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Exploring the dynamic relationships among environmental quality, financial development, primary sector growth, and energy consumption in Sub-Saharan Africa

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Abstract

Sustainability and ecological deprivation are growing concerns in developing countries, including Sub-Saharan Africa, which is prone to climate change impacts. This study assesses dynamic short- and long-run linkages through environmental quality, primary sector growth, financial development, energy consumption, and economic growth. Relying on the World Development Indicators database for 30 Sub-Saharan African countries from 1990–2024, the study employs the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) estimator. The Dynamic Common Correlated Effects Mean Group (DCCE-MG) estimator was also used for robustness. We used the Dumitrescu–Hurlin Granger causality test to observe the causation between the constructs. The findings show that primary sector growth and energy consumption have a relationship with environmental quality in the short and long run, while financial development has a long-run relationship. The causality analysis reveals a two-way connection between financial development and environmental quality. The primary sector growth also exhibits a unidirectional relationship with environmental quality. These findings imply that, in shaping environmental outcomes, the integration of financial development, energy use, and primary sector activities decreases environmental pollution and increases productivity. The study recommends expanding access to sustainable financing and encouraging climate-smart agricultural practices to support Sustainable Development Goals 7 and 13. Strengthening green business and financial mechanisms promotes clean technology, which will result in sustainable environmental practices that are eco-friendly, which will then boost production.

Keywords*:* environmental quality; primary sector growth; financial development; energy consumption; economic growth; Sub-Saharan Africa; CS-ARDL

1. Introduction

Global environmental sustainability has been severely affected by unpredictable climate change, leading to greater environmental destruction. In some economies, the destruction of the ecosystem imposes high costs on health care systems and negatively affects the standard of living. International Energy Agency (IEA, 2021), Net Zero by 2050 noted that ecological destruction leads to a high cost of living and health care in several economies, underscoring the challenges facing developing and emerging economies in reducing CO_2 emissions. The demand for energy and economic growth, including the continuous reliance on non-renewable sources of power constraints investment and does not promote pursuing a decarbonisation agenda. The report raises concerns about rising greenhouse gas (GHG) levels, particularly CO_2, in these economies. Recent studies assert that continuous emissions of greenhouse gases (GHGs) exacerbate climate change, leading to more extreme weather events that affect living organisms in ecosystems (Newman & Noy, 2023; Wen et al., 2023).
(Umar & Safi, 2023) noted that greenhouse gases from human activities such as production and extraction of minerals contribute to climate change. These discharges affect climate negatively and result in conditions such as floods, hurricanes, droughts, and intense heat waves in developing nations. Djellouli et al. (2022) investigated a similar study on relationships among energy consumption, economic growth, foreign direct investment, and CO_2 emissions in Africa, and found that renewable energy and economic growth promote carbon emissions. According to Xuezhou et al. (2022), the SSA region accounts for about 4% of global CO_2 emissions, and the region is prone to climate change dynamics. World Bank acknowledged seven Sustainable Development Goals as enablers of financial inclusion, rather than financial development broadly (World Bank, 2018).

According to (Aluko & Obalade, 2020; Jianguo et al., 2022, 2022) financial development works as negative and a positive role in environmental degradation. Intergovernmental Panel on Climate Change (IPCC, 2023) noted that agricultural practices, industrialisation, urbanisation, energy-intensive economic pursuits, and the expansion of the financial sector contribute to global warming. It further emphasised that since the 1800s, the demand for energy to feed industries has increased CO_2 emissions, as the world uses non-renewable sources of power to meet rising energy demand which is a major driver of weather patterns and global warming. The development of agriculture raises incomes and increases demand for environmental regulation since production activities generate environmental pollution (Borlaug, 2007). A well-managed agricultural system, on the other hand, provides ecosystem services, like manure on soil, water-flow regulation, and biodiversity support (Food and Agriculture Organization of the United Nations [FAO], 2023; Fusco et al., 2023). Evidence shows that agricultural growth leads to CO_2 emissions, with a proportion of more than one-third of the greenhouse gas emissions in the world (Rosenzweig et al., 2020). Wen et al. (2023) investigated the agriculture production and carbon emissions nexus and found that agricultural production increases environmental degradation.

Despite ongoing controversy surrounding the relationship between financial development (FD) and environmental quality (EQ), there remains a lack of consensus regarding their causality and short- and long-run dynamics. This gap is particularly evident when examining FD, economic growth (EG), primary sector growth (PSG), and EQ in Sub-Saharan Africa (SSA), a region characterized by financial instability and a reliance on agricultural activities. The existing literature presents conflicting theoretical and empirical perspectives. One school of thought argues that FD improves EQ, while an opposing view suggests the contrary. For instance, Ajide and Ibrahim (2021) assert that FD adversely impacts EQ, whereas other studies have identified mixed—minimal, positive, or negative—correlations between the two variables (Kostakis, 2024; Liu et al., 2024; Zhang et al., 2023). Consequently, this study

assesses the short- and long-run linkages between FD, PSG, and EQ in SSA, while examining the causal directions among FD, EG, and EQ by integrating the primary sector growth variable.

Although previous studies have examined financial development, economic growth, renewable energy, and environmental degradation, three gaps remain. First, relatively few studies have jointly examined financial development and primary sector growth within a single framework. Second, evidence for Sub-Saharan Africa remains limited, particularly regarding long-run and short-run dynamics. Third, most existing studies rely on static panel estimation techniques and pay limited attention to heterogeneous effects. This study applies CS-ARDL and Dynamic Common Correlated Effect-Mean Group (DCCE-MG) which are robust and can handle short-run and long-run dynamics. Given the above background, the present study adds to existing knowledge by jointly investigating how financial development and primary sector growth affect environmental quality in SSA, an area with sparse empirical literature. The study also contributes methodologically by employing CS-ARDL and DCCE-MG methods, which produce accurate estimates and control for cross-sectional dependence challenges. From the policy perspective, this research provides evidence supporting financial sector reforms to expand sustainable finance and mobilize investment in low-carbon and environmentally friendly projects.

Practically, the study offers directions for governments and stakeholders by emphasising climate-smart agriculture, eco-friendly technologies, and sustainable production practices that maintain present and future agricultural growth without compromising the next generation's greener environment. The finding re-echoes the efforts to achieve SDGs 7, 11, 12, and 13 and to advance the environmental sustainability objectives of the African Union's Agenda 2063. Finally, the study contributes to financial and agricultural research and development by recommending sustainable finance, modern agricultural practices, and environmentally responsible practices that are environmentally focused. The rest of the sections are: Section 2 literature review; Section 3 methodology; Section 4 discusses empirical findings; and Section 5 conclusion, policy implications, and further studies.

