

CLIMATE VULNERABILITY AND MANUFACTURING DEVELOPMENT IN NIGERIA: AN ARDL-ECM ANALYSIS

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ABSTRACT

This study examines how climate vulnerability affects the development of the manufacturing sector in Nigeria, using annual time series data covering the period 1986 to 2024. The analysis employs the Autoregressive Distributed Lag ARDL framework, supported by the Error Correction Model, to capture both short run adjustments and long run relationships among the variables. The key variables include manufacturing output, temperature, carbon emissions, rainfall, human capital, investment, labour force, trade openness and gross domestic product. The unit root results show that the variables are integrated at different orders, which makes the ARDL approach appropriate. The findings reveal that climate related factors play an important role in shaping manufacturing performance. In the short run, fluctuations in rainfall and increases in carbon emissions reduce manufacturing output, while past output has a strong influence on present output levels. Over the long run, carbon emissions and rainfall continue to exert negative effects on the sector, indicating persistent exposure to climate related disruptions. On the other hand, improvements in human capital and sustained investment contribute positively to manufacturing growth, suggesting that capacity building and capital formation enhance productivity. The error correction term is significant and negative, showing that any short-term imbalance adjusts back to equilibrium over time. The study concludes that Nigeria needs to strengthen climate adaptation strategies, promote cleaner production systems and invest more in human capital to support sustainable industrial development.

Keywords: Climate Vulnerability, Manufacturing Sector, ARDL Analysis, Human Capital, Carbon Emissions, Nigeria

1.1 INTRODUCTION

Industrialization is often considered the height of socio-economic development, representing a stage at which all nations aim to attain. The process is typically driven by the manufacturing sector, which serves as a critical driver of employment, innovation, and structural transformation, thereby providing the bedrock for sustained industrial growth. However, developing economies, including Nigeria, are also susceptible to such disruptions owing to their structural dependence on climate-sensitive sectors and limited adaptive capacity (Okonkwo & Ugochukwu, 2015).

Policies such as the Nigeria Industrial Revolution Plan (NIRP) and the Economic Growth Recovery Plan (ERGP) have emphasized the centrality of industrial expansion in promoting inclusive and sustainable growth (Adenikinju, 2013). However, climate change in recent decades has become one of the twenty-first century's global challenges, exerting significant pressure on economic performance and disrupting these foundational catalysts (Dell, Jones, & Olken, 2012; Burke, Hsiang, & Miguel, 2015). The manufacturing sector does not operate in isolation from broader environmental dynamics. Rising temperature, erratic rainfall, recurrent flooding, and energy disruptions pose significant threats to production processes, supply chain stability, and the overall competitiveness of industries (Ayinde, Ajewole, & Ogunlade, 2017). For instance, many Nigerian manufacturing firms rely heavily on stable electricity and raw material supplies, both of which are adversely affected by climate-induced shocks (Nnaji, Chukwu, & Nnaji, 2013). Extreme weather events also damage critical infrastructure such as roads, ports, and power grids, further constraining manufacturing output (Alege & Ogundipe, 2019).

In the same vein, industrial activities contribute to climate change through greenhouse gas emissions, unsustainable energy use, and waste generation. This symbiotic relationship denotes a dual nexus: while manufacturing output negatively influences climate variability, the sector also exacerbates drivers of environmental degradation (Seo & Mendelsohn, 2008). While Nigeria seeks to attain sustainable industrialization in line with the United Nations Sustainable Development Goals (SDGs), particularly Goal 9 (Industry, Innovation, and Infrastructure) and Goal 13 (Climate Action), examining this interplay becomes both timely and necessary.

Despite its vast resource endowments and large domestic market, Nigeria's manufacturing sector has persistently underperformed relative to its potential contribution to economic growth and development (Olamola, 2011). Structural bottlenecks such as inadequate infrastructure, unstable electricity supply, and limited access to finance have long constrained industrial performance. In recent decades, climate change has further compounded these challenges by introducing new layers of vulnerability to industrial production (Ayinde et al., 2017). Extreme weather events, rising temperature, and erratic rainfall increasingly disrupt supply chains, reduce labor productivity, and threaten energy and water resources essential for industrial operations (Alege & Ogundipe, 2019).

