expansion that drives increasing capital investment. Regardless of the time dimension, it was discovered that environmental regulation quality was positively connected to carbon emission. This demonstrates how enacting and upholding appropriate environmental legislation will lower carbon emissions and improve the state of the ecosystem. It is evident that greening and other more ecologically friendly policies and regulations need to be adopted and followed by all people in sub-Saharan Africa (Hassan et al., 2020). Not only that, but the error correction terms suggest that economies recover from shocks to long-run equilibrium at a rather slow pace.

### 6.2. Financial Inclusion on the Nexus Environmental Quality-Energy Consumption

According to Ozili (2023), the introduction of more financial inclusiveness in the economy has the potential to positively improve environmental quality particularly in non-EU countries. Consequently, an interaction between the energy consumption variable (ENC) and financial inclusion (FIN_INC) variable was examined, with results presented in Table 8. Within these countries, there is a long-term positive and substantial association between FIN_INC and environmental quality, however in the short term, the link is negative but statistically insignificant. This implies that raising FIN_INC reduces carbon emissions, which in the short term improves environmental quality implicitly.

Examining the mitigating impact of financial inclusion on the correlation between energy consumption and environmental quality demonstrates that, in low-income countries (LICs), financial inclusion has a negative effect on the relationship between energy consumption and carbon emissions, thereby improving environmental quality in these nations. This emphasizes how crucial it is to increase financial inclusion as a tactic for raising environmental standards in nations across Sub-Saharan Africa. These findings align with previous research by Thuy and Nguyen (2022) and Ike et al. (2020) in developing economies and G-7 countries, respectively, which suggest that financial inclusion

**Table 8: CS-ARDL estimates on financial inclusion on the nexus environmental quality-energy consumption**

| D.LEQ | Coef. | Std. Err. | Z | P>z |
|---|---|---|---|---|
| ECT | −1.271 | 0.067 | −18.93 | 0.000 |
| | | Short Run Est. | | |
| LEQ(-1) | −0.271 | 0.067 | −4.04 | 0.000 |
| ENC | 0.046 | 0.022 | 2.06 | 0.039 |
| FIN_INC | −0.055 | −0.034 | 1.6 | 0.111 |
| ENC*FIN_INC | −0.003* | 0.002 | −1.37 | 0.071 |
| LRGDP | −0.14 | 0.207 | −0.68 | 0.499 |
| REQ | 0.114 | 0.071 | 1.61 | 0.107 |
| LGCI | −0.009 | 0.059 | −0.16 | 0.875 |
| | | Long Run Est. | | |
| ENC | 0.048 | 0.028 | 1.68 | 0.098 |
| FIN_INC | 0.058* | 0.042 | 1.4 | 0.063 |
| ENC*FIN_INC | −0.003 | 0.022 | −1.25 | 0.212 |
| LRGDP | −0.166 | 0.191 | −0.87 | 0.382 |
| REQ | 0.118 | 0.067 | 1.76 | 0.078 |
| LGCI | 0.003 | 0.05 | 0.05 | 0.959 |

Source: Author's Computation using Stata 15 (2024) Note: *P<0.1, **P<0.05, ***P<0.01

**Table 9: Robustness Checks using ARDL (PMG) Estimate on the Nexus of Environmental Quality and Energy Consumption**

| D. LEQ | Coef. | Std. Err. | Coef. | Std. Err. |
|---|---|---|---|---|
| | Model A | | Model B | |
| ECT | −0.114 | 0.036 | −0.082** | 0.034 |
| | Short Run Est | | Short Run Est | |
| ENC (−1) | 0.019* | 0.01 | 0.013 | 0.01 |
| FIN_INC (−1) | - | - | −0.008 | 0.01 |
| LENC*FIN_INC (−1) | - | - | 0.166 | 0.12 |
| LRGDP (−1) | 0.616*** | 0.183 | 0.5** | 0.233 |
| REQ (−1) | −0.016 | 0.028 | −0.004 | 0.031 |
| LGCI (−1) | −0.083** | 0.036 | −0.073** | 0.037 |
| Cons | −0.689 | 0.229 | −0.305 | 0.112 |
| | Long Run Est | | Long Run Est | |
| ENC | 0.05*** | 0.006 | 0.043*** | 0.01 |
| FIN_INC | - | - | −0.008 | 0.01 |
| LENC*FIN_INC | - | - | 0.385** | 0.177 |
| LRGDP | 0.513*** | 0.104 | 0.47*** | 0.101 |
| REQ | 0.071 | 0.053 | −0.071 | 0.086 |
| LGCI | 0.203*** | 0.071 | 0.814*** | 0.157 |

Source: Author's Computation using Stata 15 (2024) Note: *P<0.1, **P<0.05, ***P<0.01

mitigates the adverse effects of $CO_2$ emissions on environmental damage. This underscores the need for the stakeholders and policy makers in the economies to promote the growth of financial inclusiveness to engender environmental sustainability.