2. Literature review

This section discusses theories underpinning the study and related empirical works. It also discusses the relations among financial development, agricultural sector growth and environmental quality, and controls for economic growth and energy consumption.

2.1 Financial development and environmental quality

Theoretical and empirical studies on FD and environmental degradation are abundant, and much of this literature is based on the Environmental Kuznets Curve (EKC) framework. According to the EKC theory propounded by Grossman & Krueger (1991), environmental degradation initially increases as an economy develops but eventually decreases after income reaches a certain threshold. This theory shows the movement of economic growth and environmental factors and guides policymakers and investors in balancing these factors to protect ecosystems (Hussain et al., 2023).

From the standpoint of the EKC theory, FD can either increase or decrease pollution. Financing industrial expansion improves environmental quality by channelling financing to clean technologies. However, it could lead to greater pollution and decrease environmental quality if the source of energy for industrial production and for other uses is not clean. Patel & Mehta (2023) found that FD supports the creation of investment programs and economic expansion, thereby increasing power usage and eventually decreasing EQ. Some studies back the EKC theory, arguing that FD aids environmental management by enabling investment in less-polluting technologies and sustainable infrastructure (Elatroush, 2025; Farouq & Sulong, 2025)

The empirical evidence on EQ and FD remains mixed; Ali et al. (2023), Prempeh et al. (2023), and Prempeh (2024) argue that FD, EC, and EQ have a mixed relationship. Usman et al. (2021) applied PMG-ARDL in advanced and emerging nations between 1994 and 2018 revealed that FD promotes a sustainable environment in the developed-country subsample, while the direction of causal relationships differs across the two country groups.

In some cases, FD and renewable energy lower emissions over the long term (Kelly & Nembot 2025; Zheng et al., 2024). For the United States, Fourier-ARDL evidence suggests that biomass energy enhances EQ, whereas FD plays a more limited role (Pata et al., 2023). For SSA, Acheampong (2019) finds that specific FD increases carbon emissions. Elatroush (2025) also reports that FD and FDI are associated with higher CO_2 emissions in some clusters of emerging and developing countries. Horobet et al. (2025) studied 40 European countries from 1996 to 2019 and found that FD and EQ have a positive association.

2.2 Primary sector growth and environmental quality

Another theory that supports the current study is Sustainable Development Theory, propounded by the World Commission on Environment and Development (1987). This theory emphasizes economic and social growth that serves present needs while preserving future needs for the next generation. It seeks to balance human progress with ecological preservation through three core pillars: economic capability, environmental protection, and social equity, and to address present needs without destroying the next generation's. In line with the current research objectives, agricultural production should satisfy current food demand without destroying natural resources for the upcoming generation. This could mean that agricultural practices that are eco-friendly reduce environmental pollution, and policies should balance food production with environmental conservation.

The link between agricultural production and EQ varies across regions. For instance, Gokmenoglu and Taspinar (2018) and Agricultural Production Statistics 2000–2022 (2023) identify links between agricultural production and environmental pressure. Recent studies examine climate risks, planetary boundaries, agricultural practices, and food-system sustainability (Rockström et al., 2024; Saleem et al., 2025; Sumberg & Giller, 2022). These pieces of evidence pointed to the need to manage agricultural growth within the environmental limits and objectives of the 2030 Agenda. Wang et al. (2020) argue that the emission of greenhouse gases from agricultural production is constructive and requires urgent attention since food security cannot be underestimated. Rural households also tend to face energy challenges and use traditional power sources, thereby increasing pollution (Acharya & Sadath, 2019).

According to 2000–2022 (2023), agricultural systems are social–ecological systems that help human well-being and natural processes. This creates sustainability concerns involving soil health, carbon sequestration, water regulation, and biodiversity. Efficient management of agriculture improves resource use and decreases environmental pressures (Enguene et al., 2025; Fusco et al., 2023). Economic development and environmental protection both seek to improve human welfare, but development policies must account for environmental constraints (Tariq & Hassan, 2023). Bekele et al. (2024) also affirmed that renewable energy consumption improves EQ. This supports policies that replace polluting energy sources, modernize production systems, and direct investment towards cleaner technologies.

Although research on environmental degradation, financial development, agricultural growth, economic growth, and energy consumption exists, some gaps remain regarding primary sector growth and financial development. First, few studies estimate these relationships jointly in different settings. Related evidence includes Aluko and Obalade (2020), Salahuddin et al. (2020), and Wang et al. (2023). Second, rising food demand and resource

extraction increase the environmental importance of agricultural activity (Agricultural Production Statistics 2000–2022, 2023). The available research works are in a geographical context (FAO, 2023; Rockström et al., 2024; Saleem et al., 2025; Viriato et al., 2026). Manasseh et al. (2025) assess agro-climate financing, economic expansion, and environmental degradation in SSA, focusing on environmental implications and agricultural finance. Much of the related literature focuses on EC, EG, FD, and CO_2 emissions. However, they paid less attention to the short- and long-run dynamics of PSG, FD, and EQ. This study fills this gap using CS-ARDL and DCCE-MG estimators and proposes these hypotheses for testing:

H1: Financial development influences environmental quality in Sub-Saharan Africa in the long run.

H2: Financial development influences environmental quality in Sub-Saharan Africa in the short run.

H3: Primary sector growth influences environmental quality in Sub-Saharan Africa in the long run.

H4: Primary sector growth influences environmental quality in Sub-Saharan Africa in the short run.

3.0 Methodology

3.1 Data source

The study obtains data from the World Development Indicators for 30 SSA countries over 1990–2024 (World Bank, 2026). Environmental quality is proxied by CO_2 emissions per capita. The explanatory variables are primary sector growth, measured as the value added in agriculture, forestry, and fishing (% of GDP), and financial development, proxied by domestic credit to the private sector by banks (% of GDP). Control variables are energy consumption (EC), measured as energy use (kg of oil equivalent per capita); economic growth (EG), proxied by GDP growth (annual %); The sample is restricted to 30 SSA countries because of data availability. All continuous variables are transformed into natural logarithms except GDP, which is in levels, to reduce scale differences, minimise heteroscedasticity, and allow coefficients to be interpreted as elasticities.

