



EXAMINING THE IMPACT OF CLIMATE CHANGE ON ECONOMIC GROWTH IN WEST AFRICA: EVIDENCE FROM A PANEL AUTOREGRESSIVE DISTRIBUTED LAG MODEL

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ABSTRACT

This study utilizes panel data from 2000–2022 to examine the nexus between climate change and economic growth in West Africa, employing a Panel Autoregressive Distributed Lag (ARDL) model and the Pooled Mean Group (PMG) estimator. After confirming the model's validity through cross-sectional dependence and unit root tests, the empirical 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. However, these factors, along with population growth, become statistically insignificant in the long run, suggesting that current growth models are unsustainable. With a highly significant error correction term indicating a swift return to equilibrium after shocks, the findings highlight a critical need for West African policymakers to shift toward renewable energy, enhance climate adaptation, and invest in productivity-led development to ensure durable, long-term economic stability.

Keywords: Autoregressive Distributed Lag (ARDL), Pooled Mean Group (PMG), Climate Change, Economic Growth

INTRODUCTION

Climate change is a formidable problem in contemporary society, demanding a more comprehensive examination of the intricate dynamics between economic development and ecological preservation. Historically, the process of economic growth has been marked by a rise in carbon-dioxide (CO₂) emissions, which is closely linked to rising industry, urbanization, and energy consumption (Smith, 2015). West Africa is known to be particularly vulnerable to climate change due to high climate variability, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change. West Africa is nowadays experiencing a rapid climate change, characterized by a widespread warming, a recovery of the monsoonal precipitation, and an increase in the occurrence of climate extremes. The observed climate tendencies are also projected to continue in the twenty-first century under moderate and high emission scenarios, although large uncertainties still affect simulations of the future West African climate, especially regarding the summer precipitation.

Climate change refers to long term shifts in temperature and weather patterns, which can be due to changes in the sun's activity, but primarily driven by human activities like the burning of fossil fuels like coal, oil and gas and also by deforestation and industrial emissions (Kumar et al., 2021). Mean annual rainfall has decreased in West Africa since the 1960s, while southern and eastern Africa has become more drought-prone. One-third of Africans now live in drought-prone areas, especially in the Sahel, around the horn of Africa and in southern Africa (PACJA, 2009). The estimates show that 1989 to 2019 was the warmest 30-year period in more than 800 years; the most recent decade, 2010-2019, is the warmest decade in the instrumental record so far (National Academy of Sciences, & The Royal Society, 2020).

This study sees the need for comprehensive adaptation approach that deal with both the short-term and long-term challenges caused by climate change, employing the Panel Autoregressive Distributed Lag (ARDL) model with Pooled Mean Group (PMG) estimator, to investigate the economic

consequences of climate change in West African countries in both the short-run and long-run dynamics of climate change in West African countries.

Many studies have been carried out in this area; some of the studies are, Agaev & Ogunnusi, (2022) adopted the panel ARDL method in estimating the influence of economic growth indicators on carbon-dioxide emission in some selected West African countries between 1990-2021. The authors adopted the Augmented Dickey Fuller -Fisher Chi-square and Philips Peron-Fisher Chi-square was used to test the variables for unit roots in order to confirm the suitability of the dynamic models under study. The result of their study suggest that alterations in GDP, availability of power, availability of gas, rural population, and urban population have lasting effects on carbon dioxide emissions in West African nations. The authors concluded that the recognition of enduring associations between CO₂ emissions and the independent variables underscores the need of considering these aspects jointly in the development of policies. Furthermore, Belford et al., (2020) analyzed the impacts of climate change on economic growth in Anglophone West Africa for the periods 1969-2016. Data were sourced from the World Development Indicator. Panel data estimations such as the fixed effect model, random effect model and Hausman test were used. The result show that in Anglophone West African countries, the growth rate of the agriculture sector and temperature are statistically significant (0.008 ** and 0.089*) and have a negative impact (-2.04 and -17.7) on the growth rate of GDP. The results generated shows that the agriculture sector is affected negatively by rainfall. The authors concluded that the research attempts to explain the impact of climate change on economic growth in Anglophone West African countries with similar CO₂ emission per capita and vulnerability to climate change. On the other hand, N'Zué, (2018) determine the impact of climate change on Cote d'Ivoire's economic performance via per capita gross domestic product (GDP) growth, change in agricultural value added, and change in the country's cereal yield. The data are obtained from the World Development Indicators of the World Bank (2017). The data ranged from 1960 to 2016. An

