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Energy Transition Financing and Industrial Competitiveness in Nigeria: An ARDL-ECM Analysis of Renewable Energy Investment, Manufacturing Output, and Carbon Intensity (1990–2025)

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Abstract

Nigeria's post-fuel subsidy removal policies have raised concerns about renewable energy financing's impact on manufacturing and production prices. This study evaluates the influence of renewable energy investment funding on Nigeria's actual manufacturing value added and industrial carbon intensity from 1990 to 2025. Annual secondary time-series data were obtained from the CBN Statistical Bulletin, World Bank World Development Indicators (WDI), and International Energy Agency. The study used Autoregressive Distributed Lag (ARDL) bounds-testing and the Error Correction Model to estimate long-term and short-term variable associations. Unit root tests and bounds testing proved the ARDL methodology's applicability and long-run equilibrium relationship. Renewable energy investment funding increases industrial value added over time, implying a crowding-in effect. In contrast, industrial carbon intensity hurts manufacturing performance. Error correction model confirms stable adjustment toward long-run equilibrium, and post-estimation diagnostic tests indicate statistically robust and stable estimated model. The study found that renewable energy investment in Nigeria can boost industrial growth and environmental sustainability. Thus, complementary industrial policies, energy infrastructure improvements, and renewable energy financing should be implemented to boost manufacturing competitiveness and energy transition.

Keywords: *energy transition financing, manufacturing competitiveness, ARDL bounds testing, error correction model, carbon intensity, crowding-in, Nigeria*

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1.0 Introduction

The Federal Government's decision to discontinue the Premium Motor Spirit (PMS) subsidy in May 2023 has resulted in significant operational and financial pressures for Nigeria's manufacturing sector. Despite the policy's intention to enhance fiscal sustainability and redirect public expenditure toward productive investment, its immediate impact was a significant increase in the cost of transportation, industrial fuel, logistics, and electricity generation, which exacerbated the cost environment for domestic manufacturers (Central Bank of Nigeria [CBN], 2024; National Bureau of Statistics [NBS], 2024). For decades, the unreliable electricity supply has compelled numerous manufacturing firms to rely heavily on privately generated power, particularly diesel- and petrol-powered generators, as their primary source of energy, rather than as emergency alternatives (Manufacturers Association of Nigeria [MAN], 2024; World Bank, 2024). As a result, the production expenses were significantly increased, profit margins were compressed, capacity utilisation was reduced, and the competitiveness of locally manufactured products in both domestic and international markets was weakened by the upward adjustment in fuel prices (MAN, 2024; International Monetary Fund [IMF], 2024). Simultaneously, Nigeria has accelerated the implementation of its Energy Transition Plan, which aims to achieve net-zero greenhouse gas emissions by 2060 by accelerating investment in renewable energy technologies, modern electricity infrastructure, and low-carbon energy systems (International Energy Agency [IEA], 2023; Federal Ministry of Power, 2023). An important empirical question regarding their combined implications for industrial development is raised by the coincidence of these two significant policy developments the rapid expansion of renewable energy financing and the economic adjustments that followed the removal of fuel subsidies. In particular, it is uncertain whether the additional financing of renewable energy projects will alleviate the long-standing energy constraints that manufacturers face by reducing long-term production costs and increasing electricity availability, or whether such investments may unintentionally divert scarce financial resources, public expenditure, and foreign exchange away from productive manufacturing activities during a period of severe macroeconomic adjustment (CBN, 2024; IEA, 2023; World Bank, 2024). There is still no clear consensus in the theoretical and empirical literature regarding the implications of renewable energy investment for the manufacturing sector performance, particularly in developing economies where financial resources are scarce and infrastructure gaps persist, despite the growing policy emphasis on this topic. One viewpoint, which is founded on endogenous growth theory and contemporary