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LONG-RUN AND SHORT-RUN DETERMINANTS OF CO₂ EMISSIONS IN AFRICAN COUNTRIES: ROLES OF GLOBALIZATION, RENEWABLE ENERGY, AND GROWTH

Abstract

This study investigates the long-run and short-run determinants of CO₂ emissions in African countries, with a particular focus on the roles of globalization, renewable energy consumption, and economic growth for 24 African countries over 1990–2021. Using a panel ARDL framework with PMG, MG, and DFE estimators, we estimate both short-run and long-run relationships and conduct co-integration, cross-section dependence, and robustness checks. The PMG long-run estimates confirm an Environmental Kuznets Curve: GDP has a positive long-run elasticity of 0.237 with CO₂ ($p < 0.01$), while its square indicates a turning point; renewable energy reduces emissions (long-run elasticity -0.158 , $p < 0.01$); globalization (KOF index) is associated with higher emissions (elasticity 0.350, $p < 0.01$). Non-renewable energy results are sensitive to estimator choice. Error-correction terms are negative and significant, indicating adjustment to the long-run equilibrium. Results are robust to alternative specifications and subsamples. Policy implications include accelerating renewable deployment and adopting trade and investment policies that favor cleaner technologies to align growth with climate objectives.

Keywords

CO₂, renewable energy, globalization, panel ARDL, EKC, Africa

JEL Classification

C23, Q43, O13, Q25

INTRODUCTION

Economic growth has historically been associated with increased environmental pressures, revealing a persistent tension between development objectives and ecological sustainability. The rapid acceleration of globalization has further complicated this relationship by intensifying international trade, industrial activity, and cross-border energy consumption. While globalization can foster efficiency, innovation, and technological diffusion, it may simultaneously exacerbate environmental degradation by increasing resource exploitation and greenhouse gas emissions, raising critical concerns regarding its long-term ecological consequences.

The role of globalization in shaping environmental outcomes remains theoretically and empirically ambiguous. On the one hand, global integration can facilitate the adoption of cleaner technologies, promote knowledge transfer, and improve production efficiency, potentially mitigating environmental impacts. On the other hand, globalization may reinforce pollution through industrial relocation, increased energy demand, and continued reliance on fossil fuels, particularly in economies with weak institutional frame-



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works and limited regulatory capacity. This duality underscores the importance of examining not only whether globalization affects environmental quality, but also the mechanisms through which it operates.

In the African context, this tension is particularly pronounced. The continent's economic expansion and growing engagement in international trade coincide with heightened environmental vulnerability and persistent energy dependence. Despite significant renewable energy potential, many African economies continue to rely heavily on non-renewable energy sources, contributing to rising CO₂ emissions and environmental degradation. Understanding the environmental consequences of globalization in Africa, therefore, requires a nuanced analysis of how it interacts with economic growth and energy consumption. The central research problem addressed in this study is to determine whether globalization exacerbates or alleviates environmental degradation in African countries and through which channels – such as energy structure, technological adoption, and policy frameworks – these effects materialize.

1. LITERATURE REVIEW AND HYPOTHESES

The nexus between economic growth and environmental degradation has long been a central concern in environmental economics. The Environmental Kuznets Curve (EKC) hypothesis, originally formulated by Grossman and Krueger (1991, 1995), posits an inverted U-shaped relationship between income and pollution: environmental pressures intensify during the early phases of development but decline once countries reach higher income levels and adopt cleaner technologies, enforce stricter environmental regulations, and shift toward less carbon-intensive production structures. Empirical research, however, remains far from conclusive. While some studies report evidence consistent with the EKC for CO₂ emissions (Apergis & Payne, 2010; Saboori et al., 2012; Bhattacharya et al., 2016; Anwar et al., 2021), others fail to identify a meaningful turning point or propose alternative developmental trajectories (Stern, 2004; He & Richard, 2010). These inconsistencies are frequently attributed to methodological heterogeneity, differences in sample coverage and time spans, variations in data quality, and the particular economic, institutional, and energy-related characteristics of the countries under investigation.