autoregressive distributed lag (ARDL) model is used to investigate the long run dynamics between climate variables (precipitation and temperature) and the country's per capita GDP, agricultural value added as % of GDP, and cereal yield. The result shows that climate change has not significantly impacted the economic performance of the country. More so, Tahtane, (2022) investigated the effect of climate change on both short and long-run economic growth in Africa using a panel of 34 selected African countries for the period of 1971–2019. Data is obtained from the world development indicators (WB-WDI). Used the cross-sectionally augmented autoregressive distributed lag (CS ARDL) and the cross-sectionally augmented distributed lag (CS-DL) approaches. The author finds that climate change is negatively associated with economic growth. Twerefou et al., (2018) The study employs the Solow (1956) and Swan (1956) growth model, and data on total energy consumption, electricity consumption and petroleum consumption to establish the causal relationship between energy consumption and economic growth for the seventeen countries in the West African sub region. The results indicate that in the short run, there is no causal relationship running from total energy, electricity and petroleum consumption to growth. The results indicate that in the long run, petroleum and electricity consumption has a statistically significant and positive impact on growth while total energy consumption had a statistically significant negative relationship with economic growth. On the other hand, Radoine et al., (2022) adopted the method of Driscoll Kraay (DK) panel regression. Covering the period 1991–2018, the data was sourced from the World Development Indicators (WDI) (2020), while data on renewable energy was collected from International Energy Agency (IEA) website. The panel result suggests that manufacturing value-added, urbanization, financial development, and foreign direct investment increase environmental degradation. In addition, the findings of their study revealed that economic growth and renewable energy consumption contribute, significantly, to environmental quality. Furthermore, Ceesay et al., (2020) used panel data estimation such as GMM, fixed effect and random effect models. Data were sourced from World Development Indicators, covering from 1969–2016, 13 selected West African countries. The result shows that, economic growth has a negative and highly significant effect on the growth of poverty in the selected West African countries. Abid et al., (2023) used the pooled mean group (PMG)-autoregressive distributed lag (ARDL) panel model, data were sourced from the World Bank, World Development Indicators (WDI, 2021), International Country Risk Guide and International Energy Agency. Over the period 1990–2018, the results revealed that there is a positive and significant impact of trade on CO₂ emissions in the long term. Emediegwu et al. (2022) used spatial panel data to investigate the impacts of climate change on agricultural productivity. Data were sourced from the World Bank's World Development Indicators (WDI), FAO agricultural statistics, and climate datasets (1991–2018). A spatial panel econometric approach was employed. Similarly, Benhamed et al. (2023) examined the spatial effects of climate change on economic growth using an international panel dataset derived from the World Bank, IMF, and climate databases from 1990–2019. The study adopted a dynamic Spatial Durbin Model (SDM) to account for both direct and indirect climate impacts. Empirical results indicated that climate variables significantly affect economic growth in developing economies. (Benhamed et al., 2023). In a similar vein, Espoir and Sunge (2021) used a dynamic spatial panel model. Data were obtained from the World Bank and emission databases which covers from 1990–