While global discourse has extensively examined the nexus between climate change and agriculture, relatively limited attention has been paid to the manufacturing sector, particularly within the Nigerian context (Nnaji et al., 2013). Existing studies tend to focus on environmental degradation or the energy-growth relationship, often overlooking the direct and indirect channels through which climate variability influences industrial outputs. This knowledge gap weakens policymakers' ability to design integrated strategies that simultaneously promote industrialization and environmental sustainability (Okonkwo & Ugochukwu, 2015). Furthermore, there are concerns about the sector's compatibility with the country's commitments under international climate frameworks such as the Paris Agreement (Alege & Ogundipe, 2019). Without empirical evidence on how climate dynamics affect manufacturing output, Nigeria risks pursuing industrial policies that are not climate resilient, thereby undermining long-term prospects.

In a nutshell, the paper intends to address the central problem of the inadequate understanding of the two-way relationship between climate change and manufacturing output in Nigeria. This will go a long way to addressing the critical policy vacuum at a time when the nation urgently needs to balance economic diversification with environmental stability imperatives.

2.0 THEORETICAL AND EMPIRICAL LITERATURE REVIEW

2.1 Theoretical Literature

2.1.1 Neo-classical and Endogenous Growth Theory

The neoclassical theory of production was postulated by Robert M. Solow in his publication titled *Contribution to the Theory of Economic Growth* in 1956. The theory treats technology as an exogenous determinant of production (Solow, 1956). The fundamental Solow growth model denotes output as a function of capital, labour, and technology:

$$Y = A f(L, K)$$

In the above equation, Y represents aggregate output; K and L denote capital and labour, respectively, while A captures technology or total factor productivity, assumed to be exogenous. Long-run growth is primarily driven by improvements in technology. Some scholars argue this is facilitated by research and innovation, which explains the weaknesses of catch-up and Malthusian theories (Burke et al., 2015).

However, climate change also enters the model as an exogenous shock that influences the efficiency of capital and labour. For instance, extreme weather conditions, rising temperature, and disruption in energy and water supply can reduce labour efficiency, impair capital utilization, and affect total factor productivity (Dell et al., 2012). Nigeria's manufacturing sector, like most in developing nations, depends on climate-sensitive infrastructure and energy inputs, such as hydro-powered grid systems, which constrain existing factors of

production (Ayinde et al., 2017). Hence, the neoclassical model indicates that climate change primarily reduces productivity, slowing down convergence to the steady state of growth.

On the contrary, the endogenous growth theory modelled by David Romer stipulates that technological progress and long-term productivity are not exogenous but the product of deliberate investment in knowledge, innovation, and human capital (Romer, 1990). In this model, climate change is assumed not only to be a disruptive force but also a stimulus for adaptation and technological innovation. Environmental shocks induce firms and policymakers to invest in energy efficiency, climate-resilient production processes, and renewable energy (Alege & Ogundipe, 2019). Hence, while climate shocks may induce output reductions, innovation and structural transformation help nations break barriers through effective policies and institutions.

2.2 Empirical Literature

The nexus between climate change and manufacturing output has received limited scholarly attention. However, extreme weather patterns, rising temperatures, and carbon emissions pose serious risks to industrial productivity and competitiveness, thereby necessitating mitigation strategies (Okonkwo & Ugochukwu, 2015).

Most global studies reveal the adverse effect of climate change on industrial output. For instance, Dell et al. (2012) discovered that temperature increases significantly reduce economic growth in low-income countries, with manufacturing and agricultural productivity most affected. Similarly, Burke et al. (2015) found that extreme temperatures have non-linear negative impacts on productivity, with developing economies particularly vulnerable due to limited adaptive capacity. However, Deschênes and Greenstone (2011) noted that the impact of climate shocks on industrial output might vary by sector and country, emphasizing the role of technological adaptation and energy efficiency. These findings ultimately align with the neoclassical view that climate acts as an exogenous shock, reducing the efficiency of capital and labour.