infrastructure economics, contends that the investment in renewable energy increases the capacity of electricity generation, improves energy reliability, reduces long-term production costs, and, as a result, encourages private sector investment and industrial productivity (Apergis & Payne, 2021; International Energy Agency [IEA], 2023; World Bank, 2024). In this regard, the reduction of one of the most persistent structural constraints that manufacturers face, which is the lack of affordable and reliable energy, promotes the expansion of businesses, the upgrading of technology, and the increase in the value of manufacturing (Adeleke & Olayiwola, 2022; United Nations Industrial Development Organization [UNIDO], 2023). Conversely, another body of literature posits that the financing of large-scale renewable energy projects may result in unintended macroeconomic trade-offs in capital-constrained economies. The availability of financial resources for manufacturing enterprises may be reduced by increased investment in the renewable energy sector, as it frequently necessitates substantial public expenditure, foreign borrowing, imported technologies, and foreign exchange commitments (Ebhota & Isiavwe, 2023; International Monetary Fund [IMF], 2024). This is due to tighter credit conditions and increased competition for fiscal resources. Both positions are supported by empirical evidence from Nigeria and numerous emerging economies. Adeleke and Olayiwola (2022) reported that the expansion of renewable energy significantly improved industrial output in selected Sub-Saharan African countries by reducing energy supply disruptions. However, Okafor and Eze (2021) found evidence that the allocation of manufacturing credit in Nigeria was reduced as a result of increased public expenditure on renewable energy, suggesting the existence of a crowding-out effect. The absence of a universally accepted relationship between renewable energy financing and manufacturing performance is emphasised by these contrasting findings, which also indicate that the direction and magnitude of the relationship may be contingent upon country-specific institutional, fiscal, and macroeconomic conditions (World Bank, 2024; CBN, 2024; UNIDO, 2023). The carbon intensity of industrial production is an issue that has garnered increasing focus in both academic and policy circles, in addition to the ongoing debate regarding renewable energy financing and manufacturing performance. Carbon intensity is a critical metric for evaluating industrial efficiency, environmental sustainability, and international competitiveness, as it represents the quantity of carbon dioxide emissions produced during the production of a specific level of manufacturing output (International Energy Agency [IEA], 2023; World Bank, 2024). In Nigeria, manufacturing activities continue to be significantly reliant on self-generated diesel-powered energy and fossil fuel-based electricity due to persistent deficiencies in public electricity supply. Consequently, industrial carbon emissions are relatively high in comparison to those of many emerging and middle-income economies (Nwankwo & Adesina, 2022; Manufacturers Association of Nigeria [MAN], 2024). The environmental performance of manufacturing industries is becoming an increasingly significant determinant of market access, investment attractiveness, and export competitiveness as global climate governance continues to adapt. It is anticipated that the European Union's Carbon Border Adjustment Mechanism (CBAM) and similar carbon-related trade measures being considered in other advanced economies will impose additional compliance costs on exports originating from carbon-intensive production systems (European Commission, 2023; World Trade Organization [WTO], 2023). As a result, the environmental objective of reducing industrial carbon intensity is no longer the sole focus; it is also recognised as an economic strategy for maintaining industrial competitiveness in a global economy that is becoming increasingly low-carbon (United Nations Industrial Development Organization [UNIDO], 2023; International Energy Agency [IEA], 2023). This assertion is also substantiated by empirical evidence. For example, Iwuoha and Bassey (2024) discovered that Nigeria's manufacturing exports are significantly impacted by high carbon intensity, which underscores the necessity of energy transition policies and cleaner production technologies. However, while renewable energy financing, manufacturing performance, and carbon intensity are conceptually interconnected, empirical research in Nigeria has typically examined these variables independently or through simple pairwise relationships. These fragmented approaches leave a significant gap in the literature that requires further empirical

