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# Asymmetric Effects of Economic Growth on Green Investment in Nigeria and the Role of Institutional Quality: Evidence from a Nonlinear ARDL Approach

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**Abstract**

Nigeria's green transition is constrained by a persistent climate-financing gap and governance weaknesses, yet the joint influence of macroeconomic performance and institutional quality on green investment remains poorly understood in this setting. This study examines the asymmetric effects of economic growth and institutional quality on green investment in Nigeria over 2000-2024 using a Nonlinear Autoregressive Distributed Lag (NARDL) model, controlling for carbon emissions, ecological footprint, and innovation. Cointegration is established via both asymptotic and McNown-Sam-Goh bootstrap bounds tests. Formal Wald tests confirm that green investment responds asymmetrically to shocks in economic growth and carbon emissions. Positive growth shocks raise green investment substantially more than equivalent negative shocks reduce it, consistent with a ratchet-type pattern where committed green projects resist unwinding during downturns. Institutional quality and innovation are positively associated with green investment over the long run, while a rising ecological footprint correlates with a decline, reflecting fossil-fuel dependence crowding out cleaner alternatives. Approximately 68% of short-run disequilibria are correct within a year, indicating a fast return to equilibrium. Robustness checks under parsimonious lag structures confirm the stability of these asymmetries. The findings suggest that accelerating green investment in Nigeria requires targeted governance reforms and counter-cyclical financing mechanisms to sustain green capital flows through economic downturns.

**Keywords**

Green investment, Nonlinear ARDL, Asymmetric effects, Institutional quality, Economic growth, Nigeria; Ecological footprint

**JEL Classification**

Q01; Q55; O43; C22; H54

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## 1. Introduction

The global imperative to transition toward low-carbon, climate-resilient development has elevated green investment to the forefront of economic policy discourse. Green investment is understood here as capital directed toward renewable energy, energy-efficient infrastructure, and other low-carbon assets, and it is widely treated as a precondition for reconciling growth objectives with environmental limits [1,2]. Global climate finance is estimated to have reached roughly USD 1.3 trillion a year in 2021/22, still far short of the USD 8.1-9 trillion a year estimated to be needed annually to 2030 to keep warming within 1.5°C [3], and the shortfall is sharpest for developing economies: Sub-Saharan Africa attracted under 1.5 percent of global energy-transition investment between 2000 and 2020 despite carrying a disproportionate share of climate risk. That gap is not simply a shortage of resources; it reflects, in large part, weaknesses in governance and institutional credibility.

A well-established strand of theory links institutional quality to investment behaviour. New institutional economics [4] and endogenous growth theory [5] both point to the same mechanism: the quality of a country's institutions shapes the incentive structure within which investment decisions are made. Governance characterised by regulatory quality, rule of law, government effectiveness, control of corruption, and accountability lowers transaction costs, raises policy credibility, and reduces the political risk that disproportionately deters long-horizon, capital-intensive green projects [6,7]. Where institutions are weak, by contrast, both domestic and foreign investors are reluctant to commit capital over the extended horizons that renewable energy and green infrastructure require, and a growing empirical literature indicates that governance quality conditions development outcomes in developing-country samples [8], that exchange-rate volatility weighs on Nigeria's non-oil exports and growth prospects [9], and that green finance and renewable-energy markets are closely interconnected [10].

Economic growth is the second determinant of interest. The environmental Kuznets curve hypothesis [11] predicts that as economies develop, they eventually acquire the financial capacity, technological capability, and social demand needed for cleaner production; more directly, sustained growth widens fiscal space, deepens capital markets, and draws private capital into sustainable technologies [12]. Growth on its own, however, is not sufficient: in institutionally weak settings the additional resources it generates tend to be dissipated through rent-seeking, misallocation, and regulatory capture, a pattern documented in resource-dependent economies more generally [13]. It follows that the joint behaviour of institutional quality and economic growth, rather than either factor considered separately, is what ultimately governs whether growth is converted into expanded green investment—a joint conditioning effect that has received little direct attention in the Africa-focused literature and that motivates the present study.

Nigeria presents a compelling but paradoxical case for examining these dynamics. As Africa's largest economy, with a GDP of approximately USD 363 billion in 2023 [14], Nigeria commands substantial macroeconomic scale and harbours extensive untapped renewable energy resources, including solar resources whose annual energy capacity is estimated at roughly 27 times its fossil-fuel capacity [15]. The Tracking SDG7 report, produced jointly by the International Energy Agency, IRENA, UNSD, the World Bank, and WHO [16], ranks Nigeria as the country with the largest population lacking electricity access—an estimated 86 million people in 2021—while the World Bank puts the annual economic cost of energy poverty at around USD 26.2 billion, roughly 2 percent of GDP. These figures underline the scale of the opportunity, yet the gap between potential and reality remains wide: in 2021/22 only about USD 2.5 billion in public and private capital, under 1 percent of GDP, was directed to climate action against an estimated annual financing gap of USD 27.2 billion. Nigeria's tracked climate finance that year was roughly equal to its foreign debt-servicing cost (USD 2.3 billion) and was dwarfed by the USD 9.3 billion spent on fossil-fuel subsidies in 2022 alone [15].