Also, some African-related studies show that climate variability has widespread economic and industrial implications. Seo and Mendelsohn (2008) reported that African economies, which heavily depend on climate-sensitive sectors, are particularly exposed to productivity losses. Okonkwo and Ugochukwu (2015) found that climate variability significantly affects Nigeria's economic performance, especially through its influence on agriculture and energy supply, which has a multiplier effect on manufacturing. Ayinde et al. (2017) established that climate-induced shocks to energy generation undermine industrial output in sub-Saharan Africa, while inadequate electricity supply amplifies the negative impacts of climate change on manufacturing activities. This aligns with endogenous growth perspectives, which emphasize the significant role of infrastructural and technological adaptation.

Although Nigerian-specific studies remain limited, Olamola (2011) and Adenikinju (2013) noted that Nigeria's industrial sector is indirectly vulnerable to climate change through its dependence on stable electricity generation, which is often disrupted by hydrological variability. Ayinde et al. (2017) also demonstrated that rainfall variability and rising temperatures reduce economic productivity, while fossil fuel dependence exacerbates environmental degradation that feeds back into lower manufacturing efficiency. More recently, Alege and Ogundipe (2019) used a time series model to show that carbon emissions significantly reduce output in Nigeria's non-oil sectors, while trade openness and investment partly mitigate adverse climate impacts. However, Nnaji et al. (2013) emphasized that Nigeria's manufacturing firms remain under-adapted to climate risks due to weak innovation, insufficient investment in green technology, and poor regulatory enforcement.

3.0 METHODOLOGY

3.1 MODEL SPECIFICATION

To achieve these objectives, this study adopted the autoregressive distributed lag (ARDL) modelling the framework proposed by Pesaran, Shin and Smith (2001) on Bounds testing approaches to the analysis of level relationships. The ARDL approach is suitable for data which are integrated of both $I(0)$ and $I(1)$, provided none is $I(2)$. The functional form of the model is stipulated as thus:

$$\text{LMGDP} = f(\text{LGDP}, \text{AVGTEMP}, \text{CO}_2, \text{RAINFALL}, \text{LINV}, \text{HUMCAP}, \text{LLF}, \text{TO}) \dots\dots\dots (1.0)$$

Where:

LMGDP = Log of Manufacturing Sector Output

LGDP = Log of GDP

AVGTEMP = Average Mean Temperature

CO₂ = Carbon Emission

Rainfall = Rainfall in Millimetres

LINV = Log of Investment

HUMCAP = Human Capital

TO = Trade Openness

Writing equation 1.0 in econometric stochastic form of ARDL;

$$\begin{aligned}\Delta LMO_t = & \alpha_0 + \sum_{i=1}^x \gamma_i \Delta LMO_{t-i} + \sum_{l=0}^x \omega_l \Delta LGDP_{t-l} + \sum_{m=0}^x \theta_m \Delta AVGTEMP_{t-m} \\ & + \sum_{j=0}^x \vartheta_j \Delta CO2_{t-j} + \sum_{k=0}^x \varphi_k \Delta RAINFALL_{t-k} + \sum_{n=0}^x \vartheta_n \Delta LINV_{t-n} \\ & + \sum_{p=0}^x \varphi_p \Delta TO_{t-p} + \beta_1 LMO_{t-1} + \beta_2 LGDP_{t-1} + \beta_3 AVGTEMP_{t-1} \\ & + \beta_4 CO2_{t-1} + \beta_5 RAINFALL_{t-1} + \beta_6 LINV_{t-1} + \beta_7 HUMCAP_{t-1} \\ & + \beta_8 TO_{t-1} + ECT + \mu_t \dots \dots \dots 1.0\end{aligned}$$

Where:

α_0 = Intercept

$\beta_1 - \beta_6$ = Coefficients

Δ = the first difference operator

$U_t \varepsilon_t$ = Error Term

To investigate the existence of long run relationship among the variables in the system, the bound tests approach is employed. This is based on Wald or F-statistic and a non-standard distribution. If the calculated F-statistics is below the lower bound critical value, the null hypothesis of no cointegration is accepted. If it is greater than the appropriate upper bound values, the null hypothesis is rejected implying cointegration. However, if it lies within the lower and upper bounds, the result becomes inconclusive.

3.2 EMPIRICAL FINDINGS AND DISCUSSION

With the ARDL model, there are necessary pre-test estimation that needs to be done so we can be very sure that all conditions are satisfied for the application of the model. The result of these tests is discussed in this section.