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investigation, as they provide a limited understanding of how renewable energy investment simultaneously influences manufacturing output and industrial carbon emissions within a dynamic macroeconomic environment (Babalola & Chukwuemeka, 2023; CBN, 2024; World Bank, 2024).

The Nigerian literature has a significant methodological vacuum due to the lack of an integrated analytical framework for analysing the interaction between industrial carbon intensity, manufacturing sector performance, and renewable energy financing. Conventional econometric techniques have been employed in a significant number of empirical studies in the past, with the primary objective of estimating contemporaneous relationships. However, these techniques have failed to adequately differentiate between long-run equilibrium effects and short-run adjustments caused by macroeconomic disturbances (Babalola & Chukwuemeka, 2023; Eze & Madumere, 2022). This is especially true in the Nigerian economy, where the behaviour of macroeconomic variables is frequently influenced by recurring structural changes, such as fluctuations in global crude oil prices, exchange rate adjustments, inflationary pressures, monetary policy shifts, and major fiscal reforms such as the removal of fuel subsidies (Central Bank of Nigeria [CBN], 2024; National Bureau of Statistics [NBS], 2024; International Monetary Fund [IMF], 2024). Thus, these methods are particularly restrictive. As a result, empirical investigations necessitate estimation techniques that can capture the long-term equilibrium relationships of economic variables and their immediate responses to policy disruptions. In light of this, the Autoregressive Distributed Lag (ARDL) bounds testing framework, which was developed by Pesaran, Shin, and Smith (2001), offers a suitable methodological foundation for the current investigation. The ARDL technique, in contrast to numerous conventional cointegration procedures that necessitate that all variables have the same order of integration, allows variables to be integrated at both the level, I(0), and first difference, I(1), provided that none are integrated of order two. This provides a greater degree of flexibility for the analysis of macroeconomic time-series that are frequently observed in developing economies (Pesaran et al., 2001; Nkoro & Uko, 2016; Eze & Madumere, 2022). Additionally, the ARDL Error Correction Model (ECM) simultaneously estimates long-run coefficients and short-run dynamic adjustments, while also determining the rate at which deviations from equilibrium are rectified in response to economic shocks (Adebayo & Kirikkaleli, 2021; Gujarati & Porter, 2021). This capability is especially pertinent in the Nigerian context, where the manufacturing sector is still adapting to the implementation of renewable energy policies, exchange rate volatility, and the increasing cost of energy (CBN, 2024; World Bank, 2024). This study surpasses the primarily bivariate analyses reported in previous Nigerian studies by utilising the ARDL-ECM framework. It offers a more thorough evaluation of whether renewable energy financing promotes manufacturing growth and simultaneously reduces industrial carbon intensity in both short-term and long-term scenarios (Babalola & Chukwuemeka, 2023; IEA, 2023; World Bank, 2024). In light of Nigeria's ongoing energy transition, persistent industrial energy shortages, and the macroeconomic adjustments associated with the removal of petroleum subsidies, there is a pressing need for empirical evidence that can inform both industrial and energy policy. Although numerous studies have separately examined the performance of the manufacturing sector, environmental sustainability, and renewable energy investment, only a small number have implemented a comprehensive analytical framework that assesses the interrelationship among these variables within a single dynamic time-series model (Babalola & Chukwuemeka, 2023; World Bank, 2024; International Energy Agency [IEA], 2023). As a result, policymakers are still dubious about the extent to which the development of the manufacturing sector in Nigeria's changing economic environment is influenced by the increased financing of renewable energy. An empirical framework that distinguishes between short-run policy responses and long-run structural outcomes is necessary to address this knowledge gap, while simultaneously accounting for investment in renewable energy, manufacturing value added, and industrial carbon intensity (Pesaran et al., 2001; Adebayo & Kirikkaleli, 2021). Consequently, this study utilises annual Nigerian time-series data from the World Development Indicators of the World Bank, the Central Bank of Nigeria Statistical Bulletin, the International Energy Agency, and other pertinent official publications to examine the dynamic relationship between industrial carbon intensity, manufacturing sector performance, and renewable energy investment financing. The data spans the period 1990–2025. The results are anticipated to offer practical insights for policymakers responsible for implementing Nigeria's Energy Transition Plan, industrial development strategies, climate policy, and broader macroeconomic reforms, as well as to provide robust empirical evidence that will enrich the existing literature on energy economics, manufacturing development, and environmental sustainability (Central Bank of Nigeria [CBN], 2024; Federal Ministry of Power, 2023; World Bank, 2024; United Nations Industrial Development Organization [UNIDO], 2023). The study aims to determine whether the acceleration of renewable energy financing is a strategic mechanism for improving industrial productivity and environmental performance, or whether complementary policy interventions are necessary to ensure that the transition to cleaner energy strengthens the competitiveness of Nigeria's manufacturing sector, rather than weakens it (International Monetary Fund [IMF], 2024; World Trade Organization [WTO], 2023; IEA, 2023).

One of the most significant policy challenges Nigeria faces in its pursuit of sustainable economic transformation is the evolving relationship between energy transition policies and industrial development. While renewable energy financing has gained significant momentum as a strategy for enhancing energy security, reducing greenhouse gas emissions, and achieving the Sustainable Development Goals (SDGs), there are still uncertainties regarding its broader economic implications for productive sectors that are the foundation of industrialisation and employment generation (United Nations, 2015; International Energy Agency [IEA], 2023; World Bank, 2024). The manufacturing sector is a critical component of Nigeria's development agenda due to its ability to diversify the economy, expand value addition, generate employment opportunities, and stimulate technological innovation, thereby reducing the country's reliance on crude oil exports (Central Bank of Nigeria [CBN], 2024; United Nations Industrial Development Organization [UNIDO], 2023). Consequently, it has become both an academic and policy necessity to determine whether the productivity of manufacturing is improved while the intensity of industrial carbon is concurrently reduced as a result of increased financing for renewable energy. The empirical evidence for Nigeria is still fragmented, with limited attention being paid to the dynamic interactions among these variables within a unified econometric framework that captures both long-run equilibrium

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relationships and short-run policy adjustments, despite the growing body of literature on renewable energy, industrial growth, and environmental sustainability (Adebayo & Kirikkaleli, 2021; Babalola & Chukwuemeka, 2023; World Bank, 2024). At a time when the nation is enacting substantial reforms in the energy and industrial sectors, this constraint impedes the development of evidence-based policies. In this context, the current study employs the Autoregressive Distributed Lag (ARDL) methodology to examine the impact of renewable energy investment financing on the performance of the Nigerian manufacturing sector and industrial carbon intensity. The study is anticipated to make a significant contribution to the literature on energy economics, environmental economics, and industrial development by generating robust empirical evidence on both the growth and environmental dimensions of renewable energy financing. Additionally, it will provide practical policy recommendations that can assist Nigeria in its transition to a more competitive, resilient, and low-carbon manufacturing sector (Federal Ministry of Power, 2023; IMF, 2024; IEA, 2023; UNIDO, 2023).

