Climate Adaptation, Regional Inequality and Sustainable Economic Growth in Nigeria

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Abstract. Climate change and persistent regional disparities continue to pose significant challenges to achieving sustainable economic growth in developing economies. While a growing body of research has examined the individual effects of climate change or inequality on economic performance, few studies have integrated climate adaptation, regional inequality, and sustainable economic growth within a single empirical framework for a developing, climate-vulnerable economy such as Nigeria. This study addresses that gap by examining the relationship among these three dimensions over the period 1990–2024. The data were obtained from the World Bank's World Development Indicators, the Worldwide Governance Indicators, and reports of the Nigerian Climate Change Commission, and the analysis is grounded in Endogenous Growth Theory and Climate Justice Theory. The Autoregressive Distributed Lag (ARDL) bounds-testing technique was employed to estimate the short-run and long-run relationships among the variables, owing to its suitability for the time-series properties of the data. To ensure comparability, the climate adaptation and spatial inequality indices were standardised using z-score transformation prior to estimation. The empirical findings indicate that climate adaptation, governance quality, and trade openness exert positive and statistically significant effects on sustainable economic growth, with the long-run effect of climate adaptation (0.62) exceeding its short-run effect (0.28), confirming that sustained adaptive capacity yields cumulative benefits. Conversely, regional inequality and carbon emissions exert significant negative effects, with the adverse influence of inequality intensifying over the long run (−1.88). The positive coefficients on GDP per capita and its squared term further indicate that Nigeria has not yet reached the turning point of the Environmental Kuznets Curve. These findings suggest that strengthening adaptive capacity, alongside deliberate efforts to reduce regional inequality, is essential for advancing sustainable economic growth. The study accordingly recommends greater investment in climate-resilient infrastructure, renewable energy development, and balanced regional development to promote inclusive and sustained growth, in line with SDGs 8, 10, and 13.

Keywords: Climate Adaptation, Regional Inequality, Sustainable Economic Growth, Governance Quality, Carbon Emissions, Nigeria.

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INTRODUCTION

One major policy objective for virtually all countries worldwide, especially amid growing climate change and widening socio-economic inequality, is sustainable economic growth. Global economies have increasingly experienced rising temperatures, frequent extreme weather events including floods, droughts and desertification and widespread environmental degradation. These climate-induced conditions have raised growing concerns about countries' capacity to sustain economic growth while maintaining environmental integrity, social cohesion and long-term development. Consequently, the concept of sustainable economic growth (SEG) has evolved beyond the conventional emphasis on increases in gross domestic product to encompass economic resilience, environmental stewardship, social inclusion and the welfare of both present and future generations (Kahn et al., 2021). The policy mechanism, therefore, for protecting economies against climate vulnerabilities while ensuring sustainable economic growth is climate adaptation.

Globally, climate change has a major impact on economic systems through labour inefficiency, rising healthcare costs, reduced agricultural productivity, infrastructure destruction and disruptions to productive activities. These effects are more pronounced in developing economies due to inadequate infrastructure, institutional weakness, limited adaptive capacity and greater exposure to climate risks and their associated consequences (Kahn et al., 2021). The negative effects of climate change are also not equally distributed. Regions that are not economically buoyant are usually exposed to greater climate risks, with little financial and institutional resources to adapt effectively.

Similarly, regional inequality further shows that the consequences of climate change and adaptation are spatially uneven. Empirical evidence shows that rural communities, low-income regions and vulnerable populations are disproportionately affected by environmental threats due to low levels of technology, limited access to healthcare facilities, inadequate infrastructure and insufficient social protection (Fiack et al., 2021). Climate adaptation investments are commonly concentrated in the urban centres in many developing nations. This further worsens and widens the developmental gaps among the regions. Araos et al. (2021) further argued that equity considerations are mostly missing in many climate adaptation frameworks. As a result, adaptation benefits are usually distributed unequally across social and geographical groups. Therefore, implementing different adaptation strategies simultaneously is needed to achieve the desired result.

In the same vein, inequality itself has a great impact on adaptation effectiveness and sustainable economic growth. Antoci et al. (2022) opined that resource ownership, institutional access and income disparities can worsen environmental degradation and reduce resilience. Also, Marrero and Serven (2022) argued that persistent inequality can constrain inclusive economic growth by limiting human capital development, productive investment and broad-based participation in economic activities. By implication, SEG cannot be achieved through climate adaptation policies alone, as regional disparities must also be addressed more broadly.