The institutional environment compounds these challenges. Nigeria ranked 140th of 180 countries on Transparency International's 2024 Corruption Perceptions Index, scoring 26 out of 100 against a global average of 43 and a Sub-Saharan African average of 33 [17]. Across the six dimensions of the World Bank's Worldwide Governance Indicators, Nigeria scores persistently in the lower percentiles for government effectiveness, regulatory quality, and rule of law [18]—dimensions that prior work identifies as particularly consequential for investor confidence in capital-intensive sectors [19,20]. Weak governance has also been linked directly to the mismanagement of climate funds and delayed progress on emissions reduction. Despite growing recognition of this institutional dimension, the Nigerian green-investment literature remains fragmented: related work has examined renewable energy consumption and environmental quality in Nigeria [21], the macroeconomic consequences of crude-oil price movements for Nigeria [22], and the links between renewable energy, environmental sustainability, and growth in Africa [23], but has not rigorously tested how institutional quality and economic growth jointly shape the level of green investment, nor whether that relationship is symmetric.

This paper contributes to literature in three specific ways. First, it provides the first Nigeria-specific nonlinear time-series evidence on how economic growth and institutional quality jointly relate to green investment, using annual data spanning 2000-2024. Second, it applies a Nonlinear ARDL (NARDL) framework that decomposes economic growth and carbon-emission shocks into their positive and negative partial sums, allowing green investment to respond asymmetrically to expansions versus contractions rather than imposing the symmetric-adjustment assumption of a standard linear ARDL. This choice is methodologically motivated: theory predicts a ratchet-type response—growth expansions may generate disproportionately large increases in green investment as fiscal space and investor optimism widen, while contractions

may not produce a matching decline because committed, often multilaterally co-financed, projects are not easily unwound–and a linear model cannot detect this pattern even if it is present. Third, it extends the analysis beyond the growth-institutions nexus by simultaneously conditioning on carbon emissions, ecological footprint, and technological innovation, and it draws out the policy implications for Nigeria's Energy Transition Plan and its broader climate-financing agenda. The remainder of the paper is organised as follows: Section 2 reviews the theoretical and empirical literature; Section 3 describes the data, variable construction, and econometric methodology; Section 4 presents and interprets the empirical results; and Section 5 draws conclusions and derives policy implications.

## 2. Empirical Literature

The empirical literature on the nexus between institutional quality, economic growth, and green investment has grown quickly, but it remains scattered across methodological frameworks and country groups. To draw out what is established and what is not–the review below is organised thematically rather than as a country-by-country catalogue, moving from cross-country and regional evidence toward the Nigeria-specific studies that most directly motivate the present design.

Institutional Quality and Green Finance. At the cross-country level, Shanyazov et al. [24] examined the role of institutional quality in the renewable energy transition of MIKTA countries (2000-2023) using a Cross-Sectionally Augmented ARDL (CS-ARDL) approach; a one-unit improvement in control of corruption raised renewable energy consumption by roughly 2.3 percent, and the error-correction term implied that about 37 percent of annual deviations from equilibrium were corrected within a year. Yadav et al. [25] examined good governance, renewable energy investment, and green finance in the BRICS economies over two decades using the same CS-ARDL approach, finding that renewable investment mitigates $CO_2$ emissions most strongly when paired with robust governance and green-finance deployment. Rahman and Sultana [26], using a panel PMG-ARDL model for 19 emerging economies (2002-2019), similarly found that institutional effectiveness, growth, and export performance jointly and positively drive renewable energy consumption, reinforcing the view that institutional quality is an active driver of green outcomes rather than a passive background condition.

Growth-Environment Asymmetries and Regional Evidence. Zhao et al. [27] is the closest methodological antecedent to the present study, applying panel NARDL to G-7 countries (1997-2021) and finding that both positive and negative shocks to green investment and institutional quality are positively associated with environmental performance, while growth shocks in either direction raise performance in the long run–evidence that the transmission mechanism differs by income level and that findings from high-income panels cannot simply be read across to Nigeria. Wang et al. [28] applied FMOLS and a VECM to oil- and non-oil-producing African countries (1999-2017) and found that institutional quality promotes growth and environmental quality in non-oil economies but has no significant growth effect in oil producers–a result of direct relevance to Nigeria as a hydrocarbon-dependent economy. At the sub-Saharan African level, Appiah et al. [29] used Bootstrap Quantile Regression and panel OLS across six institutional dimensions and found that corruption control and government effectiveness raise green GDP while rule of law and regulatory quality do not, cautioning against treating institutional quality as a single, monolithic construct. Teklie and Yağmur [30], using pooled mean group, mean group, and dynamic fixed-effects estimators for 49 African countries (2000-2021), found that green innovation, renewable energy consumption, institutional quality, and GDP per capita raise green growth in the long run, while foreign direct investment and natural-resource depletion have adverse effects; in the short run only institutional quality and GDP per capita remain significant. Degbedji et al. [31] documented considerable cross-country heterogeneity within the WAEMU bloc (2002-2017): institutional quality enhances green growth in some member states but weakens it in others, indicating that the institutional quality-green growth link is sensitive to country-specific structural conditions. Mohamed et al. [32] extended this line of enquiry to Somalia's ecological footprint (1990-2020), finding a positive GDP-footprint elasticity that flattens at higher income levels, broadly consistent with an environmental Kuznets pattern. At the global level, Gan [33] compared FMOLS, DOLS, and OLS estimators across 30 emerging economies and found that the sign of the institutional quality-carbon emissions relationship is sensitive to estimator choice; Ferreira et al. [34] found that green growth performance raises human development in high- and middle-income countries but less so in lower-income settings; Balcilar et al. [35] reported small but positive growth effects of green energy investment, concentrated in lower per-capita-income quantiles, across a panel of OECD economies; and Wu et al. [36] showed that green investment supports high-quality economic development in China through structural transformation and innovation.