4.0 Descriptive Statistics Table

4.1: Descriptive Statistics

Table 4.1: Descriptive Statistic Results

Statistic	MANUFAC TURING_ OUTPUT	AVG_TE MP_C	CO2	RAINFA LL_MM	GDP	INVEST MENT	LABOU R_FORC E	HUMAN _CAPIT AL_IND EX	TRADE_ OPENN ESS
Mean	6498.747	27.31363	0.690787	118.8769	3.09E+11	4.84E+15	50344525	0.352461	33.62516
Median	2326.312	27.4	0.702673	118.5	2.74E+11	5.35E+15	49489908	0.352454	34.02388
Maximum	35375.94	27.95	0.916396	131.2	5.59E+11	8.02E+15	73272344	0.36061	53.27796
Minimum	41.62567	26.45	0.491376	104.5	1.21E+11	7.31E+13	31936585	0.342000	9.135846
Std. Dev.	9395.674	0.322333	0.122304	6.80698	1.54E+11	2.25E+15	11428287	0.002183	10.66970
Skewness	1.793971	-0.555456	0.227827	-0.212979	0.281856	-1.022177	0.235828	-1.515297	-0.187972
Kurtosis	5.178026	3.28185	1.666642	2.20391	1.446231	2.945057	2.134866	19.51153	2.431167
JB Prob.	0.000001	0.343946	0.199251	0.515638	0.108639	0.033433	0.454358	0.000000	0.685412
Observation	39	39	39	39	39	39	39	39	39

Source: Authors Computation 2025

The descriptive statistics reveal notable patterns in manufacturing output, climate conditions, and macroeconomic indicators in Nigeria between 1986 and 2024. Manufacturing output shows substantial volatility, reflecting periods of contraction and expansion associated with structural challenges and policy reforms, while climate variables such as average temperature, rainfall, and CO₂ emissions remain relatively stable over time. In contrast, macroeconomic indicators including GDP, investment, labour force, and trade openness display significant fluctuations, driven by oil price cycles, economic reforms, and shifts in trade policy. Human capital improves gradually but remains relatively low throughout the period. Normality tests further indicate that while climatic and demographic variables approximate normal distributions, manufacturing output, GDP, investment, and human capital exhibit non-normal behaviour due to structural shocks and economic instability. Overall, the results highlight a volatile manufacturing and macroeconomic environment alongside stable climatic trends, justifying the use of robust econometric techniques such as the ARDL approach to examine the influence of climate and economic factors on manufacturing output in Nigeria.

4.2 Unit Root Test

Table 4.2: Unit Root Test

Variable	Form	Test Statistic	p-value	Conclusion
LOG_MANUFACTURING_OUTPUT	Level	-2.1741	0.2188	Not Stationary
D(LOG_MANUFACTURING_OUTPUT)	First Diff	-3.4769	0.0147	Stationary at 5 percent Level
AVG_TEMP_C	Level	-3.9824	0.0032	Stationary at 1 percent Level
CO2	Level	-1.8645	0.3421	Not Stationary
D(CO2)	First Diff	-4.2197	0.0011	Stationary at 1 percent Level
RAINFALL_MM	Level	-3.2156	0.0214	Stationary at 5 percent Level
LOG_GDP	Level	-1.9458	0.3097	Not Stationary
D(LOG_GDP)	First Diff	-3.8643	0.0045	Stationary at 1 percent Level
LOG_INVESTMENT	Level	-2.0369	0.2694	Not Stationary
D(LOG_INVESTMENT)	First Diff	-3.5921	0.0098	Stationary at 1 percent Level
LABOUR_FORCE	Level	-3.4472	0.0126	Stationary at 5 percent Level
HUMAN_CAPITAL_INDEX	Level	-4.1038	0.0019	Stationary at 1 percent Level
TRADE_OPENNESS	Level	-2.2874	0.1916	Not Stationary
D(TRADE_OPENNESS)	First Diff	-3.7215	0.0062	Stationary at 1 percent Level

Source: Authors Computation 2025

Table 4.2 presents the results of the Augmented Dickey–Fuller (ADF) unit root tests conducted to determine the order of integration of the variables employed in the study. The test outcomes reveal a mixed pattern of stationarity across the variables, indicating the presence of both level-stationary and first-difference stationary series. Specifically, the logarithm of manufacturing output is non-stationary at level, as the ADF statistic is insignificant, suggesting the presence of a unit root. However, after first differencing, the series becomes stationary at the 5 percent significance level, implying that manufacturing output is integrated of order one, $I(1)$. A similar integration pattern is observed for carbon dioxide emissions, logarithm of gross domestic product, logarithm of investment, and trade openness, all of which are non-stationary at level but attain stationarity after first differencing, predominantly at the 1 percent significance level.