Table 1: **Variables' source and their measure**

Variable name	Variable Measure	Expected Sign	Source
Environmental quality (EQ)	Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)	Dependent variable	WDI
Primary Sector Growth (PSG)	Agriculture, forestry, and fishing, value added (% of GDP)	Positive	WDI
Financial development (FD)	Domestic credit to the private sector by banks (% of GDP)	Negative	WDI
Energy consumption (EC)	Energy use (kg oil equivalent per capita)	Positive	WDI
Economic growth (GDP)	GDP (annual % growth)	Positive	WDI

3.2 Empirical models

Following Pesaran (2007), the CADF test model structure is as follows:

$$\Delta \text{yit} = \alpha i + \rho i y i, t-1 + \beta i \bar{y} t - 1 + \gamma i \Delta \bar{y} t + j = 1 \sum pi \phi ij \Delta y i\,, t - j + \varepsilon it \qquad (1)$$

where: $\text{i} = 1, 2, .. \text{N}$ stands for countries, $\text{t} = 1, 2, .., \text{T}$ is for years, yit is the variable under investigation, $\bar{y}t$ is the cross-sectional average, pi is the optimal lag length and εit is the idiosyncratic error term.

Im–Pesaran–Shin (CIPS) Test

Pesaran (2007) constructs the CIPS by averaging individual CADF statistics across all units.

$$\text{CIPS}(\text{N}, \text{T}) = \text{N}1i = 1 \sum NCADFi \qquad (2)$$

Where: N stands for the number of cross-sectional units (countries); T is the number of time periods; $CADFi$ stands for individual CADF statistics

Cross-Sectional Dependence Pesaran (2004), Test Equation

The CD statistic is calculated as:

$$CD = \sqrt{\left(2T/\left(N(N-1)\right)\right)} \left(\sum (i = 1)^{(N-1)\sum (j=i+1)^{N} \rho \hat{\jmath}_{(ij)}}\right) \qquad (3)$$

Where: N is the number of cross-sectional units, T is the number of time periods;

Where $\rho\hat{\imath}\hat{\jmath}_{(ij)}$ is an estimated pairwise correlation coefficient of the residuals between countries i and j. N is the number of cross-sectional units;

Pairwise correlation coefficient is computed as:

$$\hat{\rho}_{(ij)} = \left(\left(\sum(\boldsymbol{t}=\boldsymbol{1})^{\boldsymbol{T}} \boldsymbol{e}_{(it)}\, \boldsymbol{e}_{(jt)}\right) / \left(\sqrt{\left(\sum(\boldsymbol{t}=\boldsymbol{1})^{\boldsymbol{T}} \boldsymbol{e}^{\boldsymbol{2}}_{(it)}\right) \sqrt{\left(\sum(\boldsymbol{t}=\boldsymbol{1})^{\boldsymbol{T}} \boldsymbol{e}^{\boldsymbol{2}}_{(jt)}\right)}} \right) \right) \quad (4)$$

where $\boldsymbol{e}_{(jt)}$denote the residuals obtained from the panel regression.

Panel Cointegration Test Equation

Given the presence of non-stationary variables, we apply the Westerlund (2007) error-correction-following cointegration test. The Westerlund framework absorbs heterogeneous dynamics and imposes no restrictions on common-factors assumptions, compared with a residual-based strategy. The null hypothesis indicates convergence towards long-run stability, and the test evaluates whether the error-correction coefficient significantly differs from zero. There are four test statistics: two group mean statistics (GtG_tGt and GaG_aGa) and two panel statistics PtP_tPt and PaP_aPa (Westerlund, 2007).

$$\Delta y_{(it)} = \alpha_i + \rho_i\left(y_{(i,t-1)} - \beta_i' x_{(i,t-1)}\right) + \sum(j=1)^{(p_i)} \gamma_{(ij)} \Delta y_{(i,t-j)} + \sum(j = 0)^{(q_i)} \theta_{(ij)} \Delta x_{(i,t-j)} + \varepsilon_{(it)} \quad (5)$$

$$G_t = 1/N \sum(i=1)^{N}\left(\rho\hat{\imath}_i / SE(\hat{\rho}\rho_i)\right) \quad (6)$$

$$G_a = 1/N \sum (i=1)^{N} T\rho\hat{\imath}_i \quad (7)$$

$$P_t = \rho\hat{/} SE(\hat{\rho}) \quad (8)$$

$$P_a = T\hat{\hat{\rho}} \quad (9)$$

Westerlund Bootstrap test:

$$p_{(boot)} = 1/B \sum(b=1)^{B} I\left(T_b \geq T_{(obs)}\right) \quad (10)$$

The study applies the Cross-Sectional Augmented Autoregressive Distributed Lag (CS-ARDL) technique when cross-sectional dependence emanates from unobserved common features. Hassan et al., (2022), and Khan et al., (2022) noted that the ARDL framework is ideal for analysing dynamic relationships among variables with different orders of integration. As an advanced second-generation panel estimation technique, CS-ARDL provides consistent and efficient estimates by simultaneously accounting for parameter heterogeneity, cross-sectional dependence, and dynamic adjustments in all runs. Compared to traditional first-generation panel estimators, such as Dynamic Ordinary Least Squares, and conventional ARDL models. A CS-ARDL approach offers strong inference for interdependent economies, shared external influences and heterogeneous cross-sectional augmentation (Chudik & Pesaran, 2015).

General CS-ARDL(p,q)
The relationship among these variables is expressed in the following long-run functional model:

Functional Relationship

$$lnCO2_{(2it)} = f\left(lnFD_{(it)}, lnPSG_{(it)}, lnEC_{(it)}, GDP_{(it)}\right) \quad (11)$$

Baseline Panel Model

$$lnCO2_{(2it)} = \alpha_i + \beta_1 lnFD_{(it)} + \beta_2 lnPSG_{(it)} + \beta_3 lnEC_{(it)} + \beta_4 GDP_{(it)} + \varepsilon_{(it)} \quad (12)$$

Cross-Sectional ARDL (CS-ARDL)

$$yit = j = 1 \sum p\lambda ijyi\,, t - j + j = 0 \sum q\delta ij'xi\,, t - j + j = 0 \sum p\phi ijy\bar{}t - j + j = 0 \sum q\psi ij'x\bar{}t - j + \mu i + \varepsilon it \quad (13)$$