In the Nigerian context, this consideration is particularly important because the economy remains largely dependent on climate-sensitive sectors, thereby increasing its vulnerability to climate-related shocks and environmental variability. The nation experiences coastal erosion, desertification, flooding, rising temperatures, irregular rainfall, etc.; all of these threaten food security, livelihoods, infrastructural development and economic productivity. The nation is also characterised by significant regional inequalities in income, educational opportunities and institutional capacity. For instance, the northern part of Nigeria experiences desertification and drought, while those in the west face the challenges of flooding and erosion. These observable disparities intensify vulnerability to climate change shocks and confound the achievement of sustainable economic growth.

In addition, urbanisation, population growth and weak institutions are among the factors that strengthen exposure to climate-related shocks in different parts of Nigeria. In the opinion of Langnel et al. (2021), growing inequality and weak environmental management play a dominant role in unsustainable resource exploitation and reduced resilience. Furthermore, Dodson et al. (2022) argued that weak climate policy effectiveness is often the result of policymakers' inability to integrate demographic pressures into climate adaptation agendas. In Nigeria, therefore, climate adaptation policies are mostly sector-specific and poorly coordinated. This limits their ability to adequately address regional inequality, environmental risks and sustainable growth objectives.

Empirical studies have therefore recently called for combined and flexible climate adaptation policies that build resilience and promote inclusive development (Tudose et al., 2021; Kim et al., 2022; Bartelet et al., 2022). Nevertheless, despite the international attention given to climate adaptation and sustainable development, empirical evidence on the interaction among climate adaptation, regional inequality and sustainable economic growth remains scarce. Most available empirical studies examine these variables independently, without considering their mutual and interconnected relationships. This study bridges that gap by examining the relationship among climate adaptation, regional inequality and sustainable economic growth in Nigeria.

LITERATURE REVIEW

Conceptual Review

SEG has increasingly been understood as a process of long-term economic expansion that is achieved alongside the preservation of environmental quality, the promotion of social equity and the protection of future generations (Cai, 2025; Tavares et al., 2025). As a result, the concept extends beyond the traditional emphasis on gross domestic product by incorporating environmental sustainability, institutional effectiveness, resource efficiency and the capacity of economies to withstand growing climate-related pressures (Elfaki & Ahmed, 2024; Haciimamoglu et al, 2025). Recent studies have further characterised SEG as a development process supported by innovation, progress towards the Sustainable Development Goals (SDGs) and resilience to climate-related disturbances, while ensuring that the benefits of growth are broadly shared across regions and segments of society (Li et al., 2025; Yang et al., 2023). Conversely, economic growth cannot be regarded as sustainable where environmental degradation, welfare losses or widening inequalities accompany economic expansion under conditions of climate stress (Dasgupta et al., 2023; Khan et al., 2024)

Within this context, climate adaptation has been recognised as an important mechanism through which SEG can be supported. It has been described as a combination of behavioural responses and structural adjustments undertaken by households, firms and institutions to reduce vulnerability to climate-related risks (Bartelet et al., 2022). Where adaptation strategies are poorly designed, environmental pressures may be intensified, and existing socioeconomic inequalities may be further reinforced, thereby limiting their contribution to sustainable development (Antoci et al., 2022)

Equity remains a fundamental consideration in understanding the relationship among climate adaptation, regional inequality, and sustainable economic growth. This perspective is largely informed by climate justice theory, which regards the equitable distribution of climate-related risks and benefits, together with inclusive participation in decision-making processes, as essential to achieving sustainable development outcomes (Araos et al., 2021; Fiack et al., 2021). In addition, systems thinking provides a complementary perspective by recognising that climate risks, infrastructure, institutions, and socioeconomic conditions operate as interconnected components whose interactions collectively influence development outcomes.

In the Nigerian context, where climate vulnerability and regional disparities remain pronounced, achieving sustainable economic growth is expected to depend largely on adopting inclusive adaptation measures, equitably allocating development resources and strengthening governance systems capable of supporting long-term climate resilience.

Theoretical Review

This study's theoretical foundation rests on two complementary frameworks: Endogenous Growth Theory and Climate Justice Theory. The Endogenous Growth Theory, developed principally by Romer (1990) and Lucas (1988), argues that sustained economic growth is shaped largely by factors generated within an economy rather than by external influences. The theory identifies human capital development, technological innovation, knowledge creation and the diffusion of new ideas as the principal sources of long-term growth. In contrast to the neoclassical perspective, which assumes that additional capital eventually yields diminishing returns, endogenous growth theory suggests that investment in education, research, innovation and infrastructure can generate lasting productivity gains.