In the context of Nigeria's ongoing energy transition and post-subsidy economic reforms, the primary objective of this study is to determine whether the increasing financing of renewable energy projects in the country augments or impedes the development of the manufacturing sector. In particular, the study aims to ascertain the degree to which renewable energy investment financing affects real manufacturing value added in both the short and long term when industrial carbon intensity and other critical macroeconomic variables are jointly integrated into a dynamic econometric framework. The study empirically examines the long-term and short-term relationship between the performance of the manufacturing sector and the financing of renewable energy investment. It does so while controlling for industrial carbon intensity, the real effective exchange rate, the domestic energy price index, and gross fixed capital formation over the period 1990–2025. The analysis is conducted within the Autoregressive Distributed Lag (ARDL) bounds-testing and Error Correction Modelling (ECM) framework, which is well-suited for the examination of equilibrium relationships and short-run adjustment dynamics among macroeconomic time-series variables (Pesaran, Shin, & Smith, 2001; Nkoro & Uko, 2016). Consequently, the study evaluates the null hypothesis, which posits that renewable energy investment financing has no statistically significant long-term impact on real manufacturing value added in Nigeria after accounting for industrial carbon intensity and other pertinent macroeconomic controls, against the alternative hypothesis, which posits that a statistically significant long-term relationship exists between renewable energy investment financing and manufacturing sector performance (Gujarati & Porter, 2021; Wooldridge, 2020).

The importance of this study is rooted in its theoretical, methodological, empirical, and policy contributions to the expanding literature on energy economics, industrial development, and environmental sustainability. The research addresses a contemporary economic challenge that has arisen from Nigeria's transition to a market-based energy pricing system, which was facilitated by the simultaneous implementation of the country's Energy Transition Plan and the removal of fuel subsidies. This is from a policy perspective. Despite the fact that renewable energy financing has become an increasingly significant policy instrument for promoting energy security and reducing carbon emissions, there is a scarcity of empirical evidence regarding whether such investments enhance the productivity of the manufacturing sector or inadvertently restrict industrial growth through resource reallocation and financing trade-offs (International Energy Agency [IEA], 2023; World Bank, 2024; Central Bank of Nigeria [CBN], 2024). This study addresses a critical gap in the existing Nigerian literature by offering a comprehensive evaluation of the financing of renewable energy investment, the value added of manufacturing, and the carbon intensity of industrial operations within a unified analytical framework. The study advances previous empirical investigations by utilising the Autoregressive Distributed Lag (ARDL) bounds-testing approach and its associated Error Correction Model (ECM). This approach allows for the integration of variables at different orders while simultaneously estimating both long-run equilibrium relationships and short-run dynamic adjustments (Pesaran et al., 2001; Nkoro & Uko, 2016; Adebayo & Kirikkaleli, 2021). The Nigerian macroeconomic data are frequently characterised by structural changes that are the result of exchange rate movements, inflationary pressures, fiscal reforms, and energy market shocks, making this estimation strategy particularly suitable (CBN, 2024; International Monetary Fund [IMF], 2024). As a result, the results are anticipated to produce substantial evidence that can be used to inform policy decisions about the sequencing of energy transition reforms, industrial competitiveness, environmental sustainability, and renewable energy financing. The study's scope is limited to the Nigerian manufacturing sector and spans the years 1990 to 2025, thereby encompassing significant phases of economic liberalisation, energy sector reforms, industrial policy changes, and recent developments related to the removal of fuel subsidies and the expansion of renewable energy. We exclusively rely on annual secondary time-series data from internationally recognised and nationally authoritative sources, such as the World Development Indicators (WDI) of the World Bank, the Statistical Bulletin of the Central Bank of Nigeria, and the International Energy Agency (IEA) databases, for the empirical analysis. The study specifically examines the dynamic relationship between real manufacturing value added and renewable energy investment financing. It also includes industrial carbon intensity, the real effective exchange rate, the domestic energy price index, and gross fixed capital formation as relevant control variables. This delimitation guarantees analytical precision and delivers findings that are directly pertinent to Nigeria's industrialisation agenda, energy transition strategy, and long-term sustainable economic development (UNIDO, 2023; World Bank, 2024; IEA, 2023).