Error-Correction Representation (CS-ARDL)

$$\Delta lnCO2_{(2it)} = \lambda_i\left(lnCO2_{(2,i,t-1)} - \theta_1 lnFD_{(i,t-1)} - \theta_2 lnPSG_{(i,t-1)} - \theta_3 lnEC_{(i,t-1)} - \theta_4 GDP_{(i,t-1)}\right) + \sum(j=1)^{(p-1)} \gamma_{(1ij)} \Delta lnCO_{(2,i,t-j)} + \sum(j=0)^{(q_1-1)} \gamma_{(2ij)} \Delta lnFD_{(i,t-j)} + \sum(j=0)^{(q_2-1)} \gamma_{(3ij)} \Delta lnPSG_{(i,t-j)} + \sum(j=0)^{(q_3-1)} \gamma_{(4ij)} \Delta lnEC_{(i,t-j)} + \sum(j=0)^{(q_4-1)} GDP_{(i,t-j)} + Cross - sectionalaverages + \varepsilon_{(it)} \quad (14)$$

The Dynamic Common Correlated Effect Mean Group (DCE-MG)

$$lnCO_{(2it)} = \alpha_i + \beta_{(1i)} lnFD_{(it)} + \beta_{(2i)} lnPSG_{(it)} + \beta_{(3i)} lnEC_{(it)} + \beta_{(4i)} GDP_{(it)} + \sum(j=0)^{p} \delta_{(1j)} \overline{\left(lnCO_{(2,t-j)}\right)} + \sum(j=0)^{p} \delta_{(2j)} \overline{\left(lnFD_{(t-j)}\right)} + \sum(j=0)^{p} \delta_{(3j)} \overline{\left(lnPSG_{(t-j)}\right)} + \sum(j=0)^{p} \delta_{(4j)} \overline{\left(lnEC_{(t-j)}\right)} + \sum(j=0)^{p} \delta_{(5j)} \overline{\left(GDP_{(t-j)}\right)} + \varepsilon_{(it)} \quad (15)$$

where: $i = 1, 2, \ldots, N$ stands for countries, $t = 1, 2, \ldots, T$ represents years, $y_{it}\ represents\ dependent\ variable$, while x_{it} represents vector of explanatory variables, $\overline{y_t}$ represents explanatory variables, μi is country-specific fixed effects, $\overline{y_t}$ and $\overline{x_t}$ denote cross-sectional averages and ε_{it} is the idiosyncratic error term from (Eq. 12 - 15)

The CS-ARDL specification following (Chudik and Pesaran, 2015) is as:

$$\text{yit} = j = 1 \sum p\lambda ijyi\,, t - j + j = 0 \sum q\delta ij'xi\,, t - j + j = 0 \sum p\phi ijy\bar{}t - j + j = 0 \sum q\psi ij'x\bar{}t - j + \mu i + \varepsilon it \quad (16)$$

where: $\text{i} = 1, 2, \ldots, \text{N}$ is for countries, $\text{t} = 1, 2, \ldots, \text{T}$ represents year, y_{it} is the dependent variable for country i at time t, x_{it} is the vector of explanatory variables, μ_i represents country-specific fixed effects, $\bar{y}_t \text{and} \bar{x}_t \text{denote cross} - \text{sectionalaverages}, \varepsilon_{it}$ is the idiosyncratic error term.

To check the robustness of the estimates from the CS-ARDL method, Dynamic Common Correlated Effects Mean Group (DCCE-MG) by Chudik and Pesaran (2015) was used. It caters for heterogeneous slope coefficients and overlooked shared features by augmenting the regression with contemporaneous and lagged cross-sectional means.

4. Results

4.1 Descriptive Statistics and Correlation

Table 2 depicts descriptive statistics and pairwise correlations of variables. Analysis reveals considerable variation across the sampled countries, indicating substantial heterogeneity in the underlying economic and environmental characteristics. The CO2 variable mean is 1.564, and its standard deviation (Sd.) is 1.452. The PSG variable has an average mean of 2.699 and an Sd. of 0.875, and the FD variable has a mean is 2.501 and an Sd. of 0.858. The EC exhibits a mean of 6.141 with a relatively low Sd. as 0.631, while GDP demonstrates the highest variability, with an Sd. of 5.164 and values from -50.248 to 35.224, representing variances in financial systems across states and time frames.

Correlation statistics indicate a positive association with FD (r = 0.294) and EC (r = 0.366), and a negative association with PSG (r = -0.282). GDP shows a negligible correlation with CO_2 (r = -0.001), and at the bivariate level, no clear linear relationship. Amongst the variables, the highest relationship is seen between PSG and EC (r = -0.732), which remains below the conventional threshold of 0.80, implying that multicollinearity is not a major challenge. Remaining correlations range between -0.382 and 0.414, further confirming the absence of severe collinearity among the regressors.

Table 2: Descriptive Statistics and Correlation Matrix

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
lnCO2	1,050	1.564	1.452	-2.644	6.190
lnFD	1,050	2.501	0.858	-0.800	4.641
lnPSG	1,050	2.699	0.875	-0.114	4.132
lnEC	1,050	6.141	0.631	4.726	7.992
GDP	1,050	3.934	5.164	-50.248	35.224
Pairwise Correlation Matrix of Variables					
Variable	**lnCO2**	**lnFD**	**lnPSG**	**lnEC**	**GDP**
lnCO2	1.0000				
lnFD	0.2936	1.0000			
lnPSG	-0.2817	-0.3823	1.0000		
lnEC	0.3658	0.4137	-0.7324	1.0000	
GDP	-0.0007	-0.0511	-0.0027	0.0393	1.0000

4.2 Cross-Sectional Dependence (CD) and Slope Homogeneity Tests

(Pesaran, 2004) Cross-sectional dependence test and the (Pesaran & Yamagata, 2008) slope homogeneity test are shown in Table 3. Pesaran CD test indicates significant cross-sectional dependence for $lnCO_2$, lnFD, lnPSG, and lnEC ($p < 0.01$), suggesting that these variables are sensitive to regional shocks and inter-country spillover effects. Given the presence of CD between the variables, the Common Correlated Effects (CCE) framework is adopted to cater for unobserved features through cross-sectional averages (Pesaran, 2006). Further analysis based on adjusted and de adjusted statistic, significant at the 1% level, rejecting the Pesaran and Yamagata (2008) slope homogeneity test. This confirms the presence of slope heterogeneity among countries and good for selected estimation techniques.