In the context of climate adaptation, the theory provides a useful basis for understanding how investment in adaptation measures can support economic performance. Measures such as climate-

resilient infrastructure, improved farming practices, and effective early warning systems help to strengthen productivity while reducing the economic disruption associated with climate-related shocks. In Nigeria, where agriculture remains the primary source of livelihood for a large proportion of households and remains highly exposed to climate variability, adaptive capacity is essential to sustain agricultural productivity and foster SEG. However, significant differences in access to education, technology and essential infrastructure across regions mean that the gains from adaptation are not shared equally. As a result, some areas are better positioned to benefit from adaptation investments than others, contributing to persistent spatial disparities in economic outcomes.

Complementing the endogenous growth perspective is the Climate Justice Theory, which is based on the principles of distributive and procedural fairness. Drawing on Rawlsian principles of equity and the broader literature on climate ethics, the theory acknowledges that both the impacts of climate change and the capacity to respond to them are distributed unevenly across regions and social groups (Araos et al., 2021). Effective climate action should therefore extend beyond emission reduction and resilience enhancement to include equitable access to adaptation resources, institutional support, and meaningful participation in decision-making processes. In the Nigerian context, climate vulnerability is influenced by marked geographical and socioeconomic disparities, resulting in considerable differences in exposure and adaptive capacity across regions. These disparities indicate that both spatial and socioeconomic conditions shape climate-related risks. As a result, adaptation policies that fail to incorporate equity considerations are likely to reinforce existing regional inequalities, as greater benefits may accrue to relatively well-resourced urban areas. At the same time, vulnerable rural communities continue to experience limited capacity to adapt to climate-related challenges.

Empirical Review

The empirical evidence on the relationship among climate adaptation, regional inequality and SEG remains limited and fragmented. Although many studies have examined the economic implications of climate change, relatively few have investigated the interrelationships among these variables within a unified analytical framework. For instance, Dell et al. (2021) found that temperature increases were associated with significant reductions in economic growth in developing economies, largely due to declines in agricultural and industrial productivity.

Burke et al. (2015) further show that temperature increases exert nonlinear negative effects on output across both developed and developing economies. Consistent with this evidence, Kahn et al. (2021) reported that persistent temperature increases significantly reduced long-term per capita income growth across 174 countries. In contrast, the effect of precipitation was statistically insignificant. In a related study, Adam and Drakos (2022) identified nonlinear relationships between climate variables and economic growth in European economies, demonstrating that the magnitude and direction of climate effects differ between the short run and long run. Collectively, these findings suggest that climate change constitutes a significant structural constraint on economic performance, with the most severe consequences being borne by regions characterised by greater climatic and socioeconomic vulnerability. Callahan and Mankin (2022) reinforced this conclusion, attributing substantial economic losses to historical warming that are disproportionately borne by lower-income countries.

The literature on climate adaptation suggests that responses to climate change are heterogeneous, context-specific, and do not invariably produce favourable development outcomes. Evidence reported by Kala et al. (2023) indicates that adaptation measures implemented in developing economies can mitigate only part of the income losses associated with climate-related shocks, implying that substantial vulnerability remains. Bartelet et al. (2022) reported similar findings, observing that many households and firms do not adopt adaptation measures because of structural constraints, including poverty and limited access to financial and productive resources. In addition, Antoci et al. (2022) demonstrated that poorly designed adaptation strategies may result in maladaptation by encouraging higher levels of production and consumption, thereby intensifying environmental degradation, widening socioeconomic inequality, and increasing ecological pressure. In a similar vein, Asare-Nuamah et al. (2021) found that maladaptive practices among smallholder farmers erode sustainable development and shift vulnerability rather than reduce it.

The relationship between inequality, environmental sustainability, and economic growth has also received considerable empirical attention. Marrero and Servén (2022) found that poverty directly harms economic growth, while inequality constrains growth indirectly through its influence on poverty. Evidence from ECOWAS countries reported by Langnel et al. (2021) further indicates that income inequality influences environmental outcomes and, under certain conditions, contributes to worsening environmental degradation. Likewise, Haciimamoglu et al. (2025) showed that wealth inequality is associated with higher carbon emissions in highly unequal economies, highlighting the environmental consequences of unequal income distribution. At the macroeconomic level, Dasgupta et al. (2023) demonstrated that rising temperatures simultaneously reduce income growth and increase inequality, suggesting that climate change reinforces existing socioeconomic disparities. Relatedly, Zhao et al. (2022) showed that carbon pricing can deepen poverty and inequality unless accompanied by redistributive measures. Similar evidence was provided by Li et al. (2025), who found that urban inequality hinders progress towards several Sustainable Development Goals, particularly those relating to climate action and sustainable cities. Collectively, these studies indicate that inequality not only increases vulnerability to environmental risks but also weakens economies' capacity to achieve sustainable development.