Sub-Saharan African and Nigeria-Specific Evidence. Within Nigeria specifically, Goshit and Shido-Ikwu [37] applied the ARDL bounds test and Toda-Yamamoto causality to renewable energy consumption and growth (1990-2019) and found a negative long-run relationship together with causality running from renewable consumption to growth. Oyebanji et al. [38] applied ARDL bounds testing green growth and environmental variables (1980-2015) and found a negative long-run relationship between carbon emissions and renewable energy, alongside a positive association between deforestation and green growth. Adeku et al. [39] identified weak institutional capacity, restricted access to finance, and adverse risk perceptions as the principal structural barriers to green finance adoption in Nigeria and SSrecommended coordinated regulatory reform and capacity-building. Akpan [40] documented that renewable energy investment disclosure has a significant positive effect on the sustainable growth of listed Nigerian oil and gas companies, pointing to transparency as an underexplored institutional channel.

Taken together, three gaps motivate the present study. First, while institutional quality is broadly confirmed as a positive determinant of green and renewable-energy investment, its specific channels and magnitudes in sub-Saharan Africa's largest economy remain underexplored. Second, most existing studies impose a symmetric-adjustment (linear) specification that may conceal differential responses of green investment to positive versus negative shocks in growth and carbon emissions. Third, Nigeria-specific evidence remains sparse, and no study to date has formally modelled the asymmetric relationship between economic growth, carbon emissions, and green investment for Nigeria, with institutional quality as a conditioning determinant using a nonlinear time-series framework. Table 1 summarises the key studies reviewed.

**Table 1.** Summary of key related studies.

| Author(s)/Year | Country/Period | Methodology | Key Variables | Main Finding |
|---|---|---|---|---|
| Shanyazov et al. [24] | MIKTA, 2000-2023 | Panel CS-ARDL | Institutional quality, renewable energy | Institutional quality raises renewable energy transition |
| Yadav et al. [25] | BRICS, ~2000-2020s | Panel CS-ARDL | Governance, RE investment, green finance | Governance and green finance jointly reduce $CO_2$ |
| Rahman & Sultana [26] | 19 emerging economies, 2002-2019 | Panel PMG-ARDL | Institutional effectiveness, growth, exports | Institutions, growth, exports jointly raise renewable energy |
| Zhao et al. [27] | G-7, 1997-2021 | Panel NARDL | Green investment, institutional quality | Asymmetric positive effects of both variables |
| Wang et al. [28] | African oil/non-oil countries, 1999-2017 | FMOLS, VECM | Institutional quality, FDI, growth | Effects differ by oil-dependence status |
| Appiah et al. [29] | Sub-Saharan Africa | Bootstrap Quantile Regression, panel OLS | Six WGI dimensions, green GDP | Corruption control and government effectiveness matter most |
| Teklie & Yağmur [30] | 49 African countries, 2000-2021 | PMG/MG/DFE | Green innovation, RE, institutional quality | All raise green growth; institutions dominate short run |
| Degbedji et al. [31] | WAEMU, 2002-2017 | FMOLS | Institutional quality, green growth | Effect direction varies by country |
| Goshit and Shido-Ikwu [37] | Nigeria, 1990-2019 | ARDL bounds, Toda-Yamamoto | Renewable energy, growth | Negative long-run relationship |
| Oyebanji et al. [38] | Nigeria, 1980-2015 | ARDL bounds | Carbon emissions, renewable energy | Negative $CO_2$-RE relationship |
| Adeku et al. [39] | Nigeria | Descriptive/policy | Green finance barriers | Weak institutions, limited finance access |

Note: Table constructed from the studies reviewed above; entries are illustrative summaries and should be read alongside the full discussion in the text.

**Theoretical Framework:** This study is anchored on three complementary theoretical frameworks–Institutional Theory, Endogenous Growth Theory, and Ecological Modernization Theory–whose joint application provides a coherent basis for understanding how economic growth and institutional quality relate to green investment outcomes in Nigeria. Institutional Theory, pioneered by North [4] and extended by Acemoglu et al. [41], establishes that the formal and informal rules governing economic life–property rights, regulatory frameworks, and accountability mechanisms–determine the incentive structures within which investment decisions are made. Strong institutions reduce transaction costs, enhance policy credibility, and lower the perceived risk of long-duration capital commitments, all of which are essential for attracting investment into capital-intensive sectors such as renewable energy and green infrastructure [6,19]. In Nigeria, where the 2024 Corruption Perceptions Index score of 26 out of 100 and persistently weak World Bank governance indicators reflect deep-seated institutional weaknesses [17,18], the theory predicts that governance reform is a precondition for any sustainable expansion of green investment.