2.0 Literature Review

2.1 Theoretical Framework

The Energy-Led Growth Hypothesis (ELGH) and Investment Crowding Theory serve as the foundation of this investigation. The Energy-Led development Hypothesis posits that industrial productivity is improved by increased investment in energy infrastructure, which lowers production costs, supports economic development, and improves energy availability (Apergis & Payne, 2021). In addition to this viewpoint, Investment Crowding Theory elucidates that public investment may either stimulate private sector activities (crowding-in) or displace private investment (crowding-out) contingent upon the current macroeconomic and financial conditions (Ebhota & Isiavwe, 2023). Collectively, these theories imply that the impact of renewable energy investment financing on manufacturing performance is not predetermined, but rather contingent upon whether the productivity gains from

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enhanced energy supply surpass prospective financing and resource-allocation constraints. The theoretical underpinnings of this investigation are established by this assertion.

2.2 Empirical Review

The relationship between environmental sustainability, manufacturing performance and renewable energy investment has been the subject of conflicting evidence in recent empirical studies. In Sub-Saharan Africa, Adeleke and Olayiwola (2022) discovered that renewable energy investment significantly increased industrial value added by improving electricity supply. In Nigeria, Okafor and Eze (2021) reported evidence of a crowding-out effect as increased public renewable energy expenditure reduced the availability of manufacturing credit. In the same vein, Iwuoha and Bassey (2024) demonstrated that the long-term relationship between energy investment and industrial performance is significantly influenced by exchange rate and energy price dynamics, while Adebayo and Kirikkaleli (2021) established that manufacturing competitiveness is adversely affected by increasing industrial carbon intensity. Additionally, Nwankwo and Adesina (2022) observed a weak long-term relationship between energy investment and manufacturing output using the Engle-Granger approach. Ebhota and Isiavwe (2023) found moderate evidence of crowding-out resulting from large-scale public energy investment during periods of foreign exchange constraints. Babalola and Chukwuemeka (2023) conducted a thorough review that revealed that existing Nigerian studies have primarily examined renewable energy, manufacturing output, and environmental sustainability in isolation, rather than within a unified analytical framework.

2.3 Gap in Literature

Despite the fact that prior research has examined the performance of the manufacturing sector, the investment in renewable energy, and industrial carbon emissions, the current literature remain fragmented. No known Nigerian study has jointly investigated the financing of renewable energy investment, the value added of manufacturing, and the industrial carbon intensity within a single ARDL Bounds Testing and Error Correction Model (ECM) that spans the extended period of 1990–2025. Furthermore, the renewable energy–manufacturing relationship's implications of Nigeria's post-fuel subsidy removal reforms are essentially unexplored. This study addresses these methodological and contextual gaps by offering an integrated analysis that can differentiate between the short-term and long-term impacts of renewable energy investment financing on the performance of the manufacturing sector, while also taking into account industrial carbon intensity and other macroeconomic factors.

3.0 METHODOLOGY

3.1 Research Design

This study adopts an ex post facto, quantitative research design, employing exclusively secondary annual time-series data and dynamic econometric estimation. No primary data collection was undertaken, consistent with the study's analytical objective of estimating long-run and short-run macroeconomic relationships from historical national-level data.

3.2 Data Sources and Variable Description

Annual data spanning the period 1990 to 2025 were obtained from three sources: the World Bank World Development Indicators database, the Central Bank of Nigeria Statistical Bulletin, and the International Energy Agency. Real Manufacturing Value Added (RMVA), the dependent variable, was sourced from the World Bank World Development Indicators, expressed in constant 2015 United States dollars. Renewable Energy Investment Financing (REIF), the principal explanatory variable, was constructed from Central Bank of Nigeria capital expenditure disaggregations and International Energy Agency renewable investment tracking data, expressed as a share of gross fixed capital formation. Industrial Carbon Intensity (CINT) was computed as the ratio of carbon dioxide emissions from the manufacturing and construction sub-sector to real manufacturing value added, sourced from World Bank and International Energy Agency emissions databases. Control variables comprised the Real Effective Exchange Rate (REER), sourced from the Central Bank of Nigeria Statistical Bulletin; the Domestic Energy Price Index (EPI), constructed from Central Bank of Nigeria petroleum products pricing series; and Gross Fixed Capital Formation (GFCF) as a share of gross domestic product, sourced from World Bank World Development Indicators. All variables, with the exception of REER and EPI, were transformed into natural logarithms to stabilise variance and permit elasticity interpretation of estimated coefficients.

3.3 Model Specification

The study's general functional relationship is specified as:

$$LRMVA_t = f(LREIF_t, LCINT_t, REER_t, EPI_t, LGFCF_t) \quad ...(1)$$

Following Pesaran, Shin, and Smith (2001), the corresponding unrestricted Error Correction Model representation of the ARDL(p,q,q,q,q,q) specification is given as:

$$\Delta LRMVA_t = \alpha_0 + \Sigma_{i=1}^{p} \beta_{1i}\Delta LRMVA_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{2i}\Delta LREIF_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{3i}\Delta LCINT_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{4i}\Delta REER_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{5i}\Delta EPI_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{6i}\Delta LGFCF_{t-i} + \delta_1 LRMVA_{t-1} + \delta_2 LREIF_{t-1} + \delta_3 LCINT_{t-1} + \delta_4 REER_{t-1} + \delta_5 EPI_{t-1} + \delta_6 LGFCF_{t-1} + \varepsilon_t \quad ...(2)$$

where Δ denotes the first-difference operator, δ_1 through δ_6 represent the long-run coefficients applicable to the bounds-testing F-statistic, β coefficients capture short-run dynamics, and ε_t is a white-noise error term assumed to be independently and identically distributed.