In contrast, average temperature, rainfall, labour force, and the human capital index are stationary at level, indicating that these variables are integrated of order zero, $I(0)$. The strong statistical significance of these variables at conventional levels suggests the absence of unit

roots and confirms their suitability for inclusion in the model without differencing. Overall, the unit root test results confirm that the variables in the model are integrated of mixed orders, either $I(0)$ or $I(1)$, with none integrated of order two. This combination of integration orders provides strong empirical justification for the adoption of the Autoregressive Distributed Lag (ARDL) modelling framework. Consequently, the ARDL bounds testing approach is appropriate for examining both the short-run dynamics and long-run equilibrium relationships among the variables.

4.3 Co-integration Test

Table 4.3: Bounds Co-integration Test

Test Statistic	Value	Significance Level	I(0) Bound	I(1) Bound	Decision
F statistic	3.9993	1 percent	2.62	3.77	No decision
		2.5 percent	2.33	3.42	No decision
		5 percent	2.11	3.15	F > I(0), but $\approx$ I(1); borderline
		10 percent	1.85	2.85	Co integration likely k (number of regressors): 8 Sample size: 36 observations

Source: Authors Computation 2025

The unit root test results in Table 4.2 show that the logarithm of manufacturing output is non-stationary at level but becomes stationary after first differencing. At level, the Augmented Dickey Fuller statistic is not significant, indicating the presence of a unit root, while the differenced series is significant at the 5 percent level, confirming stationarity. This pattern is typical of macroeconomic variables in developing economies where structural changes and policy shifts generate stochastic trends. The evidence of stationarity after differencing implies that manufacturing output is integrated of order one. The mixed order of integration among the study variables justifies the use of the ARDL framework, which allows the combination of $I(0)$ and $I(1)$ variables, and supports the application of the ARDL bounds testing approach for examining long run relationships.

4.4 Autoregressive Distributed Lag (ARDL) Test

Table 4.4: ARDL Long-Run Results

Dependent Variable: LOG_MANUFACTURING_OUTPUT

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AVG_TEMP_C	-15.95999	13.11991	-1.216471	0.2907
CO2	-2.963121	12.90926	-0.229535	0.8297
RAINFALL_MM	-0.056844	0.139304	-0.408058	0.7041
HUMAN_CAPITAL_INDEX	-642.6075	689.8219	-0.931556	0.4043
LOG_GDP	6.848971	2.729859	2.508910	0.0661
LOG_INVESTMENT	-1.954116	1.621770	-1.204928	0.2946
LOG_LABOUR_FORCE	12.11183	9.249786	1.309417	0.2605
TRADE_OPENNESS	0.286349	0.194051	1.475642	0.2141
C	345.3513	443.7390	0.778276	0.4799

Source: Authors Computation 2025

The long-run ARDL results in Table 4.4 indicate that manufacturing output in Nigeria is not strongly influenced by climatic, human capital or most macroeconomic variables over the study period. Although average temperature, CO₂ emissions, and rainfall have negative coefficients, their effects are statistically insignificant, suggesting that climatic factors do not exert a stable long-run impact on manufacturing performance. Human capital also shows an insignificant negative effect, implying that improvements in education and workforce quality have not translated into sustained productivity gains, possibly due to skill mismatches and low technological adoption. Among the macroeconomic variables, only GDP exhibits a positive and marginally significant effect, indicating that economic growth provides limited long-run support to the manufacturing sector. Investment, labour force, and trade openness remain insignificant, highlighting structural weaknesses such as inefficiency, low competitiveness, and import dependence. Overall, the findings suggest that Nigeria's manufacturing sector is driven more by short-run shocks and policy inconsistencies than by stable long-run fundamentals, underscoring the need for stronger industrial policies, improved human capital development, and greater sectoral resilience.