Endogenous Growth Theory, developed by Romer [5,42] and extended by Aghion and Howitt [43], complements this institutional perspective by explaining the mechanism through which economic growth generates the financial resources, knowledge spillovers, and technological capabilities needed to scale green investment over time. This framework places deliberate investment in innovation and human capital at the centre of the growth process, treating public policy and institutional quality as active determinants of the long-run growth trajectory rather than background conditions [44,45]. For the present study, the theory implies that the growth-green investment relationship is inherently nonlinear and potentially asymmetric: growth expansions may generate disproportionately large increases in green investment as innovation externalities compound and fiscal space widens, while contractions may not produce symmetrically

proportional declines, given the irreversibility of committed projects and the stabilising role of multilateral financing arrangements [2,12]. This theoretical prediction motivates the adoption of the Nonlinear ARDL framework in the empirical strategy below.

Ecological Modernization Theory (EMT), advanced by Huber [46] and elaborated by Mol [47] and Spaargaren and Mol [48], provides the overarching developmental narrative that ties the institutional and growth channels together. The theory argues that economic modernisation, when accompanied by institutional adaptation and technological innovation, need not conflict with environmental sustainability; rather, the progressive integration of ecological values into market structures and governance systems can generate a virtuous cycle of green investment, innovation, and environmental improvement [49,50]. Applied to Nigeria, EMT implies that green investment growth will not emerge spontaneously from rising incomes alone but requires deliberate institutional redesign, including environmental regulatory reform, green-finance market development, and innovation-system strengthening [39,51].

Theory-proxy tension should be flagged explicitly. The theoretical discussion above draws on Schumpeterian and endogenous-growth accounts of domestically generated innovation, yet the empirical proxy for innovation used below (technology transfer, INNV) is measured as ICT imports as a share of total imports. Importing ICT equipment captures technology diffusion and adoption capacity rather than domestic R&D effort or green-technology invention as such; it is, at best, an indirect proxy for the innovation channel the theory describes. The proxy is retained because internationally comparable, annually observed indicators of domestic green-technology innovation are not available for Nigeria over 2000-2024, and ICT-import intensity is a standard, precedented proxy for technology diffusion in the cross-country literature. Results involving INNV should accordingly be interpreted as evidence on technology absorption rather than on domestic innovation capacity, and this distinction is revisited in the conclusion.

A related asymmetry-in-modelling choice also needs to be stated up front. Economic growth and carbon emissions are decomposed into positive and negative partial sums below because theory offers a specific directional reason to expect asymmetry in each case–the ratchet mechanism for growth, and the regulatory-pressure mechanism for emissions (elaborated in Section 4). Institutional quality is retained in symmetric (linear) form. This is a modelling simplification rather than a theoretical claim that institutional improvement and institutional deterioration have identical effects; if anything, prior work on institutional reform suggests deterioration may transmit faster than improvement (reforms typically build credibility slowly, while governance shocks can erode it quickly). The symmetric treatment of institutional quality here is dictated by the sample size: decomposing a third variable into positive and negative partial sums would add further regressors to an already parameter-heavy specification estimated on 25 annual observations (see Section 3), at a cost to the degrees of freedom that the data cannot comfortably absorb. Asymmetric institutional-quality effects are accordingly identified as a specific priority for future work with longer or higher-frequency series, rather than being tested here. Accordingly, the asymmetry claims in this paper, including those in its title, refer to economic growth and carbon emissions only; institutional quality enters as a symmetric long-run determinant.

## 3. Methodology

Annual time-series data for 25 observations (2000-2024) are employed. The choice of period and frequency reflects the availability of an unbroken, annually observed series for all six variables over 2000-2024; higher-frequency (quarterly) data are not consistently available for green investment or institutional quality in Nigeria over this period, a constraint discussed further as a limitation below. The starting point is the idea that green investment does not occur in isolation: it is shaped by how well institutions function and by how the economy performs over time. Drawing on Institutional Theory and Endogenous Growth Theory, strong institutions are expected to create a stable environment that encourages investment, while sustained economic growth provides the financial capacity for environmentally friendly projects. Ecological Modernization Theory further suggests that economic progress and environmental sustainability can reinforce one another when supported by effective policies. Table 2 defines the variables and their measurement.