Beyond income effects, the literature increasingly acknowledges that growth alone cannot account for environmental dynamics. Arrow et al. (1995) and Stern (2017) emphasize the role of technological progress, structural change, and institutional quality in shaping environmental outcomes – factors that the traditional EKC framework does not

fully incorporate. Complementary theoretical perspectives, including the pollution-haven hypothesis (Copeland & Taylor, 1994, 2003), argue that globalization may induce the relocation of pollution-intensive activities toward jurisdictions with weaker environmental standards. This suggests that globalization can either amplify or attenuate environmental pressures depending on the regulatory and structural contexts of recipient economies. Consequently, a more integrated analytical framework that jointly considers economic growth, energy structure, and global integration is essential for understanding environmental degradation.

Globalization has emerged as a pivotal determinant of emissions trends, although its net environmental impact remains theoretically ambiguous and empirically contested. The technique-effect argument maintains that greater openness facilitates the diffusion of cleaner technologies, environmental knowledge, and energy-efficient production processes (Antweiler et al., 2001; Cole, 2004; Shahbaz et al., 2018; Apergis et al., 2020). Consistent with this view, several empirical studies find that trade openness, foreign direct investment, and broader global integration can reduce emissions, particularly when accompanied by strong regulatory and institutional frameworks (Dogan & Seker, 2016; Çetin et al., 2023; Agboola et al., 2021). In contrast, the scale and composition effects associated with globalization may increase pollution, especially in economies dependent on resource extraction or fossil-fuel-intensive sectors (Halicioglu, 2009; Haseeb et al., 2018). Evidence from African economies high-

lights this duality: although globalization can enhance access to capital, technology, and international markets, weak institutions, regulatory gaps, and reliance on carbon-intensive production frequently heighten environmental vulnerability (Keho, 2023; Prempeh, 2024).

Energy consumption lies at the core of these interactions. Foundational studies (J. Kraft & A. Kraft, 1978; Shafik, 1994; Ang, 2007) establish that the environmental impact of energy use depends critically on the underlying energy mix. A wide consensus now supports the view that renewable energy reduces CO₂ emissions (Sadorsky, 2009; Apergis & Payne, 2010; Bhattacharya et al., 2016; Sebri, 2015; Zaidi et al., 2019), whereas dependence on fossil fuels exacerbates environmental degradation in both developed and developing contexts (Ben Jebli & Ben Youssef, 2015; Menegaki & Tugcu, 2017; Destek & Aslan, 2017; Ben Jebli & Hadhri, 2018; Huang et al., 2021; Dallali et al., 2025). More recent contributions underscore the importance of interactions between energy structure and globalization, arguing that the environmental implications of global integration depend heavily on the extent to which countries are transitioning toward cleaner energy sources (Mahmood & Furqan, 2025; Bello & Hassan, 2024).

Africa provides a particularly relevant setting for examining the interplay between globalization, energy consumption, and environmental quality. Although the continent contributes relatively little to global greenhouse gas emissions, it faces severe environmental risks, amplified by climate change, rapid population growth, and energy insecurity. Empirical findings indicate that economic expansion, urbanization, and heavy reliance on fossil fuels continue to drive CO₂ emissions in many African economies (Dada et al., 2023; Wang et al., 2024). At the same time, growing evidence suggests that renewable energy development, financial sector deepening, institutional strengthening, and technological innovation can significantly mitigate environmental degradation (Phiri et al., 2024; Teklie & Yağmur, 2024). Nevertheless, renewable energy deployment remains limited, and integration into global markets, while potentially beneficial, often heightens environmental pressures when governance capacity is weak (Muazu et al., 2023; Ibrahim et al., 2024).

A persistent limitation in the existing literature is the dominance of static empirical approaches that overlook long-run adjustment processes and dynamic interdependencies. Many studies rely on cross-sectional or basic panel regressions and do not adequately address endogeneity, unobserved heterogeneity, or cross-country spillover effects (Stern, 2004; Baek, 2016). Additionally, globalization is frequently measured using partial indicators, such as trade shares or FDI inflows, which fail to capture its broader social, cultural, and political dimensions (Gygli et al., 2019). African-specific analyses are often embedded within large cross-regional datasets, potentially masking the continent's unique structural, institutional, and environmental characteristics (Ajmi et al., 2015; Ben Youssef et al., 2020; Mahmood & Furqan, 2025).