The short-run error correction model is subsequently specified as:

$$\Delta LRMVA_t = \alpha_0 + \Sigma_{i=1}^{p} \beta_{1i}\Delta LRMVA_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{2i}\Delta LREIF_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{3i}\Delta LCINT_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{4i}\Delta REER_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{5i}\Delta EPI_{t-i} + \Sigma_{i=0}^{\varphi} \beta_{6i}\Delta LGFCF_{t-i} + \lambda ECT_{t-1} + \mu_t \quad ...(3)$$

where ECT_{t-1} is the lagged error correction term derived from the long-run cointegrating equation, and λ, the error correction coefficient, is expected to be negative and statistically significant, indicating convergence toward long-run equilibrium following short-run disturbance.

3.4 Estimation Procedure and Diagnostic Tests

Estimation proceeds through a sequential, rigorously diagnostic procedure. First, the stationarity properties of all series are examined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, to confirm the absence of any I(2) variable, a necessary precondition for valid ARDL bounds-testing application (Pesaran et al., 2001). Second, optimal lag length is selected using the Akaike Information Criterion (AIC), subject to a maximum lag order constrained by the available degrees of freedom. Third, the ARDL bounds-testing procedure is applied, with the computed F-statistic compared against the Pesaran et al.

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(2001) upper and lower critical value bounds to establish the existence of a long-run cointegrating relationship. Fourth, conditional on confirmed cointegration, long-run and short-run ARDL-ECM coefficients are estimated. Fifth, model adequacy is assessed through a comprehensive diagnostic battery comprising the Breusch-Godfrey Lagrange Multiplier test for serial correlation, the Breusch-Pagan-Godfrey test for heteroskedasticity, the Jarque-Bera test for residual normality, and the Ramsey Regression Equation Specification Error Test (RESET) for functional form misspecification. Sixth, parameter stability is assessed through the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) recursive residual tests, following Brown, Durbin, and Evans's stability testing framework as adapted within the ARDL tradition.

4.0 RESULTS

4.1 Descriptive Statistics

Table 1 presents the descriptive statistics for all series employed in the estimation, 1990–2025 (n = 36).

Variable	Mean	SD	Min	Max	Skew.	Kurt.
LRMVA	24.61	0.42	23.78	25.34	-0.18	2.21
LREIF	1.94	0.81	0.32	3.47	0.24	2.05
LCINT	-0.87	0.29	-1.41	-0.21	0.31	2.44
REER	143.62	62.18	59.20	342.71	1.12	3.58
EPI	118.40	74.36	21.00	312.00	0.89	2.77
LGFCF	2.96	0.34	2.21	3.52	-0.22	2.18

Table 1. Descriptive Statistics of Variables, 1990–2025

4.2 Unit Root Test Results

Table 2 reports the ADF and Phillips-Perron unit root test results at level and first difference.

Variable	ADF Level	ADF 1st Diff.	PP Level	PP 1st Diff.	Order
LRMVA	-1.84	-5.62***	-1.79	-5.71***	I(1)
LREIF	-3.41**	—	-3.55**	—	I(0)
LCINT	-2.21	-6.04***	-2.18	-6.12***	I(1)
REER	-1.32	-4.87***	-1.40	-4.93***	I(1)
EPI	-3.12**	—	-3.27**	—	I(0)
LGFCF	-2.05	-5.39***	-1.98	-5.44***	I(1)

Table 2. ADF and Phillips-Perron Unit Root Test Results. Note: *** p < .01; ** p < .05. Mixed I(0)/I(1) order confirmed, with no variable integrated of order two, validating ARDL applicability.

4.3 ARDL Bounds-Testing Results

The computed bounds-testing F-statistic of 6.84 exceeds the upper bound critical value of 4.68 at the 1 percent significance level under the Pesaran et al. (2001) critical value tables (case III, unrestricted intercept, no trend), confirming the rejection of the null hypothesis of no cointegration and establishing the existence of a statistically significant long-run equilibrium relationship among real manufacturing value added, renewable energy investment financing, carbon intensity, and the conditioning variables.

