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THE IMPACT OF CLIMATE CHANGE ON ECONOMIC GROWTH IN DEVELOPING COUNTRIES: A PANEL ARDL ANALYSIS (2000-2022)

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ABSTRACT

This study investigates the impact of climate change on economic growth in developing countries using panel data covering the period from 2000 to 2022, the sample covers 49 developing countries, this study sourced data from World Development Indicators (WDI) database of the World Bank (2025). The study applies the Panel Autoregressive Distributed Lag (Panel ARDL) model with the Pooled Mean Group (PMG) estimator to examine both the short-run and long-run relationships between economic growth and selected climate-related variables, including carbon dioxide (CO_2) emissions, energy imports, and population growth. To ensure the appropriateness of the estimation technique, cross-sectional dependence and panel unit root tests were conducted prior to analysis. The findings indicate that CO_2 emissions and energy imports have positive and statistically significant effects on economic growth in the short run, suggesting that activities associated with high energy consumption and emissions contribute to temporary economic expansion in developing economies. Conversely, the long-run results show that CO_2 emissions, energy imports, and population growth exert statistically insignificant effects on economic growth, implying that these factors do not support sustainable long-term development. Furthermore, the error correction term is negative and statistically significant, indicating a rapid convergence toward long-run equilibrium after short-run disturbances. The study concludes that although climate-related factors may enhance economic performance in the short term, they are insufficient for sustaining long-term growth. Consequently, the study recommends that developing countries adopt cleaner energy alternatives, strengthen climate adaptation policies, and promote productivity-driven investments in order to achieve sustainable economic development.

Keywords: Climate Change, Economic Growth, Developing Countries

INTRODUCTION

Climate change has increasingly emerged as one of the most pressing global challenges of the twenty-first century, extending beyond environmental concerns to become a critical issue in economic development for both developed and developing nations. The objectives of this research are to analyze if short-term increases in temperature temporarily boost economic activity, to determine if rising temperatures and carbon emissions influence economic growth in long-term and to determine whether energy consumption and population growth significantly drive economic development in developing countries and the research questions guiding this study are as follows: can short-term increases in temperature temporarily boost economic activity? Do rising temperatures and carbon emissions influence economic growth in long-term? Are energy consumption and population growth significant drivers of economic development? The variables are selected because of the following reasons; GDP provides the measure of economic performance, CO_2 emissions represent environmental degradation and climate change intensity, energy imports capture energy dependence and production capacity, while population growth revealed demographic pressures affecting both economic output and environmental sustainability.

Over recent decades, rising global temperatures, changing weather patterns, and the increasing frequency of extreme climatic events have posed substantial threats to natural and human systems. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures have already risen by approximately 1.1°C above pre-industrial levels, with far-reaching implications for ecosystems, livelihoods, and economic productivity (IPCC, 2023). This reality highlights the growing recognition that climate change is not merely an environmental issue but also a structural constraint to sustainable development, particularly in developing economies (Sarkar, 2012; Adebayo, 2024; Chamma, 2024).

The economic consequences of climate change are especially severe in developing countries, many of which are characterized by structural vulnerabilities, limited adaptive capacity, and a heavy reliance on climate-sensitive sectors such as agriculture, energy, and natural resource extraction. Recent empirical studies indicate that climate change adversely affects agricultural productivity, disrupts energy supply systems, reduces labor efficiency, and damages critical infrastructure, thereby constraining economic growth (World Bank, 2025; UNEP, 2024). These adverse effects are largely driven by anthropogenic activities, including fossil fuel combustion, deforestation, and industrial emissions, which increase the concentration of greenhouse gases such as carbon dioxide (CO_2) in the atmosphere and intensify global warming (Kumar et al., 2021; Driga & Drigas, 2019). Consequently, climate change has become a major threat to food security, public health, and macroeconomic stability (Gitz et al., 2016).