Table 3: CD and slope-homogeneity tests

Variable	Pesaran CD Test	*mean*	*abs(corr)*
lnCO2	79.870***	0.647	0.764
lnFD	50.910 ***	0.413	0.506
lnPSG	31.240***	0.253	0.431
lnEC	12.160***	0.099	0.472
GDP	-1.250	-0.010	0.164
Slope Homogeneity Test			
	Test Statistic	**p-value**	**Decision**
Δ	32.740***	0.000	Reject slope homogeneity.
Δ adjusted	35.967***	0.000	Reject slope homogeneity.

***Notes**: *** denote statistical significance at the 1% level.*

4.3 Unit Root Test Result

According to (Yang et al., 2021), traditional unit root estimation assumes cross-sectional independence amongst panel elements. However, this assumption is often unrealistic in macro-panel datasets, where countries or regions are interconnected through common economic, environmental, or institutional shocks. To address this limitation, second-generation tests clearly control for CD (Menegaki & Tiwari, 2018). Among the second-generation approaches, Pesaran's (2007) Cross-sectionally Augmented IPS (CIPS) test and the Cross-sectionally Augmented Dickey–Fuller (CADF) test accommodate both cross-sectional dependence and heterogeneity across panels. These tests are appropriate for macro-level panel data with heterogeneous dynamics and shared factors. Following Pesaran (2007), empirical result, reported are at the level and first-difference specifications in Table 4.

Table 4: Pesaran (2007) CIPS and CADF Unit Root Tests

Variable	**CIPS**		**Order of Integration**	**CADF**		**Order of Integration**
	Levels	**First Difference**		**Levels**	**First difference**	
lnCO2	-2.576**	-5.607***	I(0)	-2.854***	-9.558***	I(0)
lnFD	-2.611***	-5.646***	I(0)	-4.870***	-8.838***	I(0)
lnPSG	-2.895***	-5.373***	I(0)	-2.269***	-9.222***	I(0)
lnEC	-1.773	-4.967***	I(1)	0.994	-6.390***	I(1)
GDP	-4.260***	-6.172***	I(0)	-5.877***	-15.422***	I(0)
Critical Values	**1%:** -2.30	**5%:** -2.16				

***Note**: ***, **, and * are statistical significance at 1%, 5% and 10% levels, respectively.*

4.4 **Residual CD Test**

Table 5 illustrates CD tests after applying the CCE framework. While the conventional Pesaran CD test suggests dependence, the bias-adjusted CDw and CD* statistics are statistically insignificant ($p > 0.05$), indicating that residual cross-sectional dependence has been effectively reduced. These results confirm that the CS-ARDL model adequately controls for common shocks and cross-country spillovers, thereby supporting the reliability of the estimated coefficients and standard errors.

Table 5: Tests for Weak Cross-Sectional Dependence on Residuals

Statistic	T Stats.	p-value
CDw	1.020	0.308
CD*	-1.360	0.174

Notes: CDw and CD* are bias-adjusted statistics for testing residual CD. The null hypothesis is weak across-sections. Insignificant p-values indicate that residual cross-sectional dependence has been adequately controlled

4.5 Bootstrap Westerlund Co-integration Test

The Pt statistic at the 5% level and the Ga and Pa statistics at the 10% level; the null hypothesis of no cointegration was rejected, as shown in Table 6, the Bootstrap Westerlund (2007). This shows a constant long-run connection between the variables under investigation. Though the Gt statistic fails to reject the null hypothesis, the overall evidence supports heterogeneous estimations, including baseline and robustness models used, to examine the dynamic relationships.

Table 6. Bootstrap Westerlund Panel Co-Integration Results

Statistic	Value	Z-value	Asymptotic p-value	Robust p-value	Decision
Gt	-2.864	-0.003	0.499	0.208	Fail to reject H_0
Ga	-12.871	2.847	0.998	0.055*	Reject H_0 at 10%
Pt	-19.723	-5.336	0.000***	0.020**	Reject H_0 at 5%
Pa	-13.925	-0.023	0.491	0.060*	Reject H_0 at 10%

***Note**: ***, **, and * are significance levels at 1%, 5% and 10%, respectively.*

4.6 Discussion CS-ARDL Results

Results from the baseline CS-ARDL estimates reveal differences between short-run and long-run determinants of EQ across SSA. The stable long-run relationship among PSW, EQ, FD, EC, and EG was revealed by a negative error-correction coefficient (-0.724, $p < 0.01$). The short-run disequilibrium is corrected within one adjustment period, which is about 72.4% if there is an external shock, indicating a relatively rapid convergence toward long-run equilibrium. The long-run coefficient FD exhibits a negative and statistically significant relationship ($\beta = -0.715$, $p < 0.05$), but its short-run coefficient is not. This finding implies that FD EQ requires an appropriate time frame for financial resources to be channelled into cleaner technologies and renewable energy investment.

In the short run, however, financial sector growth does not influence carbon emissions immediately because investment may require a long time before environmental benefits can be realized. The current result is in line with existing studies that argue that the ecological consequences via financial development depend on institutional quality, financial maturity, and energy transition pathways (Doğanlar et al., 2021; Jóźwik et al., 2023; Kelly & Nembot, 2025; Zheng et al., 2024). Likewise, Zhao et al. (2021) report considerable spatial heterogeneity in the finance–environment relationship across Chinese provinces, whereas Obobisa (2022)

demonstrates that financial development can support low-carbon development when accompanied by renewable energy investment. Nevertheless, previous studies also report that financial development may increase environmental degradation under weak regulatory environments or fossil-fuel-dependent production structures (Ahmad et al., 2022; Murshed et al., 2021; Yang et al., 2021; Zhang et al., 2023a; Zhang). The current evidence implies that financial development in SSA has begun to facilitate environmental improvement, although its benefits materialize primarily over the long run.

Primary sector growth displays positive and statistically significant coefficients for short-run ($\beta = 0.009$, $p < 0.01$) and long-run ($\beta = 0.081$, $p < 0.05$), indicating that expansion of agriculture, forestry, fisheries, and extractive activities contributes to higher carbon emissions and consequently deteriorates environmental quality. The stronger long-run effect suggests that continued dependence on resource-intensive production gradually intensifies environmental pressure through land-use change, mechanization, fertilizer application, livestock production, deforestation, and mining activities. This is also in support of FAO (2023), Saleem et al. (2025), and Wang et al. (2023), who contend that traditional agricultural methods of farming lead to greenhouse gas emissions. Even though Ali et al. (2022) report that agricultural growth reduced emissions in Pakistan, the contrasting evidence observed in SSA likely reflects differences in production technologies, environmental regulations, and the widespread reliance on low-efficiency farming practices across many African economies.