Recent contributions to the adaptation governance literature have increasingly emphasised the importance of equity, institutional coordination, and policy coherence. Fiack et al. (2021) reported that many cities in the United States have incorporated social equity considerations into climate adaptation planning through policies aimed at reducing vulnerability and strengthening inclusive governance. Araos et al. (2021) reached similar conclusions, observing that equity has become more prominent in the global adaptation literature. However, its practical implementation remains uneven, particularly among socially and economically disadvantaged groups. Dodson et al. (2022) identified a key policy gap, showing that demographic and population dynamics receive limited attention within national climate adaptation strategies. In a related study, Tudose et al. (2021) found that fragmented governance arrangements increase the likelihood of maladaptation, whereas integrated policy approaches improve coordination and enhance sustainability outcomes. Complementing this view, Fuldauer et al. (2021) demonstrated that spatial systems modelling can inform national adaptation planning in ways that advance sustainable development. Focusing on Africa, Tavares et al. (2025) demonstrated that inequality is closely associated with environmental degradation, migration pressures, and weak structural transformation. Similarly, Yang et al. (2023) reported that spatial inequalities continue to persist despite evidence of gradual regional convergence. Building on this, Zhong et al. (2021) proposed an integrative framework that coordinates socio-economic and environmental dimensions to evaluate regional sustainability.

The literature on sustainable development pathways also highlights the importance of environmental innovation and structural transformation. Jain et al. (2023) and Khan et al. (2024) found that greater reliance on renewable energy promotes sustainable economic growth while reducing carbon emissions, thereby supporting the transition towards low-carbon development. Elfaki and Ahmed (2024) further demonstrated that digitalisation contributes positively to sustainable growth, although the developmental effects of globalisation remain less conclusive. Evidence provided by Agan (2024) showed that climate adaptation and clean energy innovation significantly enhance sustainable economic growth across OECD countries. Focusing on sub-Saharan Africa, Akingbade and Kayode (2025) similarly found that climate adaptation finance supports economic growth, underscoring the developmental role of adaptation investment in the region. Likewise, Sokolnicki et al. (2022) argued that integrated green recovery strategies generate stronger environmental and distributive outcomes than conventional growth-oriented policy approaches. Taken together, these studies underscore the importance of combining climate adaptation, technological innovation, institutional reform, and inclusive development policies to strengthen long-term economic sustainability.

Despite the breadth of existing evidence, two major gaps were observed in the literature. Most studies examine climate adaptation, inequality, and economic growth separately. Also, where interactions are considered, they are often theoretical or focused on non-African contexts. Second, a clear geographical gap remains, as few studies explicitly examine how climate adaptation and regional inequality jointly influence sustainable economic growth in Nigeria.

METHODOLOGY

The relationship among climate adaptation, regional inequality and sustainable economic growth in Nigeria was examined using annual time series data covering the period from 1990-2024. The analytical framework adopted for the study was primarily informed by the climate-growth framework developed by Kahn et al. (2021), which emphasised the long-run macroeconomic implications of climate change and adaptation.

Unlike previous studies that focused primarily on climate variability and agricultural productivity, this study incorporates climate adaptation and spatial inequality within a unified macroeconomic framework in order to examine their combined influence on sustainable economic growth in Nigeria.

The functional form of the model is expressed as:

$$SEG = f(CAI, SIQ, GOV, CO2, POP, TO) \quad (1)$$

The econometric model is specified as:

$$SEG_t = \alpha_0 + \alpha_1 CAI_t + \alpha_2 SIQ_t + \alpha_3 GOV_t + \alpha_4 CO2_t + \alpha_5 POP_t + \alpha_6 TO_t + \varepsilon_t \quad (2)$$

Where: (SEG) = Sustainable Economic Growth; (CAI) = Climate Adaptation; (SIQ) = Spatial Inequality Index; (GOV) = Governance Quality; (CO2) = Carbon Emissions; (POP) = Population Growth; (TO) = Trade Openness

The data for SEG, TO, CO2 and population growth were sourced from the World Bank's World Development Indicators (WDI); governance quality data were obtained from the World Governance Indicators (WGI), while the climate adaptation indicator was sourced from the ND-GAIN database.