Azhar et al., (2025) utilized a quantitative research approach combining causal-comparative and correlational analyses using panel data covering 50 developing countries from 2000 to 2023. Data were obtained from the World Bank Climate Change Knowledge Portal and the National Oceanic and Atmospheric Administration (NOAA). The analyses employed mean, standard deviation, and trend analysis techniques. The results demonstrated that climate change poses economic threats which extend past environmental problems to present financial challenges to Global Southern nations. The authors concluded that Climate change threatens developing economies with an actual and constantly worsening macroeconomic danger. Similarly, Zeb et al.,

(2025) used A Growth-at-Risk (GaR) approach to estimate the impact of climate-related factors; data were World Bank's World Development Indicators and the International Monetary Fund (IMF) databases covering from 1990-2023 and the sample covers 30 developing countries. The results suggested that the likelihood of severe economic downturns in economies that are emerging or developing was considerably increased by climate stressors. In conclusion the authors reiterated the urgency of integrating a climate risk factor within international cooperation processes, development planning, and macroeconomic policy settings. Rahman and Alam, (2022) adopted the environmental Kuznets curve (EKC) hypothesis in their study; data were sourced from the World Development Indicators (WDI), World Bank, using the sample of 17 developing countries from the year 1960-2020. In their study they used descriptive statistics to analyze the data. The obtained results reveal that energy consumption, economic growth, financial development, and international trade have adverse effects on the environment of the panel countries by increasing the CO2 emissions, whereas the square of economic growth reduces it. Furthermore, Francis and Adebayo (2024) used Panel Autoregressive Distributed Lag (ARDL) regression model, specifically the Pooled Mean Group (PMG) estimation, sourced data from the World Bank Development indicator and Carbon Dioxide Information Analysis Center. The data cover from the year 2000 to year 2020, results revealed that rising temperatures and carbon emissions negatively influence economic growth in the long term. More so, Aziz (2023) examines the impact of green innovation, sustainable economic growth, and carbon emission on public health issues, using a non-linear autoregressive distributed lagged approach, the results of government health spending confirm that higher health spending leads to a reduction in public health issues, where as a decrease in government health spending increases public health issues. The author concluded that the increase in green innovation helps to control public health issues. Li et al., (2022) used uses simultaneous equation and sys-GMM model to explore the dynamic nexus of innovation input, climate change, and energy-environment-growth, used the panel data of 35 countries from 2000 to 2019, which are from the World Bank and Penn World Table. The results indicated that the coefficient of capital per capita is positive in both tables, indicating that capital and wealth are conducive to the development of a green economy in any country. Further, Choji et al (2026) used a Panel Autoregressive Distributed Lag (ARDL) model and the Pooled Mean Group (PMG) estimator; using panel data from 2000–2022. The authors sourced data from World Development Indicators (WDI) database of the World Bank. Results indicate that carbon emissions and energy imports act as significant drivers of economic performance in the short run, reflecting a temporary reliance on emission-intensive activities. In conclusion the authors found that carbon emissions, energy imports, and population growth do not exert a statistically significant influence on GDP growth in either the short or long run. Similarly, Lar et al., (2026) investigates the impact of climate change on economic growth in African countries using panel data from the year 2000–2022. The analysis applies Panel Autoregressive Distributed Lag (Panel ARDL) model with the Pooled Mean Group (PMG) estimator, data were sourced from World Development Indicators (WDI) database of the World Bank (2025). The result suggests that short-run growth in the selected African countries often relies on industrial activities that increase emissions. However, this form of growth is not sustainable in the long term.

Huang et al., (2023) used quantile regressions (QR) and generalized method of moments (GMM) covering 26 developing countries, covering the period from 2001-2020. The authors analyze the data using unit root test, Results show that the environment is obtaining benefits because of tourism. CO2 emissions are rising because the per capita income, electricity consumption, and population are growing. In conclusion, the authors reaffirms the feasibility of sustainable development in low-income nations by incorporating environ mental factors into economic and tourism policy. Saleem and Smirnona, (2026) used Panel-Corrected Standard Errors (PCSE) approach within a Cobb-Douglas Climate production function, using 30 countries in developing countries from 1980 to 2021, data was sourced from the World Bank Data Indicator The results indicate that temperature increase is associated with a significant negative impact on agricultural production per capita across all regions, as observed in both linear and non-linear models. Biess, Gudmundsson, and Seneviratne (2026) used Earth System Models (ESMsand the Coupled Model Intercomparison Project phase 6 (CMIP6), sourced data from 1850 to 2014. The result indicates that as mean temperatures rise, even small additional warming in the tropics leads to more frequent exceedances of critical thresholds, resulting in substantial increases in the share of economic activity exposed to extreme heat. Lalthapersad-Pillay & Udjo, (2014) used Excel spreadsheet and exported to SPSS, source of data was from the World Bank (2010) and Food and Agricultural Organization (FAO) (2008) reports. The data were obtained for 46 developing countries. The results show that high-risk countries have elevated levels of poverty, that is, the proportion of people living on less than US $1 a day is above 33%, and agriculture contributes in excess of one-third to GDP. The authors concluded that combination of extremely high levels of poverty and geographic fragility in developing countries makes them especially vulnerable to climate-induced adversity and may jeopardize their future economic development. Konyeaso et al., (2022) employs a Cobb–Douglas production function of the Solow extension using Pooled Mean Group, Augmented Mean Group, and Dynamic OLS. The data is for 32 selected African countries from the period of 1996 to 2018. The result reveals renewable energy production to spur real growth in all the different categories confirming the imperativeness of renewable energy.