**Table 2.** Definition and measurement of variables.

| Variable | Symbol | Measurement | Description |
|---|---|---|---|
| Green Investment | GIN | USD million | Financial flows into environmentally sustainable projects such as renewable energy and climate-resilient infrastructure |
| Economic Growth | EG | GDP growth rate (%) | Annual percentage growth rate of gross domestic product |
| Carbon Emissions | $CO_2$ | Mt $CO_2$ equivalent | Total carbon emissions |
| Ecological Footprint | ECFP | GHA per capita | Ecological resource use relative to biocapacity |
| Institutional Quality | INQ | WGI Rule of Law (-2.5 to +2.5) | Proxy for governance quality, regulatory effectiveness, and legal enforcement |
| Technology Transfer (Innovation) | INNV | ICT imports (% of total imports) | Proxy for technological diffusion (see theory-proxy discussion above) |

Data sources. Green Investment (GIN) is compiled from the Central Bank of Nigeria (CBN) Statistical Bulletin (specifically, the Capital Importation and External Debt tables) and the World Bank International Debt Statistics (IDS) and project-level database. The aggregation procedure involves summing all annual financial disbursements (rather than commitments, to reflect actual realized capital flows) for projects classified under renewable energy and climate-resilient infrastructure. Currency conversion to USD millions was applied using the CBN end-of-year official exchange rates for any local currency disbursements. To avoid double counting between the CBN and World Bank datasets, we matched unique project identifiers and cross-referenced beneficiary institutions, retaining only unique disbursement records. The final series represents the net annual green capital inflows. Economic growth (EG) and carbon emissions ($CO_2$) are obtained from World Bank World Development Indicators; ecological footprint (ECFP) is obtained from the Global Footprint Network's National Footprint and Biocapacity Accounts; institutional quality (INQ) is the Rule of Law dimension of the World Bank's Worldwide Governance Indicators [18]; and innovation (INNV) is proxied by ICT imports as a percentage of total imports, sourced from World Bank World Development Indicators.

Institutional quality proxy. Rule of Law is used, rather than a composite of all six WGI dimensions or an alternative single dimension, because it most directly captures the contract-enforcement and property-rights environment that Institutional Theory identifies as central to long-horizon capital commitments of the kind green investment requires; it is also the dimension most consistently used as a single-indicator proxy for institutional quality in the comparable NARDL literature cited above [27]. The WGI are published biennially for 2000 and 2002, with no separate 2001 estimate; the 2001 value used in estimation was obtained by linear interpolation between the 2000 and 2002 WGI Rule of Law estimates. This affects a single data point in a 25-observation series and is disclosed here in the interest of full reproducibility.

Based on the reasoning above, green investment is treated as the outcome variable, influenced by institutional quality, economic growth, and other supporting macroeconomic and environmental factors. In its simplest form, the relationship can be expressed as

$$GI_t = f(IQ_t,\ EG_t,\ X_t) \tag{1}$$

where $X_t$ is a vector of the remaining conditioning variables (carbon emissions, ecological footprint, and innovation). To move from this general specification to an estimable Nonlinear ARDL model, economic growth and carbon emissions are first decomposed into their positive and negative partial sums, following the standard NARDL construction of Shin et al. [52]. For economic growth,

$$EG_{+t} = \sum_{(j=1)}^{t} \Delta EG_{j+} = \sum_{(j=1)}^{t} \max(\Delta EG_j, 0) \quad \text{and} \quad EG_{-t} = \sum_{(j=1)}^{t} \Delta EG_{j-} = \sum_{(j=1)}^{t} \min(\Delta EG_j, 0) \tag{2}$$

with $CO_{2+t}$ and $CO_{2-t}$ constructed analogously for carbon emissions. Because $EG_{-t}$ (and $CO_{2-t}$) accumulate only non-positive changes, they are non-increasing series; this is important for interpreting the sign of their coefficients (see Section 4). Institutional quality, ecological footprint, and innovation are retained as symmetric (level) regressors, for the reasons set out in Section 2. The long-run NARDL specification is therefore

$$\ln GIN_t = \beta_0 + \beta_1 EG_{+t} + \beta_2 EG_{-t} + \beta_3 \ln CO2_{+t} + \beta_4 \ln CO2_{-t} + \beta_5 INQ_t + \beta_6 \ln ECFP_t + \beta_7 \ln INNV_t + \mu_t \tag{3}$$

Under this construction, the long-run effect on ln GIN of a one-unit cumulative contraction (a one-percentage-point fall in EG or a one-percent fall in $CO_2$) is the negative of the corresponding coefficient ($-\beta_2$ or $-\beta_4$), so the Wald tests of $\beta_1 = \beta_2$ and $\beta_3 = \beta_4$ in Section 4 are tests of symmetry between the effect of an increase and the effect of a decrease. The corresponding Unrestricted Error Correction Model (UECM), estimated to recover both the short-run dynamics and the long-run relationship in a single step, is

$$\begin{aligned}\Delta \ln GIN_t = {} & \alpha_0 + \rho \cdot \ln GIN_{t-1} + \theta_1 EG_{+t-1} + \theta_2 EG_{-t-1} + \theta_3 \ln CO2_{+t-1} + \theta_4 \ln CO2_{-t-1} + \theta_5 INQ_{t-1} + \theta_6 \ln ECFP_{t-1} + \theta_7 \ln INNV_{t-1} + \\ & \sum_{i=1}^{p} \varphi_i \Delta \ln GIN_{t-i} + \sum_{i=0}^{q} (\pi_i + \Delta EG_{+t-i} + \pi_i - \Delta EG_{-t-i}) + \sum_{i=0}^{q} (\gamma_i + \Delta \ln CO2_{+t-i} + \gamma_i - \Delta \ln CO2_{-t-i}) + \sum_{i=0}^{q} \delta_i \Delta INQ_{t-i} + \\ & \sum_{i=0}^{q} \lambda_i \Delta \ln ECFP_{t-i} + \sum_{i=0}^{q} \kappa_i \Delta \ln INNV_{t-i} + \varepsilon_t\end{aligned} \tag{4}$$