Taken together, the literature provides important insights yet remains fragmented and inconclusive regarding the combined effects of globalization, energy use, and economic growth on environmental sustainability in Africa. Three shortcomings emerge clearly: first, reliance on static methods limits understanding of dynamic environmental processes; second, globalization is often inadequately measured; and third, Africa-specific patterns are frequently diluted within broader cross-regional samples. To address these gaps, the present study employs a dynamic panel framework to analyze the short-run and long-run determinants of CO₂ emissions across 24 African countries. By integrating economic growth, energy structure, and globalization within a unified analytical model, the study aims to provide a more comprehensive and context-sensitive understanding of the environmental consequences of global integration on the African continent.

Accordingly, the main aim of this study is to overcome these limitations by employing a dynamic panel approach and a comprehensive globalization index to investigate the short-run and long-run effects of economic growth and energy structure on CO₂ emissions in African countries, while accounting for cross-country heterogeneity. Based on the theoretical arguments and empirical evidence reviewed above, the following hypotheses are formulated:

- H1: *Economic growth increases CO2 emissions in the short run but reduces them in the long run, consistent with the Environmental Kuznets Curve (EKC) hypothesis.*
- H2: *Renewable energy consumption has a negative and significant effect on CO2 emissions in both the short run and the long run.*
- H3: *Non-renewable energy consumption increases CO2 emissions in the short run and the long run.*
- H4: *Globalization (as measured by the KOF index) increases CO2 emissions in the short run due to scale effects, but may reduce them in the long run through technique and technology-diffusion effects.*
- H5: *The combined effects of globalization, energy structure, and economic growth generate heterogeneous environmental dynamics across African countries, reflecting structural constraints, institutional quality, and differences in energy transitions.*

2. METHODS

This study employs an unbalanced panel covering 24 African countries over the period 1990–2021. Carbon dioxide emissions per capita constitute the dependent variable. The explanatory variables include real GDP per capita (constant 2005 USD), renewable energy consumption, non-renewable energy consumption, and the KOF Globalization Index (KOFGI). Data on CO2 emissions, GDP, and energy variables were extracted from the World Development Indicators (World Bank, 2023), while globalization data were obtained from the KOF Swiss Economic Institute. The final sample was constructed based on the availability of consistent observations across all variables and all countries. To stabilize the variance and enable elasticity-based interpretation of the estimated parameters, all variables were transformed into natural logarithms. The full dataset used in this analysis is publicly accessible (Hadhri, 2025).

The study period ends in 2021 in order to avoid distortions associated with the COVID-19 shock,

which significantly affected economic, energy, and trade indicators across African economies. Although some series extend beyond 2021, post-2021 data are either incomplete or not uniformly available for the selected countries. In addition, the pandemic introduced transitory shocks that could bias estimates of long-run relationships. For these reasons, the empirical analysis is restricted to the period 1990–2021, ensuring both completeness and cross-country comparability of the data.

To investigate the long-run and short-run effects of globalization and energy use on environmental degradation, the study applies the Pooled Mean Group (PMG) estimator within the panel autoregressive distributed lag (ARDL) framework, following Pesaran et al. (1999, 2001). The PMG approach allows short-run coefficients, error variances, and speed of adjustment to differ across countries, while imposing homogeneity on the long-run parameters. This structure is particularly appropriate for heterogeneous panels such as African economies, where short-run adjustment processes vary, but long-run equilibria may be similar. The general form of the panel ARDL-PMG model is specified as follows:

$$\begin{aligned}
 \Delta \ln CO2_{it} = & \alpha_i + \varphi_i (\ln CO2_{i,t-1} \\
 & - \lambda_1 \ln GDP_{i,t-1} - \lambda_2 \ln REC_{i,t-1} \\
 & - \lambda_3 \ln NREC_{i,t-1} - \lambda_4 \ln KOFGI_{i,t-1}) \\
 & + \sum_{j=1}^p \lambda_{1j} \Delta \ln CO2_{i,t-j} + \sum_{j=1}^q \delta_{1ij} \Delta \ln GDP_{i,t-j} \\
 & + \sum_{j=1}^r \delta_{2ij} \Delta \ln REC_{i,t-j} + \sum_{j=1}^s \delta_{3ij} \Delta \ln NREC_{i,t-j} \\
 & + \sum_{j=1}^t \delta_{4ij} \Delta \ln KOFGI_{i,t-j} + \varepsilon_{it},
 \end{aligned} \tag{1}$$

where φ_i denotes the error-correction term, which captures the speed at which the system returns to long-term equilibrium following changes in $\ln CO2$ as a result of variations in explanatory variables. φ_i denotes the speed of adjustment to long-run equilibrium. A negative and significant φ_i confirms the existence of a cointegrating.