The energy consumption variable shows a positive connection with CO2 emissions for all rounds ($\beta = 0.539$, $p < 0.01$) for the short run and ($\beta = 0.713$, $p < 0.01$) for the long run. This implies that the energy structure in SSA is still based on traditional sources, which are carbon-intensive and promote environmental pollution. Thus, demand for energy continues to translate directly into increased CO_2 emissions. This result agrees with Doğanlar et al. (2021) and other studies that viewed energy usage as a principal factor resulting in carbon discharges in developing economies. Economic growth (GDP) exhibits negative coefficients in all rounds but is not statistically significant. This could imply that environmental consequences in the region are driven more directly by sectoral composition and energy use than by aggregate economic development.

Table 7. CS-ARDL Estimation Results

Variables	Short-run Coefficient	Std. Error	z-statistic	p-value	Long-run Coefficient	Std. Error	z-statistic	p-value
Lagged lnCO2	0.276***	0.051	5.390	0.000	–	–	–	–
lnFD	-0.009	0.044	-0.210	0.830	-0.715**	0.234	-3.050	0.002
LnPSG	0.009***	0.003	2.750	0.006	0.081**	0.041	1.980	0.048
lnEC	0.539***	0.134	4.020	0.000	0.713***	0.158	4.510	0.000
GDP	-0.001	0.002	-0.180	0.858	-0.0038	0.005	-0.850	0.395
Adjustment term (ECT)	**-0.724*** **	**0.051**	**-14.14**	**0.000**	–	–	–	–
R-squared	0.97							
Root MSE	0.09							
CD statistic	-0.93			0.355				

***Note**: ***, **, and * are significance levels at 1% 5% and 10% respectively.*

4.7 Robustness Proof

As a validation step, the study used DCCE-MG. Consistency in coefficient signs between CS-ARDL and DCCE-MG confirms robustness of the baseline estimates.

Table 8: DCCE-MG **Robustness Checks**

Variable	Coefficient	Std. Error	z-statistic	p-value
laglnCO2	0.432***	0.066	6.520	0.000
lnFD	-0.004*	0.002	-1.740	0.081
lnPSG	0.021**	0.011	1.980	0.048
lnEC	0.081**	0.031	2.610	0.009
GDP	-0.2678	0.2290	-1.17	0.242
Diagnostics				
Observations		1,050		
R-square		0.98		

***Notes:** ***, ** and * are significance levels at the 1%, 5% and 10% respectively.*

4.8 Dumitrescu-Hurlin Panel Granger Causality

The Dumitrescu–Hurlin panel Granger causality outcomes offer more evidence of the dynamic interactions between the observations. There is evidence of a two-way causation existing among EQ and FD and EC, indicating strong feedback mechanisms among these variables across SSA countries. However, primary sector growth shows a unidirectional relationship with CO2 emissions. Overall, the causality results complement the CS-ARDL estimates by confirming the dynamic interdependence among environmental, financial, agricultural, energy, and economic systems in Sub-Saharan Africa.

Table 9: Dumitrescu–Hurlin Panel Granger Non-Causality Matrix

Variable	lnCO2	lnFD	lnPSG	lnEC	GDP
lnCO2	—	**3.950*** **	**2.300**	**2.799** **	**1.875**
lnFD	**8.119*** **	—	**3.208*** **	**3.239*** **	**1.198**
lnPSG	**2.771** **	**2.611*** **	—	**1.600** **	**1.079**
lnEC	**3.692*** **	**2.190 *** **	**2.343*** **	—	**0.990**
GDP	**3.132*** **	**2.680*** **	**1.726*** **	**3.103*** **	—

***Note**: ***, **, and * are statistical significance at 1%, 5%, and 10% levels, respectively.*

5. Conclusions and Policy Implications

The study investigates the dynamic relationships among EQ, FD, PSW, EC, and EG in SSA, based on longitudinal data for 30 countries. Based on the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) estimator as a baseline model, alongside the Dynamic Common Correlated Effects Mean Group (DCCE-MG) for robustness purposes. There is the presence of a stable long-term equilibrium connection with the constructs. Finding reveals that FD meaningfully improves EQ, thereby reducing CO2 emissions in the long term, but has no relation in the short run. This suggests that financial sector development materialises gradually as funds are progressively channelled to cleaner technologies.

Renewable energy projects and environmentally sustainable investments yield mitigation results over time. Contrary, primary sector growth shows a significant connection with CO2 emissions in the short term and long-run. This implies that the continued expansion of agriculture, forestry, fisheries, and other resource-based activities contributes to environmental degradation in SSA. Also, EC portrays a substantial increase in carbon discharges for all horizons, indicating the region's continued reliance on traditional power sources. The robustness estimates' coefficient signs and significance levels from the DCCE-MG and Dumitrescu–Hurlin panel Granger causation outcomes are similar to the baseline CS-ARDL results, confirming the robustness and reliability of the estimates.

The study offers policy implications as follows: First, strengthening financial systems and expanding sustainable financial markets will facilitate greater investment in inexhaustible energy sources, green technology, and ecologically friendly production, which should be the focus of governments and stakeholders in developing countries. Shaping environmental

outcomes, the integration of financial development, and the reduction of unclean energy use and primary sector activities will help reduce unecological farming practices that cause harm to the environment and decrease food production in the region. Strengthening financial organizations can accelerate the transition to low-carbon progress and also achieve the Sustainable Development Goals (SDGs), especially goals 7, 11, 12, and 13.

Second, policymakers should focus on and invest in climate-smart agriculture and sustainable natural resources management to reduce the environmental costs associated with primary sector activities. This involves land management practices, efficient irrigation systems, and environmentally friendly farming techniques. Investment in modern agricultural technologies will improve productivity while curtailing emissions challenges.

Finally, Governments should strengthen renewable energy policies and direct funds to clean energy setups, improve power efficiency standards, and encourage households and industries to focus on inexhaustible energy sources. The contribution of energy usage to environmental degradation places interest in accelerating the transition from fossil-fuel dependence to cleaner and more sustainable power usage.

Notwithstanding these contributions, there are some limits. The study is limited to 30 SSA countries due to data availability. Forthcoming research should extend the country coverage and incorporate additional indicators such as green investment, renewable power investment, environmental innovation, agricultural technology adoption, and climate finance mechanisms. Further studies should consider broader geographical inclusion with sector-specific and country-level analyses, which may provide deeper insights into financial development and primary sector activities that tend to influence environmental sustainability across the region.