where $\rho$ is the error-correction coefficient (reported as ECT(-1) in Section 4), long-run coefficients are recovered as $\beta_j = -\theta_j/\rho$, and p, q are lag orders selected by the Akaike Information Criterion. Long-run symmetry between the positive and negative components (e.g., $\beta_1 = \beta_2$) is tested with a standard Wald test, reported in Section 4.

Sample size and degrees of freedom. The dataset comprises 25 annual observations. This is a genuine and binding constraint: conventional guidance for ARDL/NARDL bounds testing, including the small-sample critical-value tables of Narayan [53], is tabulated from a minimum of 30 observations, so the present sample falls below even the smallest sample size for which small-sample-adjusted critical values are directly available. Estimating a six-variable NARDL with partial-sum decomposition and multiple lags on 25 observations exhausts degrees of freedom quickly–the Ramsey RESET test in Section 4, for example, is estimated on only 10 residual degrees of freedom–and this raises a real risk of overfitting that the diagnostic tests alone cannot fully rule out. The implications of this constraint, and how it should be weighed against the results reported below, are discussed explicitly in Sections 4 and 5; the results should be read as suggestive evidence appropriate to a short annual series for a single country, rather than as precision estimates suitable for point-forecasting or for calibrating specific policy thresholds. To address this limitation, the asymptotic bounds test of Pesaran

et al. [54] is supplemented in Section 4 by the bootstrap ARDL bounds test of McNown et al. [55] that does not rely on tabulated critical values, and all results are read as indicative.

Given the nature of the Nigerian data, the Nonlinear Autoregressive Distributed Lag (NARDL) approach is appropriate, as it allows for the estimation of both short-run and long-run relationships even when variables are not integrated at the same order, and—as elaborated in Section 4—it accommodates the asymmetric partial-sum decomposition motivated above.

## 4. Empirical Results

Table 3 presents the descriptive statistics for all variables employed in the analysis over the study period 2000-2024. The mean value of green investment (GIN) stands at USD 582.12 million, with a standard deviation of USD 724.35 million, reflecting considerable temporal dispersion. The pronounced positive skewness of 1.721 indicates that the distribution of green investment is right-tailed, consistent with the episodic and lumpy nature of capital commitment to low-carbon projects in developing economies, where investment surges tend to be driven by discrete policy events, donor-funded initiatives, or singular large-scale projects rather than smooth, continuous accumulation [7,15]. Economic growth (EG) averaged 4.28% per annum, with a standard deviation of 2.98%, encompassing episodes of contraction (minimum -1.79%) and a peak of 11.32% in the commodity boom years of the early 2000s. Carbon emissions ($CO_2$) averaged 108.64 Mt, while institutional quality (INQ) averaged -1.133 on the WGI scale, indicating persistently weak governance across the sample. Innovation (INNV) averaged 6.336 on the ICT-import measure, exhibiting moderate negative skewness (-0.255).

**Table 3.** Descriptive statistics.

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. | Skewness |
|---|---|---|---|---|---|---|
| GIN | 25 | 582.12 | 724.35 | 45.00 | 2800.00 | 1.721 |
| EG | 25 | 4.28 | 2.98 | -1.79 | 11.32 | -0.042 |
| $CO_2$ | 25 | 108.64 | 13.28 | 89.00 | 131.91 | -0.193 |
| ECFP | 25 | 1.155 | 0.028 | 1.10 | 1.22 | -0.027 |
| INQ | 25 | -1.133 | 0.056 | -1.27 | -1.04 | -0.302 |
| INNV | 25 | 6.336 | 1.717 | 3.10 | 8.90 | -0.255 |

Note: GIN = Green Investment (USD million); EG = Economic Growth (%); $CO_2$ = Carbon Emissions (Mt); ECFP = Ecological Footprint; INQ = Institutional quality (WGI Rule of Law); INNV = Innovation (ICT imports, % of total imports). All statistics computed for 25 annual observations (2000-2024).

Table 4 reports unit root test results from the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Zivot-Andrews (ZA) tests, accounting for structural breaks.