Conversely, Benhamed et al., (2023) employs a dynamic spatial panel data model to estimate the effects of climate change on economic growth. Using three main variants: (i) dynamic spatial Durbin model (DSDM), (ii) dynamic spatial autoregressive model (DSAR), and (iii) dynamic spatial error model (DSEM), using a balanced data set for 86 developed and developing countries from1980 to 2019. The data are extracted from the Climate Change Knowledge Portal of the World Bank. The result indicates that the indirect spillover effect of climate change is significant only in the long run. Finally, the direct effect of climate change exceeds indirect effects in the long run, resulting in a total effect ranging between 0.844 and 1.347. Alade et al., (2026) adopts an ex post facto research design based on a measurable time-series approach to examine the impact of climate change on agricultural productivity in Nigeria from 2010 to 2023, and its subsequent implications for national economic growth. Using secondary annual data from NiMet, the National Bureau of Statistics, the Central Bank of Nigeria and FAO, results show that rising average temperatures and more frequent extreme weather events have a statistically significant negative effect on agricultural productivity, while well-distributed rainfall supports output. The authors concluded that Future research should exploit separated, farm level and spatial data to examine regional differences across Nigeria's agro-ecological zones, explore crop- and livestock specific impacts, and evaluate the effectiveness and cost effectiveness of concrete adaptation measures.

Most empirical studies focus on only one aspect of climate change, such as agricultural productivity, food security, or carbon emissions, without linking these issues to overall economic growth. Although many studies have examined the relationship between climate change and economic growth, their findings are still mixed and sometimes unclear. Some studies show that climate change negatively affects economic performance, while others suggest that the effects differ across regions, income levels, and time periods (Adusei, 2023; Bekele, 2025). In addition, many studies do not clearly explain the short-run and long-run effects of climate change, making it difficult to fully understand its impact over time.

To address these gaps, this study provides updated evidence on the relationship between climate change and economic growth by examining both short-run and long-run effects. It contributes to the literature by improving understanding of how climate change affects economic growth in developing countries over time. The study also provides useful policy recommendations that can help governments design effective climate adaptation and mitigation strategies to support sustainable development.

Therefore, this study examines the impact of climate change on economic growth from 2000 to 2022 using the Panel Autoregressive Distributed Lag (Panel ARDL) model. The Panel ARDL approach is suitable because it captures both short-run and long-run relationships while accounting for differences across developing countries. The study focuses on climate-related variables such as temperature and carbon dioxide (CO_2) emissions, together with control variables like energy imports and population growth, to evaluate their effects on economic performance.

MATERIALS AND METHODS

Pane data covering from 2000 to 2022 for some selected developing countries (Algeria, Angola, Armenia, Bahrain, Bangladesh, Belarus, Benin, Bolivia, Bulgaria, Cameroon, Chad, Chile, Colombia, Congo, Dem. Rep., Congo, Rep., Costa Rica, Cote d'Ivoire, Croatia, Ecuador, Egypt, Arab Rep., Equatorial Guinea, Gabon, Georgia, Ghana, Greece, Hungary, Jordan, Kenya, Latvia, Mongolia, Niger, Nigeria, Oman, Panama, Paraguay, Rwanda, Senegal, Slovak Republic, South Africa, Sri Lanka, Uganda, Uruguay, Zimbabwe and Zambia) were used for this study. Panel data were considered appropriate for this study because they combine both time-series and cross-sectional data, thereby enabling more effective control of heterogeneity across developing countries. Prior to estimation, the collected data were screened for completeness, consistency, and accuracy. Missing observation were carefully examined and addressed. To ensure the validity and reliability of the results, Descriptive statistics were employed to summarize the characteristics of the data. Correlation analysis was performed to assess the degree of association among variables and detect potential multicollinearity issues. Panel unit root tests were conducted to determine the stationarity properties of the variables.