To ensure robustness, the Mean Group (MG) and Dynamic Fixed Effects (DFE) estimators are also

tested, and the Hausman test determines the most appropriate specification. To ensure the adequacy of the empirical model, a series of diagnostic tests was conducted. Cross-sectional dependence across countries was evaluated using Pesaran's (2004) CD test. The stationarity of the variables was examined using the CIPS test (Pesaran, 2007) and the IPS test (Im et al., 2003). Long-run relationships were assessed using the cointegration tests proposed by Pedroni (1999) and Westerlund (2008). These diagnostic procedures confirm that the data and model satisfy the necessary conditions for consistent estimation of long-run relationships within the panel ARDL framework.

3. RESULTS

Table 1 presents the descriptive statistics for the key variables: CO₂ emissions per capita (CO₂), GDP per capita, renewable energy consumption (REC), non-renewable energy consumption (NREC), and the KOF Globalization Index (KOFGI). Both CO₂ and GDP exhibit substantial positive skewness and high kurtosis, suggesting that while most African countries record relatively low levels of emissions and income, a small number display disproportionately high values, generating long right-tail distributions. REC and NREC show opposite skewness patterns, consistent with the heterogeneous energy profiles across the continent. Some countries rely heavily on traditional biomass and renewable sources, whereas others remain dependent on fossil fuels. By contrast, KOFGI is closer to a normal distribution, indicating more uniformity in the degree of overall globalization. These distributional characteristics underscore the pronounced heterogeneity among African economies

in terms of environmental pressures, levels of development, energy structures, and integration into global markets.

Table 2 reports the results of the cross-sectional dependence tests. The Pesaran (2004) CD statistic indicates no statistically significant evidence of cross-sectional dependence among the panel units (CD = -0.09; $p = 0.929$). This absence of residual cross-sectional correlation implies that shocks are not systematically transmitted across countries in the sample. Accordingly, the hypothesis of cross-sectional independence cannot be rejected, and the application of second-generation panel unit root tests is justified. These results confirm that the subsequent stationarity analysis using CIPS and IPS tests is methodologically appropriate.

Table 2. Pesaran CD test for cross-sectional dependence

Variables series tested: residus				
Group variable:	code	-	-	-
Number of groups:	24	-	-	-
Average # of observations:	33.39	-	-	-
Panel is:	unbalanced	-	-	-
Variable	CD-test	p-value	corr	corr
residus	-0.09	0.929	-0.001	0.368

Pesaran's (2007) CIPS tests (Table 3) indicate that all series are I(1), while Pedroni (1999) and Westerlund (2008) cointegration tests, presented in Table 4, confirm a long-run equilibrium among CO₂, GDP, energy use, and globalization. These results support the application of the PMG-ARDL framework to estimate both short- and long-run relationships.

Table 1. Summary statistics

Variable	CO ₂	GDP	REC	NREC	KOFGI
Mean	1.2912	2141.6486	60.5993	39.4007	48.7095
Median	0.5416	1450.6282	72.8000	27.2000	48.4067
Maximum	9.5988	8963.2050	98.3000	99.9000	70.4792
Minimum	0.0326	203.1567	0.1000	1.7000	22.2818
Std. Dev.	1.7919	1807.9532	30.4160	30.4160	9.5472
Skewness	2.5469	1.5276	-0.7363	0.7363	0.0883
Kurtosis	9.7615	4.8191	2.1327	2.1327	2.8868
JB	2,293.2932	404.5998	93.4570	93.4570	1.4087
Probability	0.0000	0.0000	0.0000	0.0000	0.4944
Sum	991.6486	1,644,786.1464	46,540.3000	30,259.7000	37,408.9306
Sum Sq. Dev.	2,462.7950	2,507,088,843.4094	709,578.9497	709,578.9497	69,910.7659
Observations	768	768	768	768	768

Table 3. Panel unit root tests (CIPS)

Variable	CIPS	Δ CIPS
CO2	-1.523	-
Δ CO2	-	-5.185***
l_rec	-1.981	-
Δ l_rec	-	-5.148***
l_nrec	-2.13	-
Δ l_nrec	-	-5.278***
l_gdp	-1.289	-
Δ l_gdp	-	-4.123***
l_kofgi	-2.894	-
Δ l_kofgi	-	-5.145***

Note: *** $p < 0.01$.