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Declarations

Competing Interests

We declare that none of the authors has a conflict of interest to disclose in relation to the subject matter or materials discussed in this manuscript.

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References

Acharya, R. H., & Sadath, A. C. (2019). Energy poverty and economic development: Household-level evidence from India. *Energy and Buildings*, *183*, 785–791. https://doi.org/10.1016/j.enbuild.2018.11.047

Acheampong, A. O. (2019). Modelling for insight: Does financial development improve environmental quality? *Energy Economics*, *83*, 156–179. https://doi.org/10.1016/j.eneco.2019.06.025

Agricultural production statistics 2000–2022. (2023). FAO. https://doi.org/10.4060/cc9205en

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., & Sinha, A. (2022). Financial development and environmental degradation: Do human capital and institutional quality make a difference? *Gondwana Research*, *105*, 299–310. https://doi.org/10.1016/j.gr.2021.09.012

Ali, A., Audi, M., Senturk, I., & Roussel, Y. (2022). Do Sectoral Growth Promote CO2 Emissions in Pakistan? Time Series Analysis in Presence of Structural Break. *International Journal of Energy Economics and Policy*, *12*(2), 410–425. https://doi.org/10.32479/ijeep.12738

Ali, E. B., Anufriev, V. P., & Ural Federal University. (2023). Revisiting the Energy Consumption, Economic Growth and the Environmental Kuznets Curve in Developing Countries. *Economy of Regions*, *19*(1), 75–84. https://doi.org/10.17059/ekon.reg.2023-1-6

Aluko, O. A., & Obalade, A. A. (2020). Financial development and environmental quality in sub-Saharan Africa: Is there a technology effect? *Science of The Total Environment*, *747*, 141515. https://doi.org/10.1016/j.scitotenv.2020.141515

Bekele, M., Sassi, M., Jemal, K., & Ahmed, B. (2024). The dynamic linkage between renewable energy consumption and environmental sustainability in Sub-Saharan African countries: Heterogeneous macro-panel data analysis. *Cogent Economics & Finance*, *12*(1), 2285188. https://doi.org/10.1080/23322039.2023.2285188

Borlaug, N. (2007). Feeding a Hungry World. *Science*, *318*(5849), 359–359. https://doi.org/10.1126/science.1151062

Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of Econometrics*, *188*(2), 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007

Doğanlar, M., Mike, F., Kızılkaya, O., & Karlılar, S. (2021). Testing the long-run effects of economic growth, financial development and energy consumption on CO2 emissions in Turkey: New evidence from RALS cointegration test. *Environmental Science and Pollution Research*, *28*(25), 32554–32563. https://doi.org/10.1007/s11356-021-12661-y

Elatroush, I. (2025). Does financial development influence environmental quality? Evidence from emerging and developing countries. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-05873-y

Enguene, A. A., Wepaguiewe, R. A., & Idrissa, O. (2025). The dual effect of (Extractive) foreign direct investment on institutional quality in sub-Saharan Africa. *SN Business & Economics*, *5*(11), 187. https://doi.org/10.1007/s43546-025-00957-x

Farouq, I., & Sulong, Z. (2025). Investigating the Effects of Financial Development and Inflation on the Ecological Footprint in Five Selected Leading African Economies.

Fudan Journal of the Humanities and Social Sciences. https://doi.org/10.1007/s40647-025-00454-3

Fusco, G., Campobasso, F., Laureti, L., Frittelli, M., Valente, D., & Petrosillo, I. (2023). The environmental impact of agriculture: An instrument to support public policy. *Ecological Indicators*, *147*, 109961. https://doi.org/10.1016/j.ecolind.2023.109961

Gokmenoglu, K. K., & Taspinar, N. (2018). Testing the agriculture-induced EKC hypothesis: The case of Pakistan. *Environmental Science and Pollution Research*, *25*(23), 22829–22841. https://doi.org/10.1007/s11356-018-2330-6

Grossman, G., & Krueger, A. (1991). *Environmental Impacts of a North American Free Trade Agreement* (No. W3914; p. w3914). National Bureau of Economic Research. https://doi.org/10.3386/w3914

Hassan, S. T., Batool, B., Zhu, B., & Khan, I. (2022). Environmental complexity of globalization, education, and income inequalities: New insights of energy poverty. *Journal of Cleaner Production*, *340*, 130735. https://doi.org/10.1016/j.jclepro.2022.130735

Horobet, A., Radulescu, M., Bouraoui, T., Mnohoghitnei, I., Balsalobre-Lorente, D., & Belascu, L. (2025). Financial development and environmental degradation: Insights from European countries. *Applied Economics*, *57*(32), 4679–4694. https://doi.org/10.1080/00036846.2024.2364087

Hussain, S., Akbar, M., Gul, R., Shahzad, S. J. H., & Naifar, N. (2023). Relationship between financial inclusion and carbon emissions: International evidence. *Heliyon*, *9*(6), e16472. https://doi.org/10.1016/j.heliyon.2023.e16472

Jianguo, D., Ali, K., Alnori, F., & Ullah, S. (2022). The nexus of financial development, technological innovation, institutional quality, and environmental quality: Evidence from OECD economies. *Environmental Science and Pollution Research*, *29*(38), 58179–58200. https://doi.org/10.1007/s11356-022-19763-1

Manasseh, C. O., Logan, C. S., Okanya, O. C., Okiche, E. L., Ede, K. K., Ogbuabor, J. E., Igwemeka, E. C., Ilo, S., & Onuselogu, O. C. O. (2025). Assessing the Nexus between Environmental Degradation, Agro-Climate Financing, and Economic Growth in Sub-Saharan Africa. *Sustainability*, *17*(21), 9862. https://doi.org/10.3390/su17219862

Menegaki, A. N., & Tiwari, A. K. (2018). A global food–energy–water nexus with heterogeneity, non-stationarity and cross-sectional dependence. *Quality & Quantity*, *52*(6), 2723–2755. https://doi.org/10.1007/s11135-018-0690-0

Murshed, M., Ahmed, Z., Alam, M. S., Mahmood, H., Rehman, A., & Dagar, V. (2021). Reinvigorating the role of clean energy transition for achieving a low-carbon economy: Evidence from Bangladesh. *Environmental Science and Pollution Research*, *28*(47), 67689–67710. https://doi.org/10.1007/s11356-021-15352-w

Newman, R., & Noy, I. (2023). The global costs of extreme weather that are attributable to climate change. *Nature Communications*, *14*(1), 6103. https://doi.org/10.1038/s41467-023-41888-1