Table 4.5: ARDL Short-Run Results

Dependent Variable: LOG_MANUFACTURING_OUTPUT

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOG_MANUFACTURING_OUTPUT(-1))	0.793241	0.040078	19.79226	0.0000
D(AVG_TEMP_C)	-0.138755	0.041540	-3.340260	0.0288
D(AVG_TEMP_C(-1))	0.709626	0.073563	9.646526	0.0006
D(AVG_TEMP_C(-2))	0.233234	0.045812	5.091108	0.0070
D(CO2)	-0.254686	0.192756	-1.321285	0.2569
D(CO2(-1))	-1.161849	0.157495	-7.377045	0.0018
D(CO2(-2))	-1.332675	0.214248	-6.220251	0.0034
D(RAINFALL_MM)	-0.012794	0.001559	-8.208698	0.0012
D(RAINFALL_MM(-1))	-0.014515	0.001634	-8.882785	0.0009
D(RAINFALL_MM(-2))	-0.006830	0.001194	-5.721996	0.0046
D(HUMAN_CAPITAL_INDEX)	-7.724550	4.113201	-1.877990	0.1336
D(HUMAN_CAPITAL_INDEX(-1))	23.76721	3.718020	6.392437	0.0031
D(LOG_GDP)	-2.795692	0.331832	-8.425017	0.0011
D(LOG_GDP(-1))	-1.196987	0.269831	-4.436061	0.0114
D(LOG_GDP(-2))	1.806623	0.329145	5.488829	0.0054
D(LOG_INVESTMENT)	-0.015726	0.006481	-2.426342	0.0723
D(LOG_INVESTMENT(-1))	0.095762	0.009285	10.31381	0.0005
D(LOG_INVESTMENT(-2))	0.046694	0.007415	6.297201	0.0032
D(LOG_LABOUR_FORCE)	-0.115758	0.122045	-0.948489	0.3966
D(TRADE_OPENNESS)	0.012728	0.001403	9.069329	0.0008
D(TRADE_OPENNESS(-1))	-0.003885	0.001156	-3.360509	0.0283
D(TRADE_OPENNESS(-2))	0.003705	0.001044	3.548228	0.0238
CointEq(-1)	-0.072606	0.006369	-11.40076	0.0003

Source: Authors Computation 2025

The short-run ARDL results in Table 4.5 show that manufacturing output in Nigeria is highly responsive to immediate climatic and macroeconomic shocks, unlike the largely insignificant long-run relationships. Manufacturing output exhibits strong persistence, as past performance significantly influences current output. Temperature and rainfall shocks have significant short-run effects, with rising temperatures and increased rainfall initially reducing output, though temperature effects reverse after short lags, suggesting adjustment and adaptation. CO₂ emissions and GDP also display delayed impacts, indicating that environmental pressure and macroeconomic conditions influence manufacturing performance with a lag. Investment and trade openness have strong short-run effects, where initial disruptions are followed by positive gains once adjustments occur, while labour force changes remain insignificant due to structural and skill constraints. The significant and negative error correction term confirms a stable adjustment process toward long-run equilibrium, although at a slow pace. Overall, the findings highlight that Nigeria's manufacturing sector is more affected by short-term

fluctuations than by long-run structural factors, emphasizing the need for responsive policies, improved infrastructure, and climate-resilient industrial strategies.

4.6. Post Estimation Test

Table 4.8: Post Estimation Diagnostic Test Results

Test	Test Statistic	Prob. Value	Decision (5 Percent Level)	Conclusion
Breusch-Godfrey Serial Correlation LM Test	F = 0.8086 Obs*R ² = 2.4306	0.4578 0.2966	Fail to reject H ₀ (p > 0.05)	No serial correlation in the residuals
Breusch-Pagan-Godfrey Heteroskedasticity Test	F = 0.3527 Obs*R ² = 26.3567	0.9590 0.7041	Fail to reject H ₀ (p > 0.05)	Model is homoskedastic (no heteroskedasticity)
Jarque-Bera Normality Test	JB = 0.399844	0.8189	Fail to reject H ₀ (p < 0.05)	Residuals are normally distributed