Table 1. Measurement of Variables

Variables	Denotation	Measurement	Supporting Literature
Sustainable Economic Growth	SEG	Green GDP growth adjusted for environmental sustainability	Kahn et al. (2021)
Climate Adaptation	CAI	Renewable energy consumption (% of total energy use)	Fiack et al. (2021)
Spatial Inequality	SIQ	regional inequality	Marrero & Servén (2022)
Governance Quality	GOV	Government effectiveness	Kaufmann et al. (2020)
Carbon Emissions	CO2	CO_2 emissions per capita	IPCC (2022)
Population Growth	POP	Annual population growth rate	WDI
Trade Openness	TO	Ratio of imports plus exports to GDP	World Bank

Source: Author's Compilation

The study employed descriptive statistics, correlation analysis, unit root tests, cointegration analysis and the Autoregressive Distributed Lag (ARDL) model developed by Pesaran et al. (2001) as regression techniques to examine the study's objective. The justification for employing ARDL was that it is suitable for studies with variables that exhibit a mixture of orders, that is, I(0) and I(1).

The ARDL model is specified as:

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{k} \beta_1 \Delta Y_{t-1} + \sum^{k} \beta_2 \Delta X_{t-1} + \lambda_1 ECT_{t-1} + \varepsilon_t \quad (3)$$

RESULTS AND DISCUSSION

Pre-estimation Result

Table 2. Descriptive Statistics

Variable	Mean	Std. Dev	Minimum	Maximum
SEG	4.2811	2.1130	-1.4210	8.9605
CAI	0.00001	1.1520	-2.3119	2.4470
SIQ	0.00001	1.0231	-2.0280	2.1830
GOV	-0.8420	0.5220	-1.7810	0.1540
CO2	0.7110	0.2260	0.3121	1.2330
POP	2.6140	0.3810	1.9820	3.2450
TO	35.1720	9.8250	18.4210	58.9110

Note: (SEG) = Sustainable Economic Growth; (CAI) = Climate Adaptation; (SIQ) = Spatial Inequality Index; (GOV) = Governance Quality; (CO2) = Carbon Emissions; (POP) = Population Growth; (TO) = Trade Openness

Source: Author's Computation (2026)

From the descriptive statistics presented in Table 2, the Climate Adaptation Index (CAI) has a mean close to zero and a standard deviation of 1.1520, reflecting its standardised nature. The considerable difference between the minimum and maximum values indicates substantial variation in climate adaptation capacity over the study period. This variation suggests that the level of adaptation was not uniform but changed over time, possibly in response to shifts in climate policies, renewable energy development, and environmental investment.

Similarly, the Spatial Inequality Index (SIQ) has a mean value close to zero and a standard deviation of 1.0231, consistent with its standardisation. The observed spread between the minimum and maximum values points to pronounced disparities in development across regions throughout the study period. Both the Climate Adaptation Index (CAI) and the Spatial Inequality Index (SIQ) were standardised using z-score transformation before estimation. Consequently, a one-unit change in either index represents a one standard deviation change from the sample mean rather than a one-unit change in the original measurement scale.

Governance quality (GOV) records a mean value of −0.8420, which lies closer to the minimum value (−1.7810) than to the maximum value (0.1540). This distribution suggests that institutional quality remained relatively weak for much of the study period. The negative average further reflects persistent governance challenges associated with weak regulatory effectiveness, corruption, and limited institutional capacity.

Carbon emissions (CO_2) have a mean value of 0.7110 and a relatively low standard deviation of 0.2260, indicating limited variation over time. This pattern suggests that environmental pressure remained fairly stable during the period, although gradual increases in industrial activity and energy consumption were associated with periods of higher emissions.

Population growth (POP) averages 2.6140, indicating that demographic expansion remained consistently high throughout the study period. The relatively small standard deviation of 0.3810 suggests that population growth followed a stable long-term trend rather than exhibiting substantial year-to-year fluctuations.

Trade openness (TO) records a mean value of 35.1720, positioned closer to the minimum value of 18.4200 than to the maximum value of 58.9110. This finding suggests that Nigeria's degree of integration into the global trading system remained moderate over most of the study period, although periods of stronger external trade performance were also observed (Table 3).

Table 3. Correlation Matrix

Variables	SEG	CAI	SIQ	GOV	CO2	POP
SEG	1					
CAI	0.7110	1				
SIQ	-0.6210	-0.4340	1			
GOV	0.6460	0.5370	-0.4810	1		
CO2	-0.3010	-0.1440	0.3810	-0.2670	1	
POP	-0.3920	-0.2480	0.2360	-0.1740	0.4112	1
TO	0.5740	0.4830	-0.3610	0,3080	-0.1250	-0.2110

Source: Author's Computation (2026)

Applying the conventional threshold of 0.80 for multicollinearity diagnostics revealed that the pairwise correlation results reported in Table 3 do not exhibit multicollinearity issues, as correlation coefficients for the explanatory variables are below the critical benchmark. This implies that the explanatory variables are not likely to distort coefficient estimates or weaken statistical inference.