2018. The findings revealed significant spatial spillover effects of emissions on economic development across neighboring countries. On the other hand, Jeetoo et al. (2023) examined the Environmental Kuznets Curve (EKC) hypothesis in the context of climate change using a spatial panel framework. Data were sourced from global development and climate databases from 1990–2019. The findings confirmed the EKC hypothesis once spatial dependence was incorporated. The authors concluded that environmental policies should account for cross-country spillover effects to be effective. On the contrary, Adesete et al. (2023) explored the effects of climate change on food security in Sub-Saharan Africa using panel data from FAO and the World Bank covering from 1995–2020. Employing the System-GMM estimator, the study found that rising temperatures worsen food insecurity, while climate adaptation investments help mitigate these adverse effects. The authors concluded that strengthening adaptive capacity is essential for achieving food security in developing regions (Adesete et al., 2023). Suproń et al. (2024) examined the climate–energy–growth using panel data from the Three Seas Initiative region from 1995–2020, Employing System-GMM. (Suproń et al., 2024). In the study of Okeke and Ogbuabor (2024) they investigated the relationship between climate change and poverty dynamics in developing economies using panel data and the System-GMM approach. The authors concluded that pro-poor and climate-resilient policies are essential for reducing vulnerability. Farajzadeh (2023) examined the impact of climate change on economic growth using cross-country panel econometric techniques. Data were sourced from the World Bank and climate datasets data coverage: 1990–2018. The results showed that climate variables exert a significant negative influence on economic growth. The study concluded that effective climate mitigation policies are necessary for sustained economic development. Also Agan (2025) used multi-country panel data and System-GMM estimation from 2000–2022 to analyze the dynamic impacts of climate change and adaptation on economic growth. The results showed that adaptation expenditure significantly reduces climate-induced growth losses. The study concluded that adaptation investment plays a crucial role in sustaining long-run economic growth. Kadanali (2020) analyzed the long-run effects of climate change on economic growth using global panel data from the World Bank covering from 1960–2017. Panel co-integration and panel ARDL methods were employed. The results indicated a statistically significant negative long-run relationship between climate change and economic growth. The study concluded that long-term growth prospects depend heavily on climate adaptation strategies. Mubenga-Tshitaka (2024) analyzed climate variability and agricultural productivity in East Africa using panel data sourced from FAO, World Bank, and regional meteorological agencies covering the year 1961–2020. A dynamic panel threshold model estimated via System-GMM was employed. The results indicated that climate variability significantly reduces agricultural productivity. The author concluded that adaptation policies should focus on preventing economies from crossing critical climate change. Using heterogeneous panel estimators, Sequeira et al. (2018) analyzed the effects of climate change on economic growth across countries with varying income levels. Data were obtained from the World Bank and global climate sources (1960–2014). The results showed that climate change has a negative impact on economic growth, with more severe effects observed in low-income and developing countries. The authors concluded that climate change impacts are heterogeneous and that uniform

policy responses may be ineffective, underscoring the importance of country-specific climate strategies. Furthermore, Lar et al. (2026) investigates the impact of climate change on economic growth in African countries using panel data from the year 2000–2022. used Panel Autoregressive Distributed Lag (Panel ARDL) model with the Pooled Mean Group (PMG) estimator, to capture both short-run and long-run equilibrium relationships between economic growth and key climate-related variables. The data were sourced from the World Development Indicators (WDI) database of the World Bank (2025). The results show that only CO₂ emissions have a significant short-run positive effect on GDP growth, while their long-run effects are statistically insignificant. The authors concluded 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.

From the empirical review, some of the studies provided evidence of long-run climate effects but are mostly cross-regional or multi-country in scope. The previous studies hardly incorporate country-specific institutional and structural characteristics. Much of the empirical literature concentrates on single outcome variables such as agricultural productivity, food security, or carbon emissions.

To bridge existing gaps, this study make use of comprehensive data from 2000 to 2022 using Panel ARDL model with the Pooled Mean Group estimator to straighten out the short-run and long-run impacts of carbon dioxide emissions, energy imports, and population growth on GDP in West African Countries.

MATERIALS AND METHODS

Secondary panel data spanning from 2000-2022 for some selected West African countries (Benin, Cote d'Ivoire, Ghana, Niger, Nigeria and Senegal) were used for this study. The data used for this study were sourced from World Development Indicators (WDI) database of the World Bank. The variables include Carbon dioxide emissions (CO₂), Energy Imports (EI) and Population Growth (PG) as the independent variables. Gross Domestic Product (GDP) 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:

$$GDP = f(CO_2, EI, PG) \tag{1}$$

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

The long-run relationship is specified as:

$$GDP_{it} = \alpha_i + \beta_1 CO_{2it} + \beta_2 EI_{it} + \beta_3 PG_{it} + \varepsilon_{it} \tag{2}$$

Where;

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

α_i : is the country-specific intercept.

β_1 and β_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:

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

Where;

Δ : denotes first difference

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

λ_i and δ_i : represent short-run coefficients.

μ_{it} : is the error term

RESULTS AND DISCUSSION

Results

This chapter 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	295.4895	-19.92593	4.787441	2.715185
Median	203.4925	7.792110	4.896577	2.648564
Maximum	2059.330	72.00873	15.32916	3.773246
Minimum	8,192697	-323.2239	-5.370447	1.1920290
Std. Dev.	351.6274	101.7002	3.206639	0.456026
Observations	125	125	125	125

Table 1 shows the descriptive statistics for CO₂ emissions, energy imports (EI), GDP growth, and population growth (PG). CO₂ emissions have the highest standard deviation

(351.6274), indicating large differences in emissions among countries.