Source: Authors Computation 2025

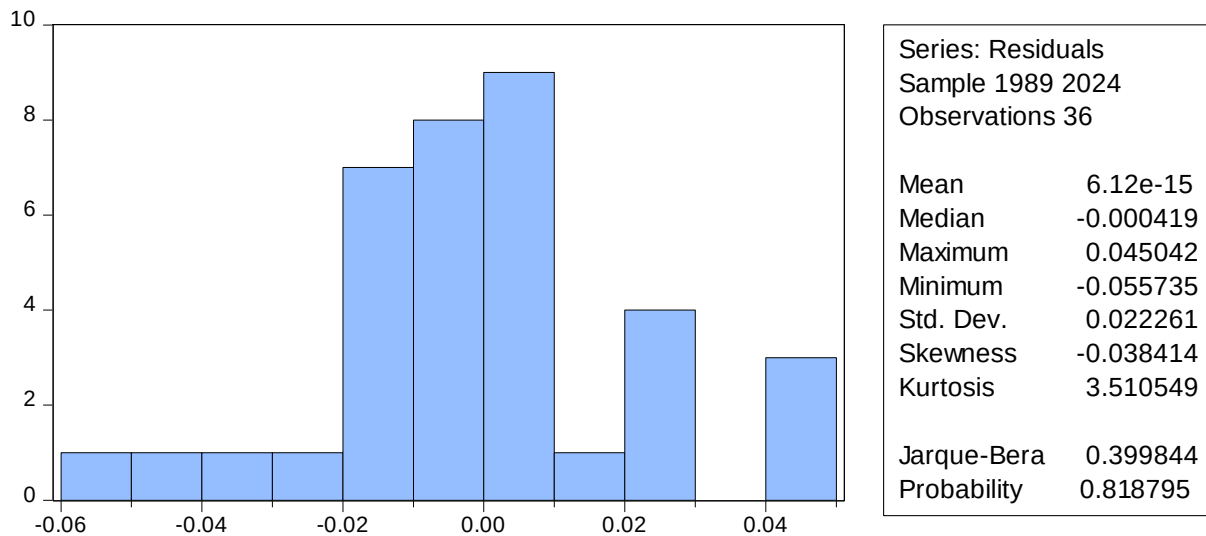


Figure 1: Normality Test Result

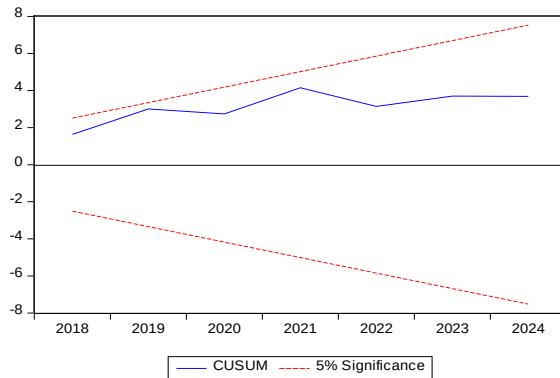


Figure 2: CUSUM Graph

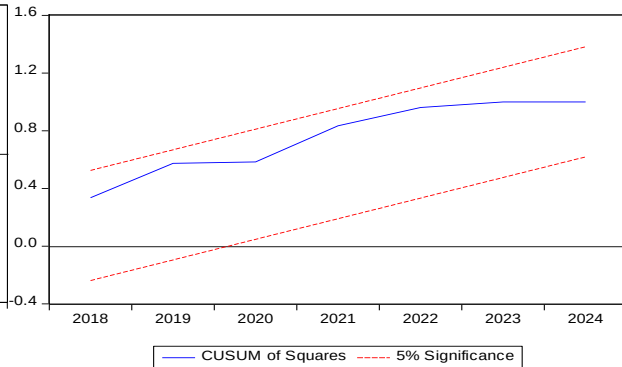


Figure 3: CUSUM Square Graph

Source: Authors Computation 2025

The post-estimation diagnostic tests confirm that the ARDL model is statistically sound and suitable for reliable inference. The Serial Correlation LM test (F-stat = 1.3489; $p = 0.2821$) shows no evidence of autocorrelation, indicating that the residuals are independent over time. The Heteroskedasticity test (F-stat = 0.6666; $p = 0.7812$) suggests that the error terms exhibit constant variance, implying homoskedasticity. The Jarque–Bera normality test (JB = 0.3998; $p = 0.8189$) further confirms that the residuals are normally distributed, satisfying an essential assumption for valid hypothesis testing. The stability of the model is reinforced by the CUSUM and CUSUMSQ plots, which remain within the 5 percent significance boundaries, confirming parameter stability throughout the sample period. Overall, these diagnostic results demonstrate that the model is well specified, free from major econometric problems, and robust enough to support credible policy conclusions.