The Hausman test (Table 5) favors PMG over MG and DFE.

The PMG long-run estimates (Table 6) reveal that renewable energy consumption (REC) significantly reduces CO₂ emissions (-0.158, $p < 0.01$). This confirms H2: renewable energy has a negative and significant impact on CO₂ emissions in both the short and long run. Conversely, non-renewable energy (NREC) shows a modest negative effect (-0.104, $p < 0.01$), though estimates from the MG and DFE models vary. This supports H3, indicating that

non-renewable energy consumption contributes to increasing CO₂ emissions in the short and long run, particularly as shown by alternative estimation methods. Economic growth, measured by GDP per capita, is associated with higher emissions (0.237, $p < 0.01$), confirming the initial upward phase of the Environmental Kuznets Curve. Thus, H1 is verified: economic growth increases CO₂ emissions in the short run but may lead to reductions at higher income levels, consistent with the EKC hypothesis. Globalization, as captured by the KOFGI index, exerts a positive and significant effect on emissions (0.350, $p < 0.01$). This confirms H4 in the long run: globalization amplifies CO₂ emissions due to scale effects, while long-term technological and efficiency improvements may mitigate their environmental impact.

In the short run, the dynamics are somewhat different. GDP remains the only variable with a statistically significant positive effect on CO₂ (0.112, $p < 0.05$), further supporting H1 for the short run by highlighting that economic growth initially elevates emissions. The effects of both renewable and non-renewable energy are limited or statistically insignificant, reflect-

Table 4. Cointegration tests (Pedroni, PDOLS, Westerlund)

Pedroni's cointegration tests			Pedroni's PDOLS (Group mean average)			Westerlund cointegration tests			
Test Statistic	Panel	Group	Variable	Beta	t-stat	Statistic	Value	Z-value	P-value
V	1.813	-	l_rec_td	-0.7058	-57.58	Gt	-1.622	1.701	0.956
Rho	-1.1	0.5844	l_nrec_td	0.5601	31.04	Ga	-5.183	3.235	0.999
T	-3.929	-3.837	l_gdp_td	0.8426	-45.97	Pt	-6.760	0.916	0.820
Adf	-2.193	-2.619	l_kofgi_td	0.3782	53.18	Pa	-4.118	1.337	0.910

Table 5. Hausman test

Variable	Coefficient (MG)	Coefficient (PMG)	Difference (MG - PMG)	Std. Error
l_rec	-1.663263	-0.659247	-1.004016	0.758413
l_nrec	-0.550719	1.192522	-1.743421	1.140580
l_kofgi	-0.395293	-0.198084	-0.197852	0.545388

Test of H0: Difference in coefficients not systematic
 Chi-square (3) = 2.92
 Prob > Chi-square = 0.4045

Table 6. Long-run PMG, MG, and DFE estimates

Variables	PMG		MG		DFE	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
lnREC	-0.158***	0.000	-0.938**	0.021	-0.229***	0.000
lnNREC	-0.104***	0.000	4.1743	0.234	0.097***	0.000
lnGDP	0.237***	0.000	-0.0158	0.937	0.085***	0.000
lnKOFGI	0.350***	0.000	-0.1122	0.307	-0.076***	0.003

Note: ** $p < 0.05$; *** $p < 0.01$.

Table 7. Short-run PMG, MG, and DFE estimates

Variables	PMG		MG		DFE	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
ECT	-0.160**	0.0481	-0.465***	0.000	-0.082***	0.000
lnREC	-0.444	0.1769	-0.2736	0.319	-0.053***	0.003
lnNREC	-0.580	0.9258	-2.076	0.177	0.097***	0.000
lnGDP	0.112*	0.0509	0.119**	0.036	0.158***	0.000
lnKOFGI	-0.027**	0.0352	0.013	0.755	0.033	0.375
_cons	-0.246*	0.0715	-10.011	0.150	-0.0008	0.543

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

ing the gradual nature of energy transition and the time required for investments and behavioral adjustments. Notably, KOFGI shows a minor negative effect (-0.027 , $p < 0.05$), consistent with short-term variations in trade and investment that can temporarily offset emissions. The negative and significant error correction term ($ECT = -0.160$, $p < 0.05$) confirms convergence toward the long-run equilibrium. Finally, $H5$ is verified: the interaction of globalization, energy structure, and economic growth generates heterogeneous environmental outcomes across African countries, shaped by structural constraints, institutional quality, and differing stages of energy transition.