**Table 4.** Unit root test results.

| Variable | ADF Level | ADF 1st Diff. | PP Level | PP 1st Diff. | ZA Level | ZA Break Year | ZA 1st Diff. | Order |
|---|---|---|---|---|---|---|---|---|
| lnGIN | -1.824 | -4.312*** | -1.912 | -4.817*** | -4.215 | 2016 | -5.102*** | I(1) |
| EG | -2.104 | -5.671*** | -1.987 | -5.913*** | -3.562 | 2009 | -6.014*** | I(1) |
| ln$CO_2$ | -1.763 | -4.105*** | -1.831 | -4.344*** | -2.987 | 2012 | -5.488*** | I(1) |
| lnECFP | -2.431 | -4.789*** | -2.208 | -5.014*** | -3.102 | 2020 | -5.371*** | I(1) |
| INQ | -1.987 | -5.112*** | -2.014 | -5.342*** | -3.445 | 2020 | -5.784*** | I(1) |
| lnINNV | -1.542 | -4.621*** | -1.689 | -4.908*** | -2.876 | 2017 | -5.219*** | I(1) |
| Critical Values (5%) | -2.986 | -2.986 | -2.979 | -2.979 | -4.800 | — | -4.800 | — |

Note: *** denotes rejection of the unit root null hypothesis at the 1% level. Zivot-Andrews (ZA) tests are estimated with 15% trimming of each end of the sample, which excludes break dates at the sample boundary.

The identified break years merit two comments. First, five of the six reported dates plausibly align with well-documented events in Nigeria's recent macroeconomic history: the 2009 break in EG is broadly consistent with the domestic banking-sector crisis and the global financial crisis; the newly identified 2016 break in lnGIN (estimated with a standard 15% trim to avoid boundary artefacts) aligns closely with Nigeria's severe macroeconomic recession and subsequent capital flight; the 2012 break in ln$CO_2$ is broadly consistent with the January 2012 fuel-subsidy removal crisis; the 2017 break in lnINNV is broadly consistent with Nigeria's exit from recession and the naira devaluation/import-substitution period; and the shared 2020 break in both lnECFP and INQ is consistent with the COVID-19 downturn. These parallels are offered as

plausible context, noting that a Zivot-Andrews break is a statistical artefact of the series and its underlying cause is not formally identified by the test itself.

All six series are found to be non-stationary in levels but stationary at first difference, i.e., integrated of order one, I(1). It is worth stating explicitly why this uniform I(1) result does not disqualify the NARDL bounds-testing approach: the bounds test of Pesaran et al. [54] is derived to remain valid whether the underlying regressors are I(0), I(1), or a mixture of the two, provided none is integrated of order two, I(2); the pure-I(1) case observed here is consequently a valid, nested special case of the general testing framework rather than a violation of its assumptions. This uniform I(1) ordering satisfies the necessary precondition for the NARDL bounds testing framework of Shin et al. [52], which requires only that no variable be integrated of order two. Table 5 reports the bounds test for cointegration.

**Table 5.** NARDL bounds test for cointegration results.

| Test Statistic | Value | I(0) Bound (5%) | I(1) Bound (5%) |
|---|---|---|---|
| F-statistic (Asymptotic) | 7.824*** | 2.62 | 3.79 |
| t-statistic (ECT) | -4.312*** | -2.86 | -3.53 |
| Bootstrap F-stat (5,000 reps) | 7.824*** | Bootstrap p-value: 0.002 | Decision: Reject $H_0$ |
| Lag order (AIC) | 2 | | |

Note: *** indicates significance at the 1% level.

To address the small-sample limitations of asymptotic critical bounds, we applied the McNown-Sam-Goh bootstrap bounds test with 5,000 replications. The bootstrap p-value of 0.002 confirms cointegration at the 1% level, robustly validating the long-run relationship despite the short sample size (N=25). With that caveat noted, the estimated F-statistic of 7.824 exceeds even the upper I(1) bound at the 5% level, and the ECT t-statistic of -4.312 lies below the corresponding lower bound, jointly indicating a long-run cointegrating relationship among the variables. Having established cointegration, Table 6 reports the long-run NARDL coefficient estimates.

**Table 6.** NARDL long-run coefficient estimates.

| Variable | Coefficient | Std. Error | t-Statistic | p-Value | Significance |
|---|---|---|---|---|---|
| Panel A: Positive Shocks (Asymmetric Components) | | | | | |
| $EG^+$ (Positive EG shocks) | 0.4821 | 0.1123 | 4.293 | 0.001 | *** |
| $lnCO_2^+$ (Positive $CO_2$ shocks) | 1.2314 | 0.2187 | 5.631 | 0.000 | *** |
| Panel B: Negative Shocks (Asymmetric Components) | | | | | |
| $EG^-$ (Negative EG shocks) | -0.2134 | 0.0987 | -2.162 | 0.044 | ** |
| $lnCO_2^-$ (Negative $CO_2$ shocks) | -0.8712 | 0.1934 | -4.504 | 0.000 | *** |
| Panel C: Symmetric Regressors | | | | | |
| lnECFP | -1.8743 | 0.4521 | -4.146 | 0.001 | *** |
| INQ | 0.9234 | 0.2867 | 3.220 | 0.006 | *** |
| lnINNV | 1.4521 | 0.2134 | 6.805 | 0.000 | *** |
| Constant | 3.2187 | 1.0432 | 3.086 | 0.008 | *** |

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. $EG^+$ and $EG^-$ represent cumulative positive and negative partial sums of economic growth (Equation 2); $lnCO_2^+$ and $lnCO_2^-$ represent corresponding partial sums of log carbon emissions. Dependent variable: ln(Green Investment). Under Equation (2), $EG^-$ and $lnCO_2^-$ are non-increasing partial sums, so the long-run effect of a one-unit contraction equals the negative of the reported coefficient.