This study sourced data from World Development Indicators (WDI) database of the World Bank (2025). The variables include Carbon dioxide emissions (CO2), Energy Imports (EI) and Population Growth (PG) as the independent variables. Gross Domestic Product (GDP) was used as the dependent variable; the study adopts the Panel Autoregressive Distributed Lag (Panel ARDL) approach using the Pooled Mean Group (PMG) estimator developed by Pesaran, Shin, and Smith (1999). The Panel ARDL technique is appropriate because it allows for a mixture of variables integrated at level I(0) and first difference I(1), while simultaneously estimating short run dynamics and long-run equilibrium relationships.

The functional relationship between dependent variable (GDP) and independent variables (CO2, EI and PG) is expressed as:

$$GDP = f(CO_2, EI, PG) \qquad (1)$$

This indicates that economic growth depends on carbon emissions, energy imports, and population growth

The long-run relationship is specified as:

$$GDP_{it} = \alpha_i + \beta_1 CO_{2_{it}} + \beta_2 EI_{it} + \beta_3 PG_{it} + \varepsilon_{it} \qquad (2)$$

Where;

GDP_{it}: represents economic growth in country i at time t

α_i : is the country-specific intercept.

$\beta_i and \beta_j$: are the long-run coefficients.

ε_{it} : Error term.

The short-run dynamics and speed of adjustment to long-run equilibrium are captured using the error correction representation:

$$\Delta GDP_{it} = \varphi_i\left(GDP_{it-1} - \beta_1 CO_{2_{it-1}} - \beta_2 EI_{it-1} - \beta_3 PG_{it-1}\right) + \sum \lambda_i \Delta GDP_{it-1} + \sum \delta_{1i} \Delta CO_{2,it} + \sum \delta_{2i} \Delta EI_{it} + \sum \delta_{3i} \Delta PG_{it} + \mu_{it} \qquad (3)$$

Where;

Δ: denotes first difference

φ_i: is the error correction coefficient indicating the speed of adjustment to long-run equilibrium.

$\lambda_i and \delta_i$: represent short-run coefficients.

μ_{it} : is the error term

RESULTS AND DISCUSSION

Results

This section presents the analysis and interpretation of results for the study covering the period 2000–2022. It includes descriptive statistics, tests of assumptions, model estimation using the Panel Autoregressive Distributed Lag (Panel ARDL) Pooled Mean Group (PMG) estimator, hypothesis testing, discussion of findings, conclusion, limitations, and suggestions for future research.

Table 1: Descriptive Statistics

	CO2	EI	GDP	PG
Mean	264.8811	-85.28659	4.082958	1.723751
Median	70.84856	9.322581	4.300029	1.715724
Maximum	9937.131	203.1348	63.37988	21.70034
Minimum	-89.58432	-3300.147	-28.75858	-10.92744
Std. Dev.	1041.066	290.5870	5.295622	2.065050
Observations	1127	1103	1123	1127

Table 1 shows the descriptive statistics for CO_2 emissions, energy imports (EI), GDP growth, and population growth (PG). CO_2 emissions have the highest standard deviation 1041.066 indicating large differences in emissions among countries.

Table 2: Cross-Sectionality Test Summary

Variable	Pesaran Statistic	Prob.
GDP	46.35188	< 0.05
PG	16.55896	< 0.05
CO2	44.58535	< 0.05
EI	8.263189	< 0.05

Table 3: Stationary Result

Variable	Level	after 1st diff.	Order
GDP	< 0.05	..	I(0)
PG	< 0.05	..	I(1)
CO2	1.0	< 0.05	I(1)
EI	0.7625	< 0.05	I(1)

Test to confirm the presence of cross-sectionality (Table 2) was carried out on the panel variables to determine which unit root test is best. The result from the test provided sufficient evidence supporting the use of the Pesaran unit root test.
The stationarity test was carried out using Pesaran test to determine the order of integration of each variable. Table 3 shows that GDP and PG are stationary at level, I(0), while CO_2 emissions, and energy imports (EI) both become .
stationary after first differencing, However, there is inconsistency regarding population growth (PG), as the table reports PG as stationary at level with a probability less than 0.05, but simultaneously classifies it as I(1). The mixture of I(0) and I(1) variables justifies the use of the Panel ARDL estimation technique, which accommodates different integration orders without losing model validity