4.6. Discussion of Findings

The findings of this study reveal that climate vulnerability plays a more pronounced role in shaping manufacturing output in Nigeria in the short run than in the long run. The ARDL results show that fluctuations in rainfall, temperature, and carbon emissions exert significant short-term effects on manufacturing performance, reflecting the sector's immediate exposure to environmental shocks. Excessive rainfall consistently reduces output, likely due to flooding, transport disruptions, and damage to industrial infrastructure, while temperature increases initially suppress productivity before adjustment occurs. These results align with earlier studies that emphasize the sensitivity of industrial activity in developing economies to climate variability, particularly where infrastructure and adaptive capacity remain weak.

In contrast, the long run estimates suggest that climatic variables do not exert statistically strong and stable effects on manufacturing output over time. This indicates that while climate shocks disrupt production in the short run, their long-term influence may be absorbed through gradual adaptation, substitution of inputs, or structural adjustments within firms. However, the insignificance of human capital and investment in the long run points to deeper structural

constraints in Nigeria's manufacturing sector. Weak industrial training systems, limited technological diffusion, and inefficiencies in capital utilization appear to undermine the ability of human capital development and investment to translate into sustained productivity gains.

Macroeconomic factors also exhibit mixed dynamics. GDP shows only marginal long run significance, suggesting that overall economic growth provides limited support to manufacturing unless accompanied by targeted industrial policies. In the short run, investment and trade openness demonstrate significant adjustment effects, highlighting their importance in stimulating manufacturing output when supported by favorable conditions. The significant and negative error correction term confirms that deviations from equilibrium are corrected over time, albeit slowly, reinforcing the idea that Nigeria's manufacturing sector is driven more by short term shocks and policy environments than by strong long run fundamentals. Overall, the findings underscore the vulnerability of the sector to climate and macroeconomic instability and the need for resilience focused industrial strategies.

5. Conclusion and Policy Recommendations

This study examined the impact of climate vulnerability on manufacturing development in Nigeria over the period 1986 to 2024 using the ARDL ECM framework. The empirical findings reveal that Nigeria's manufacturing sector is highly sensitive to short run climatic and macroeconomic shocks, particularly changes in rainfall, temperature, and carbon emissions. These factors significantly influence manufacturing output in the short term, reflecting the sector's exposure to climate related disruptions such as flooding, infrastructure damage, and energy inefficiencies. In contrast, most climatic, human capital, and macroeconomic variables were found to be insignificant in the long run, suggesting that manufacturing performance in Nigeria is not driven by stable long-term fundamentals but rather by short term disturbances and policy environments.

The results further indicate that structural weaknesses limit the sector's ability to translate economic growth, investment, and human capital development into sustained manufacturing productivity. Although GDP shows marginal long run influence, investment and labour force effects remain insignificant, highlighting issues such as inefficient capital utilisation, skill mismatches, and low technological adoption. The presence of a significant error correction mechanism confirms that deviations from equilibrium are gradually corrected, but the slow speed of adjustment underscores the fragility of the sector. These findings suggest that without deliberate structural reforms, Nigeria's manufacturing sector will remain vulnerable to both climate variability and macroeconomic instability.

Based on these outcomes, policy efforts should focus on strengthening climate resilience and improving industrial capacity. Government should prioritise investments in climate resilient infrastructure, including flood control systems, transport networks, and reliable energy supply, to reduce production disruptions. In addition, promoting cleaner and energy efficient

manufacturing technologies through green financing, tax incentives, and regulatory support would mitigate environmental risks while enhancing productivity. Equally important is the need to reform human capital development by aligning education and technical training with industrial needs, alongside policies that encourage innovation, technology transfer, and effective investment utilisation. An integrated industrial and climate policy framework is therefore essential for achieving sustainable manufacturing development in Nigeria.

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