Table 4. Augmented Dickey-Fuller Unit Root Test

Variable	Level	First Difference	Order of Integration
SEG	-3.8742***		I(0)
CAI		-5.1123***	I(1)
SIQ		-4.8241***	I(1)
GOV		-5.0372***	I(1)
CO2		-4.6814***	I(1)
POP	-4.0121***		I(0)
TO		-5.2935***	I(1)

Source: Author's Computation (2026)

The unit root results presented in Table 4 revealed that SEG and POP are stationary at level, while CAI, SQI, GOV, CO2 and TO became stationary after first differencing. The coexistence of I(0) and I(1) variables confirms the presence of a mixed integration structure. Hence, the Autoregressive Distributed Lag (ARDL) bounds test is considered appropriate for the estimation of both the long-run and short-run relationships among the variables.

Regression Results

Analysis of the Effect of Climate Adaptation and Regional Inequality on Sustainable Economic Growth in Nigeria

Table 5. ARDL Results

Variables	Short Run Estimates	Long Run Estimates
CAI	.2841*** (2.5174)	.6245*** (4.1186)
SIQ	-.7634 (-3.9942)	-1.8826*** (-5.3827)
GOV	.5077** (2.2741)	1.2465** 2.9138)
CO2	-.3314* (-1.8934)	-.9136* (-1.9671)
POP	-.1172 (-1.2147)	-.3381 (-1.3362)
TO	0.0187** (2.1136)	.0432** (2.5175)
ECM (-1)	-.6713*** (-6.8214)	

Note: (SEG) = Sustainable Economic Growth; (CAI) = Climate Adaptation; (SIQ) = Spatial Inequality Index; (GOV) = Governance Quality; (CO2) = Carbon Emissions; (POP) = Population Growth; (TO) = Trade Openness. *Source:* Author's Computation (2026)

The short-run estimates in Table 5 indicate that climate adaptation (CAI) has a positive and statistically significant effect on sustainable economic growth in Nigeria. The estimated short-run coefficient of 0.2841 suggests that a one-standard-deviation increase in the Climate Adaptation Index (CAI), which was standardised prior to estimation, is associated with an increase of approximately 0.2841 units in sustainable economic growth. The long-run coefficient of 0.6243 remains positive and statistically significant, indicating that sustained improvements in adaptive capacity generate even greater benefits for long-term sustainable economic growth. This finding implies that improvements in climate adaptation, reflected in greater investment in renewable energy, climate-resilient infrastructure, irrigation systems, and environmental protection, contribute to improved economic resilience and productivity.

Spatial inequality (SIQ) exerts a negative and statistically significant effect in both the short run and the long run. The short-run coefficient of −0.7634 indicates that a one-standard-deviation increase in regional inequality reduces sustainable economic growth by approximately 0.7634 units. The long-run coefficient of −1.8826 further indicates that persistent regional inequality is a substantial structural impediment to achieving sustainable economic growth in Nigeria. This result suggests that disparities in access to infrastructure, education, healthcare, and economic opportunities limit productive participation and weaken the inclusiveness of economic growth.

Governance quality (GOV) exhibits a positive and statistically significant relationship with sustainable economic growth in both the short run and the long run. The estimated coefficients suggest that improvements in institutional quality, regulatory effectiveness, and public sector accountability strengthen sustainable economic performance by enhancing policy implementation, improving resource allocation, and fostering a more favourable investment environment.

Carbon emissions (CO_2) are associated with a negative and statistically significant effect on sustainable economic growth in both periods. The estimated coefficients indicate that increasing environmental degradation and greater dependence on carbon-intensive production activities undermine long-term development by weakening environmental quality and placing additional pressure on ecological systems.

Trade openness (TO) maintains a positive and statistically significant relationship with sustainable economic growth in both the short run and the long run. This finding suggests that greater participation in international trade contributes to sustainable growth through improved market access, technological spillovers, higher productive efficiency, and increased economic competitiveness.

Population growth (POP) records a negative coefficient; however, the estimated effect is not statistically significant. This finding indicates that population expansion, in itself, does not exert a measurable influence on sustainable economic growth over the study period.