Table 2: Cross-sectionality Test Summary

Variable	Pesaran Statistic	Prob.
GDP	0.520661	0.6026
PG	3.641775	0.0003
CO2	16.31982	<0.05
EI	-2.653941	0.008

Table 3: Stationarity Result

Variable	Level	after 1 st diff.	Order
GDP	0.0031	..	I(0)
PG	0.8306	< 0.05	I(1)
CO2	1.0	0.0042	I(1)
EI	0.9719	< 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 for 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 alone is stationary at level, I(0), while CO₂ emissions, Population Growth (PG), and energy imports (EI) all become stationary after first differencing, 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	0.336434	0.051787	-0.013307
EI	0.336434	1.0	-0.151274	0.068118
GDP	0.051787	-0.151274	1.0	0.177252
PG	-0.013307	0.068118	0.177252	1.0

The results in Table 4 indicate that carbon dioxide emissions (CO₂) and GDP have a weak positive correlation (r = 0.051787), suggesting that economic growth in developing countries is marginally associated with rising emissions. Energy imports (EI) show a weak negative correlation with GDP (r = -0.151274), implying that inefficient energy use may suppress growth. Population growth (PG) shows a weak positive relationship with GDP (r = 0.177252), 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. The Panel ARDL model was used to estimate both the short-run and long-run relationships between the dependent variable (GDP) and the independent variables (CO₂, EI, and PG).

Table 5: Short-run Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ01 (ECM)	-1.017579	0.120389	-8.452446	< 0.05
D(CO ₂)	0.008534	0.022445	0.380230	0.7049
D(EI)	-0.106530	0.134987	-0.789191	0.4325
D(PG)	-4.505106	7.057066	-0.638383	0.5252

The results in Table 5 indicate that in the short run, although both CO₂ emission has a positive effect on GDP growth, CO₂ emissions still remains statistically insignificant (p = 0.7049). This suggests that CO₂, EI, and PG are all statistically insignificant and have no effect on GDP growth. The error

correction term (COINTEQ (-1)) is negative and significant, confirming stability and that short-run deviations from equilibrium are corrected instantly, at a speed of 102% each period.

Table 6: Long-run Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2	-0.001988	5.64E-09	-3.52E-13	1.0000
EI	0.032051	6.09E+10	-5.26E-13	1.0000
PG	-0.137028	7.15E+12	-1.92E-14	1.0000

The long-run results in Table 6 show that CO₂ 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.

Based on the estimation results, the final Panel ARDL model for the study is presented below, capturing both the short-run dynamics and long-run equilibrium relationships between climate change variables and economic growth.

Short-run Error Correction Model:

$$\Delta GDP_{it} = -1.017579COINTEQ01_{it-1} + 0.008534\Delta CO_{2it} - 0.106530\Delta EI_{it} - 0.137028\Delta PG_{it} + \varepsilon_{it} \quad (4)$$

Long-run Equation

$$GDP_{it} = -0.001988CO_{2it} + 0.032051EI_{it} - 0.137028PG_{it} + u_{it} \quad (5)$$

Discussion

The results from the Panel ARDL model (Tables 5 & 6), show how carbon dioxide emissions (CO₂), energy imports (EI), and population growth (PG) affect economic growth in both the short run and the long run. The error correction term (-1.017579, p = <0.05) is negative and significant, meaning that any short-term imbalance between the variables is immediately corrected indicating stability. In simple terms, the model returns to long-run stability immediately after a shock, confirming that the relationship among the variables is steady over time.

In the short run, although CO₂ emissions (0.008534) have a positive effect on economic growth, all the variables in the equation have an insignificant effect on GDP growth (p > 0.05). This finding reflects the experience of major West

African countries, where the effect of industrialization is not yet visible.

In the long run, CO₂, EI, and PG still remain statistically insignificant ($p = 1.000$). This means these variables do not have a lasting impact on GDP over time. This supports the idea that although West African countries have started to move into the industrialization era, its effects still remains to be seen in both the short-run and the long-run.

CONCLUSION

Utilizing a Panel ARDL (PMG) model to analyze West African data from 2000 to 2022, this study 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. Despite this lack of direct impact, the negative and significant error correction term confirms the model's stability and its capacity to revert to long-term equilibrium following temporary fluctuations. To expand upon these results, future research should incorporate broader indicators such as renewable energy adoption, technological innovation, and environmental policy to better track sustainable transitions. Additionally, researchers are encouraged to utilize alternative methodologies like Dynamic System GMM or CCEMG to better address country-level endogeneity and heterogeneity, while also shifting toward localized, country-specific analyses to provide more tailored policy recommendations.

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