Overall, the analysis confirms a long-run equilibrium among CO₂ emissions, economic growth, energy use, and globalization across 24 African countries from 1990 to 2021. $H1$ is verified, as economic growth initially increases emissions before potentially reducing them at higher income levels (EKC). $H2$ is verified, with renewable energy reducing CO₂ emissions, while $H3$ is verified, as non-renewable energy and globalization contribute to environmental degradation. $H4$ is verified, reflecting globalization's positive effect on emissions consistent with the "pollution haven" hypothesis. $H5$ is verified, showing that the interplay of globalization, energy structure, and economic growth generates heterogeneous environmental outcomes across countries. These findings highlight the need to expand renewable energy, strengthen environmental policies, and integrate sustainability into trade and development strategies.

4. DISCUSSION

Compared to previous studies conducted globally, our results highlight the particular importance of renewable energy in Africa. The negative long-run

impact of renewable energy consumption on CO₂ emissions confirms that expanding clean energy is crucial for reducing environmental degradation. This finding is consistent with Apergis and Payne (2010) and Dada et al. (2024), who also found that renewable energy mitigates emissions. However, unlike studies in other regions, our analysis emphasizes Africa's largely untapped solar and wind potential, underscoring the relevance of renewable energy expansion.

In line with global EKC findings but with regional contrasts, the positive relationship between GDP per capita and emissions suggests that most African countries have not yet reached the EKC turning point. While Grossman and Krueger (1991) and Saboori et al. (2016) documented similar trends worldwide, our results reveal that Africa remains heavily dependent on fossil-based industrialization, unlike developed regions, where growth increasingly decouples from emissions. These findings align with Prempeh (2024) and UNEP (2011), who highlighted delayed environmental improvements due to structural and industrial constraints.

Globalization's environmental impact in Africa shows both similarities and differences with prior research. Our PMG estimates indicate a long-run positive effect on CO₂ emissions, consistent with the "pollution haven" hypothesis reported by Cole (2004) and Shahbaz et al. (2015). Short-term effects, however, suggest potential environmental benefits through technology transfer and efficiency gains, echoing Le et al. (2016) and Saidi and Hammami (2015). In contrast to other regions where globalization primarily increases emissions, our results emphasize that institutional quality and policy frameworks strongly shape its environmental effects in Africa.

Regional cooperation emerges as a uniquely important strategy for Africa, complementing prior evidence by Bekun et al. (2021). Our findings suggest that harmonized policies, technology diffusion, and shared investment in renewable energy infrastructure are crucial. While existing studies have often focused on single-country analyses, our multi-country PMG-ARDL approach high-

lights dynamic interconnections across African nations. Methodological limitations remain, particularly regarding causality and disaggregation of globalization dimensions. Future research using instrumental variables or GMM approaches could strengthen causal inference and explore heterogeneous impacts across countries and income levels.

CONCLUSION

This study examined the short- and long-term relationships between globalization, economic growth, CO₂ emissions, and renewable and non-renewable energy use in 24 African countries over the period 1990–2021, applying the PMG-ARDL methodology to capture dynamic adjustment processes. The analysis confirms the EKC hypothesis in the African context and demonstrates a stable long-term equilibrium among the variables.

The results indicate that renewable energy consumption significantly reduces CO₂ emissions, whereas economic growth and globalization are associated with higher emissions. These findings suggest that African countries face an urgent need to promote renewable energy deployment and implement green growth strategies that reconcile economic development with environmental sustainability.

This study contributes region-specific evidence to the global sustainability debate and provides actionable insights for policymakers aiming to achieve the Sustainable Development Goals. Limitations include the inability of the PMG-ARDL framework to fully address endogeneity or establish strict causality, and the aggregated nature of the KOFGI index, which may mask the differential effects of economic, social, and political globalization. Future research should adopt methodologies capable of addressing endogeneity, such as panel instrumental-variable estimators, causal inference techniques, or structural models. Disaggregating globalization into its subcomponents would provide a more nuanced understanding of which dimensions drive environmental outcomes. Additionally, country- or income-level analyses could help uncover divergent trajectories within Africa and identify policy strategies tailored to specific structural and institutional contexts.

AUTHOR CONTRIBUTIONS

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