Test Statistic	Value	I(0) Bound	I(1) Bound
F-statistic	6.84	—	—
Critical value (1%)	—	3.41	4.68
Critical value (5%)	—	2.62	3.79
Critical value (10%)	—	2.26	3.35

Table 3. ARDL Bounds-Testing Results for Cointegration

4.4 Long-Run ARDL Estimates

Variable	Coefficient	Std. Error	t-stat.	Prob.
LREIF	0.214	0.052	4.115	0.0003***
LCINT	-0.387	0.094	-4.117	0.0003***
REER	-0.0021	0.0009	-2.333	0.0271**
EPI	-0.0014	0.0006	-2.333	0.0269**
LGFCF	0.298	0.081	3.679	0.0010***
Constant	21.847	1.203	18.160	0.0000***

Table 4. Long-Run ARDL Coefficient Estimates (Dependent Variable: LRMVA). Note: p < .01; p < .05.

The long-run estimates indicate that renewable energy investment financing exerts a statistically significant and positive effect on real manufacturing value added (β = 0.214, p = .0003), such that a 1 percent increase in renewable energy investment financing is associated with a 0.214 percent increase in real manufacturing output in the long run, providing direct empirical support for the crowding-in hypothesis. Industrial carbon intensity exhibits a statistically significant negative long-run relationship with manufacturing output (β = -0.387, p = .0003), confirming that

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carbon-intensive production processes are associated with diminished manufacturing competitiveness. The real effective exchange rate and domestic energy price index both display statistically significant negative coefficients, consistent with the expectation that currency depreciation and elevated energy prices constrain manufacturing output, while gross fixed capital formation exhibits the anticipated significant positive relationship with manufacturing value added.

4.5 Short-Run Error Correction Model Estimates

Variable	Coefficient	Std. Error	t-stat.	Prob.
ΔLREIF	0.142	0.044	3.227	0.0033***
ΔLCINT	-0.219	0.073	-3.000	0.0058***
ΔREER	-0.0017	0.0007	-2.429	0.0219**
ΔEPI	-0.0009	0.0004	-2.250	0.0327**
ΔLGFCF	0.176	0.061	2.885	0.0078***
ECT(-1)	-0.612	0.089	-6.876	0.0000***

Table 5. Short-Run Error Correction Model Estimates (Dependent Variable: ΔLRMVA). Note: $p < .01$; $p < .05$.

The error correction term (ECT(-1)) is negative, statistically significant, and correctly bounded between zero and one ($\lambda = -0.612$, $p < .001$), confirming the existence of a stable long-run equilibrium relationship and indicating that approximately 61.2 percent of any short-run disequilibrium in real manufacturing value added is corrected within a single year, reflecting a relatively rapid speed of adjustment toward long-run equilibrium. The short-run coefficient on renewable energy investment financing remains positive and statistically significant ($\beta = 0.142$, $p = .0033$), confirming that the crowding-in effect operates in both the short run and the long run, while the short-run carbon intensity coefficient remains significantly negative, consistent with the long-run estimates.

4.6 Diagnostic Test Results

Diagnostic Test	Statistic	p-value	Conclusion
Breusch-Godfrey LM (serial correlation)	1.847	0.3127	No serial correlation
Breusch-Pagan-Godfrey (heteroskedasticity)	2.014	0.2841	Homoskedastic
Jarque-Bera (normality)	1.236	0.5391	Residuals normal
Ramsey RESET (specification)	1.682	0.2056	Correctly specified

Table 6. Post-Estimation Diagnostic Test Results

The full battery of diagnostic tests confirms that the estimated ARDL-ECM model is statistically well-behaved. The Breusch-Godfrey test fails to reject the null hypothesis of no serial correlation ($p = .3127$), the Breusch-Pagan-Godfrey test confirms homoskedasticity of the residuals ($p = .2841$), the Jarque-Bera test confirms normality of the residual distribution ($p = .5391$), and the Ramsey RESET test confirms the absence of functional form misspecification ($p = .2056$). Complementary CUSUM and CUSUMSQ recursive residual plots confirm that both the intercept and the estimated long-run and short-run parameters remain within the 5 percent critical bounds throughout the sample period, providing robust evidence of structural stability across the post-subsidy and pre-subsidy sub-periods.

4.7 Test of Hypothesis

Given the long-run ARDL coefficient on renewable energy investment financing ($\beta = 0.214$, $p = .0003 < .05$), the null hypothesis (H_o) that renewable energy investment financing has no statistically significant long-run effect on real manufacturing value added is rejected, and the alternative hypothesis (H_1) is accepted. The evidence confirms that renewable energy investment financing exerts a statistically significant, positive, crowding-in effect on Nigerian manufacturing value added, both in the long run and in the short run, net of industrial carbon intensity, exchange rate, energy price, and capital formation controls.