Additionally, the findings demonstrate that real GDP, a gauge of economic growth, has a negligible positive short- and long-term effects on environmental quality in SSA. This outcome is consistent with theoretical predictions and previous research by Afolabi (2023) and Zuo et al. (2022), suggesting that economic expansion increases energy consumption and greenhouse gas emissions, thereby reducing environmental quality. The growing economic activities in SSA countries, especially in the first decade of the twenty-first century, have contributed to pollution and emissions, driven by efforts to industrialize and diversify economies, ultimately impacting environmental quality negatively. This finding underscores the need for Sub-Saharan African countries to embrace renewable and clean energy as they make bold effort to achieve industrialization and economic transformation.

### 6.3. Robustness Checks: ARDL (PMG) Estimate on the Nexus of Environmental Quality and Energy Consumption

There exist many estimation problems with panel data analysis that may lead to results that are not entirely accurate. Robustness assessments are therefore crucial. The Pooled Mean Group (PMG) estimator is applied in this instance. The results are shown in Table 9.

The results show that energy consumption and carbon emissions have a statistically significant positive relationship over the long term. This implies that environmental deterioration in this region is caused by rising energy usage. This suggests that increased energy demand for domestic and industrial uses raises carbon emissions, which harms the environment in the short and long terms.

Furthermore, the analysis reveals positive elasticities between carbon emissions ($CO_2$) and real GDP (RGDP), as well as gross capital investment (GCI), in the selected African countries, indicating a growth in industrial activity. This empirical evidence aligns with previous studies by Baz et al. (2020) in Pakistan. This demonstrates how Sub-Saharan Africa's growing investment expenditure promotes environmental deterioration. This suggests that financial investment may give the continent's environmental degradation the much-needed boost. Nonetheless, the results demonstrate that the quest of economic growth, which fuels rising capital investment, comes at the expense of environmental deterioration in Sub-Saharan Africa.

Regardless of the time dimension, it was discovered that environmental regulation quality was inversely connected to carbon emission. This shows that passing and putting into practice suitable environmental laws has a noticeable influence on reducing carbon emissions and enhancing environmental quality. It is obvious that everyone in sub-Saharan Africa needs to adopt and adhere by laws and regulations that are more environmentally friendly, including greening (Dimnwobi et al., 2023). The relationship between energy consumption and carbon emissions is found to be positively impacted by financial inclusion, as demonstrated in the model.

## 7. CONCLUSION AND RECOMMENDATIONS

This study includes 20 of the 46 SSA countries categorizing into low-income countries (LICs) based on per capita gross national incomes, as defined by the World Economic Outlook and World Bank. Annual secondary data from 1991 to 2022 were analyzed using the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) estimator, chosen for its ability to handle uneven panel data with structural breaks, cross-sectional dependence, and both long- and short-run models. To ensure robustness, a panel ARDL-PMG analysis was also conducted. Financial inclusion has varying effects with the analysis showing that over time, improved financial inclusion can enhance environmental quality by mitigating the impact of energy consumption on carbon emissions. Also, there is the need for environmentally friendly regulations and highlight the trade-off between economic expansion and environmental degradation in Sub-Saharan Africa.

Given that financial inclusion has a moderating effect on the negative influence of energy consumption on environmental quality, policymakers in SSA should give priority to programs that increase financial service accessibility, especially in disadvantaged and rural areas. To improve financial inclusion and assist with sustainable development projects, this involves encouraging microfinance institutions, mobile banking, and digital payment systems. Adopting sustainable energy practices, such as making investments in renewable energy sources like solar, wind, and hydroelectric power, should be a top priority for governments and corporations. In addition to lowering carbon emissions, this shift to clean energy would improve energy security and lessen the negative effects on climate change. Authorities in these countries need to encourage financial institutions to offer green financing options that support environmentally sustainable projects and initiatives. This could include funding for renewable energy projects, energy-efficient technologies, and eco-friendly infrastructure development. To cut pollution and protect the environment, it is essential to bolster environmental laws and enforcement systems. Governments ought to pass and implement strict legislation to reduce emissions from waste management, transportation, and industry. Corporations can also be encouraged to adopt cleaner production processes by offering incentives and subsidies for the advancement of eco-friendly technologies and practices.

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