The error correction term, ECM(−1), is negative and statistically significant, with an estimated coefficient of −0.6713. This result indicates that approximately 67.13% of deviations from the long-run equilibrium are corrected within one year following a short-run disturbance. The magnitude and statistical significance of the error correction coefficient provide strong evidence of a stable long-run equilibrium relationship among sustainable economic growth, climate adaptation, regional inequality, governance quality, carbon emissions, population growth, and trade openness in Nigeria.

Table 6: Diagnostic Tests

Tests	Values	Prob
Jarque Bera	1.8624	0.3942
Breusch-Godfrey LM	1.2843	0.2912
Breush-Pagan-Godfrey	1.1164	0.3478
F-Bounds Test		
F-Statistics	5.8431	
Critical values (5%)	I(0): 2.45 I(1): 3.61	

Source: Author's Computation (2026)

The F-statistic of 5.8431 exceeds the upper-bound critical value of 3.61 at the 5% significance level, confirming the existence of cointegration among climate adaptation, regional inequality, governance quality, carbon emissions, population growth, trade openness, and sustainable economic growth in Nigeria. The diagnostic tests further indicate that the residuals are normally distributed, free from serial correlation, and homoskedastic.

DISCUSSION

The empirical findings reveal that climate adaptation has a positive and statistically significant effect on sustainable economic growth in Nigeria in both the short run and the long run. The positive and statistically significant relationship observed suggests that improvements in

climate adaptation contribute to greater economic resilience by reducing vulnerability to climate-related shocks and supporting sustained productive activities. This finding is consistent with Kahn (2014), who reported that climate adaptation mechanisms mitigate the economic costs associated with climate risks and improve long-term productivity. Burke et al. (2015) provided similar evidence, highlighting the importance of adaptive capacity in sustaining economic performance under changing climatic conditions. The present finding, however, differs from that of Dell et al. (2012), who argued that the effectiveness of adaptation measures in many developing countries is often constrained by weak institutions, inadequate infrastructure, and limited financial capacity.

The positive relationship observed in both periods implies that investments in renewable energy strengthen productive resilience and reduce vulnerability to climate-induced disruptions. This finding aligns with Kahn (2014), who found that climate adaptation mechanisms reduce the economic costs associated with climate-related risks and improve long-run productivity performance. The result is also consistent with Burke et al. (2015), who found that adaptive capacity plays a critical role in sustaining economic productivity under changing climatic conditions. However, the finding contrasts with Dell et al. (2012), who reported that developing economies often experience weak adaptation outcomes due to structural and institutional constraints. The positive contribution of climate adaptation to sustainable economic growth supports the attainment of SDG 13 (Climate Action) by showing that adaptation investments can enhance resilience while promoting long-term economic performance.

The finding further complements SDG 7 (Affordable and Clean Energy), as increased investment in renewable energy and other climate-resilient technologies strengthens adaptive capacity and reduces exposure to environmental risks. In addition, the improvement in economic productivity associated with effective adaptation contributes to the achievement of SDG 8 (Decent Work and Economic Growth) through the promotion of stable and sustainable long-term economic development.

The findings further reveal that spatial inequality negatively affects sustainable economic growth in both the short run and the long run. The negative and statistically significant relationship between spatial inequality and sustainable economic growth suggests that widening regional disparities undermine long-term development by limiting equitable access to infrastructure, healthcare, education, and employment opportunities. Such disparities weaken productive participation, constrain human capital development, and reduce the inclusiveness of economic growth. This finding is consistent with Marrero and Rodríguez (2013), who showed that inequality impedes long-run economic growth by reducing social mobility and inefficiently allocating productive resources. Hallegatte et al. (2018) reported similar evidence, showing that regional disparities reinforce persistent poverty and weaken resilience to economic and environmental shocks. The present finding, however, contrasts with Forbes (2000), who argued that moderate levels of inequality may encourage investment and promote short-run economic growth. The evidence from this study therefore supports SDG 10 (Reduced Inequalities) by showing that narrowing regional disparities is fundamental to achieving inclusive and balanced development. The finding also contributes to SDG 8 (Decent Work and Economic Growth), as equitable access to productive opportunities remains essential for sustaining long-term economic growth.

Furthermore, governance quality is found to exert a positive and statistically significant influence on sustainable economic growth in both the short run and the long run. The estimated coefficients indicate that improvements in institutional effectiveness, regulatory quality and public accountability enhance policy implementation, strengthen resource allocation, and create a more stable environment for sustainable economic development. This finding corroborates the evidence reported by Acemoglu and Robinson (2012), who identified strong institutions as a fundamental determinant of long-run economic prosperity. It is also consistent with Kaufmann et al. (2010), who showed that improvements in governance effectiveness contribute significantly to economic performance and development stability. The result further supports SDG 16 (Peace, Justice and Strong Institutions) by emphasising the importance of accountable institutions, effective governance, and sound regulatory frameworks in promoting sustainable and inclusive economic development.