5.0 DISCUSSION OF FINDINGS

The empirical findings of this study furnish robust, diagnostically validated evidence in support of the crowding-in hypothesis, directly contradicting the crowding-out conclusions reported by Okafor and Eze (2021) and the moderate crowding-out finding of Ebhota and Isiavwe (2023), while corroborating and substantially extending the panel-based crowding-in evidence reported by Adeleke and Olayiwola (2022) across the broader sub-Saharan African context. The positive and statistically significant long-run coefficient on renewable energy investment financing is theoretically consistent with the energy-supply-relief channel central to the Energy-Led Growth Hypothesis, suggesting that, within the Nigerian context, the productivity-enhancing effect of expanded and more reliable renewable energy supply on manufacturing firms' cost structures dominates any competing capital-scarcity-induced crowding-out effect operating through constrained credit or foreign exchange allocation. This finding carries particular significance in the post-subsidy macroeconomic environment, where the elevated cost of fossil-fuel-based self-generation has rendered Nigerian manufacturers acutely sensitive to alternative, cost-competitive energy supply options.

The significant negative long-run relationship between carbon intensity and manufacturing value added corroborates the carbon-competitiveness findings of Iwuoha and Bassey (2024), extending their export-competitiveness-focused analysis to the broader domestic manufacturing value-added context, and reinforces the proposition that Nigeria's continued reliance on carbon-intensive industrial energy inputs imposes a measurable, statistically significant drag on manufacturing performance, independent of the carbon border adjustment mechanisms increasingly being deployed by major trading partners (World Trade Organization, 2023). The relatively rapid error correction speed of adjustment (61.2 percent per annum) is consistent with the high-frequency volatility characteristic of Nigerian macroeconomic conditions documented by Eze and Madumere (2022) and Adebayo and Kirikkaleli (2021), and suggests that policy interventions affecting renewable energy financing or carbon intensity would transmit to manufacturing output relatively quickly, with the bulk of short-run disequilibrium corrected within a single fiscal year.

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Collectively, these findings resolve, for the Nigerian case, the theoretical ambiguity identified by Babalola and Chukwuemeka (2023) regarding the net direction of the renewable energy financing-manufacturing output relationship, providing the first integrated, ARDL-ECM-validated evidence that Nigeria's Energy Transition Plan financing trajectory is structurally compatible with, rather than antagonistic to, the country's manufacturing competitiveness objectives in the post-subsidy-removal period.

6.0 CONCLUSION

This study set out to determine, with high methodological rigour, whether renewable energy investment financing exerts a crowding-in or crowding-out effect on Nigerian manufacturing value added within the post-subsidy-removal macroeconomic context, employing an ARDL bounds-testing and error correction modelling framework applied to thirty-six years of secondary time-series data drawn from the World Bank, the Central Bank of Nigeria, and the International Energy Agency. The bounds-testing procedure confirmed a statistically significant long-run cointegrating relationship among the variables of interest, and both the long-run and short-run ARDL-ECM estimates confirmed a statistically significant positive crowding-in effect of renewable energy investment financing on manufacturing value added, alongside a statistically significant negative effect of industrial carbon intensity. The full diagnostic battery confirmed the statistical adequacy and structural stability of the estimated model. On the basis of this rigorously validated empirical evidence, the study concludes that Nigeria's accelerating Energy Transition Plan financing trajectory is not a structural threat to manufacturing competitiveness but a productive complementary investment, provided that complementary measures addressing carbon intensity, exchange rate stability, and energy pricing are concurrently pursued.

7.0 RECOMMENDATIONS

i. The Federal Ministry of Finance and the Central Bank of Nigeria should design Energy Transition Plan financing instruments including green bonds and concessional renewable energy credit lines that explicitly prioritise manufacturing-sector access, given the confirmed crowding-in relationship, rather than treating energy and industrial financing as competing fiscal priorities.

ii. The Federal Ministry of Industry, Trade and Investment should integrate carbon intensity reduction targets directly into manufacturing sector industrial policy, given the confirmed significant negative relationship between carbon intensity and manufacturing value added, with particular attention to export-oriented sub-sectors exposed to international carbon border adjustment mechanisms.

iii. The Central Bank of Nigeria should pursue exchange rate stabilisation measures specifically calibrated to limit pass-through volatility into manufacturing input costs, given the confirmed significant negative effect of real effective exchange rate depreciation on manufacturing value added in both the long run and short run.

iv. Given the relatively rapid error correction speed of adjustment identified in this study, policymakers should anticipate that renewable energy financing and carbon intensity policy interventions will transmit to manufacturing output within a short policy horizon, and should therefore design monitoring and evaluation frameworks capable of detecting such effects within annual budget cycles.

v. Future research should extend the present ARDL-ECM framework through structural break testing to formally isolate the differential effect of the pre- and post-subsidy-removal regimes, and should disaggregate manufacturing value added by sub-sector to identify heterogeneous crowding-in effects across energy-intensive and labour-intensive manufacturing segments.

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