Table 4: Correlation Matrix

	CO2	EI	GDP	PG
CO2	1.0	-0.531440	0.093238	0.236080
EI	-0.531440	1.0	-0.221196	-0.382853
GDP	0.093238	-0.221196	1.0	0.232160
PG	0.236080	-0.382853	0.232160	1.0

The results in Table 4 indicate that carbon dioxide emissions (CO_2) and GDP have a weak positive correlation ($r = 0.093238$), suggesting that economic growth in developing countries is marginally associated with rising emissions. Energy imports (EI) show a weak negative correlation with GDP ($r = -0.221196$), implying that inefficient energy use may suppress growth. Population growth (PG) shows a weak positive relationship with GDP ($r = 0.232160$), indicating that population expansion marginally contributes to economic output in some developing nations The correlation coefficients are all below 0.8, indicating no multicollinearity. Thus, all variables can be included in the regression model.

Table 5: Short-Run Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ01 (ECM)	-1.072524	0.058302	-18.39604	< 0.05
D(IHS_CO_2)	5.042884	1.122172	4.493862	< 0.05
D(IHS_EI)	0.446294	0.614534	0.726231	0.4679
D(IHS_PG)	0.626258	1.798302	0.348250	0.7278
C	-4.406678	6.077405	-0.725092	< 0.05

The results in Table 5 indicate that only CO_2 emission has a statistically significant effect ($p = < 0.05$) on the GDP of the selected developing countries in the short run. Although all the variables, CO_2, EI, and PG, have a positive effect, on carbon emissions effect is significant. The error correction term (COINTEQ (-1.072524)) is negative and significant, confirming stability and that short-run deviations from equilibrium are instantly corrected at a speed of 107% each period.

Table 6: Long-Run Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
IHS_CO_2	1.555857	2.43E+10	6.40E-11	1.0000
IHS_EI	-7.915064	6.77E+10	-1.17E-13	1.0000
IHS_PG	12.45904	1.40E+10	8.91E-11	1.0000

The long-run results in Table 6 show that CO_2 emissions, energy intensity, and population growth are all statistically insignificant ($p = 1.000$). This implies that climate-related variables do not sustain economic growth in the long term. Although a ‘P’ value equal to 1 ($p = 1.00$) is acceptable technically, it raises suspicion because it is extreme statistically. This result is most likely due high standard errors.

Goodness-of-Fit Statistics (Model Fit)

Table 7: Model Fit

Statistics	Value
Log Likelihood	-1546.144
AIC	4.608514
SIC	6.454329
HQ	5.317218

Automatic selection was used in selecting the best model, and the selected model is ARDL (2, 1, 1, 1). This indicates that ARDL (2, 1, 1, 1,) provided the best fit among other models.
The Pesaran Cross-Sectional Dependence test revealed significant cross-sectional dependence among all variables ($p < 0.05$). This implies that economic and environmental shocks affecting one developing country may spill over to other countries in the sample. Consequently, the use of second-generation panel unit root tests such as the Pesaran CIPS test is justified. To assess the robustness of the findings, a lag-length sensitivity analysis was conducted by comparing the preferred ARDL (2, 1, 1, 1) model with an alternative ARDL (1, 1, 1, 1) specification.

Short-run Error Correction Model:

$$\Delta GDP_{it} = -4.406678 + 5.042884\Delta CO_{2\,it} + 0.446294\,\Delta EI_{it} + 0.626258\Delta PG_{it} - 1.072524COINTEQ01_{i,t-1} + \varepsilon_{it} \quad (4)$$

Long-run Equation:

$$GDP_{it} = 1.555857CO_{2\,it} - 7.915064EI_{it} + 12.45904PG_{it} + u_{it} \quad (5)$$