The results also show that carbon emissions negatively affect sustainable economic growth in both the short and long run. The negative and statistically significant relationship between carbon emissions and sustainable economic growth suggests that greater reliance on carbon-intensive production imposes substantial environmental and economic costs over time. Rising emissions contribute to environmental degradation, weaken ecosystem resilience, and adversely affect the productive capacity required for sustained economic development. This finding is consistent with Stern (2004), who argued that environmental degradation constitutes a major constraint to sustainable economic growth, particularly in developing economies. Burke et al. (2015) reported similar evidence, finding that climate-induced environmental deterioration reduces aggregate economic productivity and weakens long-term growth prospects. The present finding, however, differs from the Environmental Kuznets Curve hypothesis advanced by Grossman and Krueger (1995), which posits that environmental degradation may increase during the early stages of economic development before declining as income levels rise and environmental regulations become more effective. The policy implications of this finding are closely aligned with the Sustainable Development Goals (SDGs). The adverse effect of carbon emissions on sustainable economic growth provides empirical support for SDG 13 (Climate Action) by underscoring the importance of reducing greenhouse gas emissions and strengthening climate mitigation efforts. The finding also complements SDG 12 (Responsible Consumption and Production) by highlighting the need for cleaner production processes and more efficient use of natural resources. Furthermore, lower carbon emissions improve environmental quality and reduce exposure to pollution-related health risks, thereby supporting SDG 3 (Good Health and Well-being).

Trade openness exerts a positive and statistically significant effect on sustainable economic growth in both the short run and long run. The positive relationship indicates that greater integration into the global economy enhances technology transfer, market access, productive specialisation, and resource allocation efficiency. This finding is consistent with Frankel and Romer (1999), who established that trade openness stimulates economic growth through productivity enhancement and international market integration. This finding provides empirical support for SDG 8 (Decent Work and Economic Growth) by indicating that greater trade integration contributes to sustained economic expansion through improved market access, enhanced productivity, and increased productive efficiency. The result also aligns with SDG 9 (Industry, Innovation and Infrastructure), as openness to international trade facilitates technology transfer, innovation diffusion, and industrial development.

CONCLUSION AND RECOMMENDATIONS

This study concludes that climate adaptation, governance quality, and trade openness are significant positive determinants of sustainable economic growth in Nigeria in both the short run and the long run, while spatial inequality and carbon emissions adversely affect growth performance over the same periods. Based on the empirical findings, it is recommended that sustained investment be directed toward climate adaptation measures, particularly the expansion of renewable energy systems, climate-resilient agricultural practices, and climate-resilient public infrastructure, to strengthen economic resilience and support long-term sustainable growth. Furthermore, deliberate policy efforts should reduce regional disparities through balanced regional development, improved access to quality education and healthcare, and increased provision of physical infrastructure in underserved areas. Institutional reforms should also be strengthened by enhancing transparency, improving regulatory effectiveness, and reinforcing public sector accountability to promote efficient policy implementation and effective resource management. Lastly, stricter enforcement of environmental regulations is required to reduce carbon emissions, while greater investment in green production technologies, renewable energy, and environmentally sustainable industrial practices should be encouraged to facilitate the transition towards a low-carbon economy.

However, the proxies adopted for climate adaptation and sustainable economic growth are constrained by data availability and measurement limitations inherent in secondary datasets. Therefore, future research should employ multidimensional measures of spatial inequality and examine alternative transmission channels such as green investment, technological innovation, and human capital development.

Author Contributions (CRediT Taxonomy)

First Author: Conceptualisation (supporting); Writing - Original Draft; Literature Review; Investigation; Data Interpretation. The first author wrote the original draft of the manuscript, structured the paper, integrated the relevant literature, interpreted the findings, and prepared the initial version of all major sections.

Second Author: Conceptualisation (lead); Supervision; Writing – Review & Editing;

Validation. The second author led the study's conceptualisation, refined the research objectives and theoretical framework, provided overall academic supervision, critically reviewed and edited the manuscript, and validated the intellectual content to ensure scholarly rigour and coherence.

Third Author: Methodology; Formal Analysis; Data Curation; Software; Validation. The third author designed the research methodology, developed the model specification, conducted the formal data analysis, managed and curated the dataset, and verified the robustness and accuracy of the analytical procedures and empirical results.

All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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The authors declare no conflicts of interest

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The data used will be made available based upon request.

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