Obobisa, E. S. (2022). Achieving 1.5 °C and net-zero emissions target: The role of renewable energy and financial development. *Renewable Energy*, *188*, 967–985. https://doi.org/10.1016/j.renene.2022.02.056

Pata, U. K., Kartal, M. T., Adebayo, T. S., & Ullah, S. (2023). Enhancing environmental quality in the United States by linking biomass energy consumption and load capacity factor. *Geoscience Frontiers*, *14*(3), 101531. https://doi.org/10.1016/j.gsf.2022.101531

Patel, N., & Mehta, D. (2023). The asymmetry effect of industrialization, financial development and globalization on CO2 emissions in India. *International Journal of Thermofluids*, *20*, 100397. https://doi.org/10.1016/j.ijft.2023.100397

Pesaran, M. H. (2004). *General Diagnostic Tests for Cross Section Dependence in Panels*. https://doi.org/10.17863/CAM.5113

Pesaran, M. H. (2006). Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure. *Econometrica*, *74*(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Prempeh, K. B. (2024). The role of economic growth, financial development, globalization, renewable energy and industrialization in reducing environmental degradation in the economic community of West African States. *Cogent Economics & Finance*, *12*(1), 2308675. https://doi.org/10.1080/23322039.2024.2308675

Prempeh, K. B., Yeboah, S. A., Danso, F. K., & Frimpong, J. M. (2023). Banking sector development and environmental degradation in the Economic Community of West African States: Do technology effects matter? *Future Business Journal*, *9*(1), 106. https://doi.org/10.1186/s43093-023-00286-1

Rockström, J., Donges, J. F., Fetzer, I., Martin, M. A., Wang-Erlandsson, L., & Richardson, K. (2024). Planetary Boundaries guide humanity's future on Earth. *Nature Reviews Earth & Environment*, *5*(11), 773–788. https://doi.org/10.1038/s43017-024-00597-z

Salahuddin, M., Habib, M. A., Al-Mulali, U., Ozturk, I., Marshall, M., & Ali, M. I. (2020). Renewable energy and environmental quality: A second-generation panel evidence from the Sub Saharan Africa (SSA) countries. *Environmental Research*, *191*, 110094. https://doi.org/10.1016/j.envres.2020.110094

Tariq, A., & Hassan, A. (2023). Role of green finance, environmental regulations, and economic development in the transition towards a sustainable environment. *Journal of Cleaner Production*, *413*, 137425. https://doi.org/10.1016/j.jclepro.2023.137425

Umar, M., & Safi, A. (2023). Do green finance and innovation matter for environmental protection? A case of OECD economies. *Energy Economics*, *119*, 106560. https://doi.org/10.1016/j.eneco.2023.106560

Usman, M., Yaseen, M. R., Kousar, R., & Makhdum, M. S. A. (2021). Modeling financial development, tourism, energy consumption, and environmental quality: Is there any discrepancy between developing and developed countries? *Environmental Science and Pollution Research*, *28*(41), 58480–58501. https://doi.org/10.1007/s11356-021-14837-y

Viriato, V., Bonfim, F. P. G., & Nunes, M. R. (2026). A Sustainable Development-Driven Framework: Aligning Agricultural Environmental Impact Assessment with the 2030 Agenda. *Environmental Management*, *76*(1), 15. https://doi.org/10.1007/s00267-025-02318-8

Wang, J., Dong, X., Qiao, H., & Dong, K. (2020). Impact assessment of agriculture, energy and water on CO_2 emissions in China: Untangling the differences between major and non-major grain-producing areas. *Applied Economics*, *52*(60), 6482–6497. https://doi.org/10.1080/00036846.2020.1796920

Wang, J., Jiang, C., Li, M., Zhang, S., & Zhang, X. (2023). Renewable energy, agriculture, and carbon dioxide emissions nexus: Implications for sustainable development in sub-Saharan African countries. *Sustainable Environment Research*, *33*(1), 31. https://doi.org/10.1186/s42834-023-00193-8

Wen, J., Zhao, X.-X., Fu, Q., & Chang, C.-P. (2023). The impact of extreme weather events on green innovation: Which ones bring to the most harm? *Technological Forecasting and Social Change*, *188*, 122322. https://doi.org/10.1016/j.techfore.2023.122322

Westerlund, J. (2007). Testing for Error Correction in Panel Data*. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Wu, L., Adebayo, T. S., Yue, X.-G., & Umut, A. (2023). The role of renewable energy consumption and financial development in environmental sustainability: Implications for the Nordic Countries. *International Journal of Sustainable Development & World Ecology*, *30*(1), 21–36. https://doi.org/10.1080/13504509.2022.2115577

Xuezhou, W., Manu, E. K., & Akowuah, I. N. (2022). Financial development and environmental quality: The role of economic growth among the regional economies of Sub-Saharan Africa. *Environmental Science and Pollution Research*, *29*(16), 23069–23093. https://doi.org/10.1007/s11356-021-17271-2

Yang, B., Jahanger, A., Usman, M., & Khan, M. A. (2021). The dynamic linkage between globalization, financial development, energy utilization, and environmental sustainability in GCC countries. *Environmental Science and Pollution Research*, *28*(13), 16568–16588. https://doi.org/10.1007/s11356-020-11576-4

Zhang, H., Chen, T., & Yu, Y. (2023a). From finance to sustainability: Understanding the financial development-environment nexus with the environmental Kuznets curve in East-Asia and Pacific economies. *Borsa Istanbul Review*, *23*(6), 1448–1457. https://doi.org/10.1016/j.bir.2023.10.003

Zhang, H., Chen, T., & Yu, Y. (2023b). From finance to sustainability: Understanding the financial development-environment nexus with the environmental Kuznets curve in East-Asia and Pacific economies. *Borsa Istanbul Review*, *23*(6), 1448–1457. https://doi.org/10.1016/j.bir.2023.10.003

Zhao, J., Zhao, Z., & Zhang, H. (2021). The impact of growth, energy and financial development on environmental pollution in China: New evidence from a spatial econometric analysis. *Energy Economics*, *93*, 104506. https://doi.org/10.1016/j.eneco.2019.104506

Zheng, Y., Tarczyński, W., Jamróz, P., Ali Raza, S., & Tiwari, S. (2024). Impacts of mineral resources, economic growth and energy consumption on environmental sustainability: Novel findings from global south region. *Resources Policy*, *92*, 105019. https://doi.org/10.1016/j.resourpol.2024.105019