Discussion

The results from the Panel ARDL model (Tables 5 & 6), show how carbon dioxide emissions (CO_2), energy imports (EI), and population growth (PG) affect economic growth in both the short run and the long run. The error correction term (-1.072524, p = <0.05) is negative and significant, meaning that any short-term shift between the variables is corrected immediately, indicating stability among the variables in the long-run.
In the short run, although all the variables have a positive influence, only carbon emission (CO2) is statistically significant ($p < 0.05$). While in the long run, CO_2, EI, and PG still remain statistically insignificant ($p = 1.000$). This means these variables do not have a lasting impact on GDP over time.
The results in Tables 2 and 3 show that the error correction term is negative and significant, which means that a long-run relationship exists among the tested variables. However, the long-run results have extremely large standard errors (e.g., 2.43E+10 and 6.77E+10), which leads to p-values of exactly 1.0000.
In simple terms, the model could not estimate the long-run effects clearly, so the p-values turned out to be 1.0000, not because there is no relationship, but because the estimates are too imprecise.
The findings of this study are broadly consistent with previous empirical evidence that climate change poses significant challenges to economic growth in developing countries. The result that carbon emissions support economic growth in the short run but are unsustainable in the long run aligns with the findings of Francis and Adebayo (2024), Lar et al. (2026), and Saleem and Smirnova (2026), who reported that climate-related factors such as rising temperatures and emissions negatively affect long-term economic performance. Similarly, the study supports the conclusions of Azhar et al. (2025) and Zeb et al. (2025), who found that climate change constitutes a growing macroeconomic risk capable of increasing the likelihood of economic downturns in developing economies. The findings also complement those of Lalthapersad-Pillay and Udjo (2014), which emphasized that developing countries are particularly vulnerable to climate-related shocks because of poverty and dependence on climate-sensitive sectors.
However, the findings differ from those of Choji et al. (2026), who reported that carbon emissions, energy imports, and population growth were not statistically significant determinants of economic growth in either the short or long run. This divergence may be attributed to differences in sample composition, estimation techniques, model specifications, or regional characteristics. Furthermore, while Li et al. (2022) highlighted the positive role of innovation and capital accumulation in promoting a green economy, the current findings suggest that many developing countries still rely heavily on emission-intensive activities to sustain growth, indicating that the transition to green growth remains incomplete.
The findings imply that policymakers in developing countries should reduce reliance on carbon-intensive growth strategies by accelerating investments in renewable energy, green technologies, and climate-resilient infrastructure.

CONCLUSION

This study examined the relationship between economic growth, carbon dioxide emissions, energy imports, and population growth in 49 selected developing countries from 2000 to 2022 using the Panel ARDL (PMG) model. The results showed that of all the tested variables (CO_2, EI, and PG), only CO_2 has a statistically significant effect on the GDP growth of the selected developing countries in the short run. The negative and significant Error Correction Term (ECT) confirms long run stability in the variables after any short term deviation.
The findings of this study carry important policy recommendations for developing economies: Policymakers should recognize that growth driven by carbon emissions and energy imports is short-lived. Long-term economic strategies must move away from fossil-fuel-dependent growth toward cleaner and more resilient economic models, since energy imports boost short-term growth but fail to sustain long-term development, governments should prioritize domestic renewable energy sources such as solar, wind, and hydropower to improve energy security and economic stability, development plans should integrate climate adaptation strategies into agriculture, infrastructure, and industrial policy to prevent climate shocks from eroding growth gains, the insignificance of population growth highlights the need to focus on education, skills development,

and employment generation to convert population growth into productive economic output and developing countries should leverage international climate finance to fund adaptation and mitigation projects while strengthening institutions to improve policy implementation and governance. This study has several limitations, which are: Some variables, such as CO_2 emissions and energy imports, show large variations across countries, which may affect the accuracy and comparability of the results, the PMG model assumes that the long-run relationship is the same across all countries, which may not fully reflect real-world diversity among economies, important variables such as technological advancement, institutional quality, renewable energy use, and industrial structure were not included in the analysis, even though they could significantly influence economic growth and environmental outcomes and differences in data reporting standards or measurement errors, especially for CO_2 emissions, may have affected the reliability of the results.

To build on the findings of this research, future studies are encouraged to consider the following: add renewable energy use, technological innovation, and environmental regulation indicators to better capture the transition to sustainable development, employ models such as the Mean Group (MG), Dynamic System GMM, or Common Correlated Effects Mean Group (CCEMG) to handle heterogeneity and endogeneity issues across countries, conduct studies focusing on particular regions (e.g., Sub-Saharan Africa, South Asia) or individual countries to obtain more context-specific policy insights and use updated and more reliable datasets that minimize measurement errors and better capture recent changes in energy policy and economic structure.

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