### 4.1 Economic Growth (Asymmetric Effects)

The positive partial-sum component of economic growth ($EG^+$) carries a long-run coefficient of 0.4821, statistically significant at the 1% level (t = 4.293), implying that a sustained positive shock—specifically, a cumulative 1-percentage-point increase in Nigeria's economic growth rate—is associated, in the long run, with a 0.482% increase in green investment. The economic intuition is grounded in the theory of environmental demand: as incomes rise, households and firms accumulate the financial resources to afford cleaner technologies, while governments gain the fiscal space to fund green infrastructure and regulatory enforcement [5,12]. Higher growth also deepens domestic capital markets, reduces the risk premium on long-duration assets, and signals macroeconomic stability to foreign green investors, all of which amplify the investment response [2].

The negative partial-sum component ($EG^-$) carries a coefficient of -0.2134, significant at the 5% level (t = -2.162). Because $EG^-$ is constructed as a cumulative sum of only the negative changes in economic growth (Equation 2), it is by construction a non-increasing series: a further fall in the growth rate makes $EG^-$ more negative. The coefficient must

therefore be read with its sign reversed for a contraction: a cumulative one-percentage-point fall in the growth rate is associated, in the long run, with a 0.213% increase in green investment (−1 × −0.2134), not a decrease. The asymmetry is accordingly not one of magnitude alone: expansions raise green investment (by 0.482% per percentage point), whereas contractions are not associated with a decline in it and, if anything, with a modest rise. This is consistent with the theoretical expectation that committed, often multilaterally co-financed, green projects are not unwound in downturns, and it is also compatible with counter-cyclical public or concessional green spending during contractions; we treat these mechanisms as plausible explanations rather than tested ones, given the short sample. The asymmetry is confirmed formally by the Wald test reported below ($F = 8.341$, $p = 0.011$).

### 4.2 Carbon Emissions (Asymmetric Effects)

The long-run coefficient on $lnCO_2^+$ (positive emission shocks) is 1.2314, highly significant at the 1% level ($t = 5.631$), indicating that rising carbon emissions are associated with a larger volume of green investment in the long run. This is consistent with a "pollution-haven crowding-in" or regulatory-ratchet mechanism [20]: as emissions escalate, the social and regulatory costs of inaction rise, generating pressure for green policy interventions and incentivising abatement investment. The coefficient on $lnCO_2^-$ (negative emission shocks) is -0.8712 ($t = -4.504$, $p < 0.001$). As with $EG^-$, $lnCO_2^-$ is a cumulative sum of negative changes, so its sign must be reversed for a reduction: a cumulative one-percent fall in emissions is associated with a 0.871 percent increase in green investment. Green investment therefore rises with movements in emissions in both directions, more strongly with increases (1.231) than with reductions (0.871). Emission reductions are accordingly not associated with a relaxation of green-investment effort; abatement-related investment appears to accompany falling emissions. Because partial sums of trending series can pick up common trends, the size of both coefficients should be interpreted cautiously. The asymmetry between the positive and negative $CO_2$ coefficients is statistically confirmed by the Wald test ($F = 6.712$, $p = 0.019$).

### 4.3 Reconciling the Carbon Emissions and Ecological Footprint Results

A direct tension needs to be addressed rather than left implicit: positive $CO_2$ shocks are associated with more green investment ($\beta^+ = 1.231$), while a rising ecological footprint is associated with less green investment ($\beta = -1.874$), even though both variables index environmental pressure. The two variables are not capturing the same thing, and this is the basis for treating them differently rather than a genuine contradiction. $CO_2^+$ measures a flow—the year-on-year escalation of emissions—which plausibly triggers a reactive regulatory and reputational response (the "regulatory-ratchet" channel above) largely independent of the country's broader resource-use pattern. Ecological footprint, by contrast, is a stock-like, structural measure of aggregate resource dependence (land, energy, and material use relative to biocapacity) that proxies the depth of Nigeria's embeddedness in a fossil-fuel-and-land-intensive growth model; a persistently high or rising footprint indicates that capital, policy attention, and institutional capacity remain absorbed by conventional resource-intensive activity, crowding out the "policy bandwidth" and capital that green investment requires. On this reading, a sudden increase in emissions prompts a reactive green-investment response, while a chronically high or rising ecological footprint signals sustained structural crowding-out that suppresses it; the two results are therefore complementary rather than contradictory, but the interpretation rests on treating one variable as a shock and the other as a structural-trap indicator, and should be read as a plausible mechanism rather than a tested one.

### 4.4 Institutional Quality

The coefficient on INQ is 0.9234, statistically significant at the 1% level ($t = 3.220$, $p = 0.006$). Interpreted against the WGI Rule of Law scale, which ranges from approximately -2.5 (weakest) to +2.5 (strongest) governance, a one-standard-deviation improvement in institutional quality (approximately 0.056 index units, from Table 3) is associated with a long-run increase of approximately 5.2 percent in green investment ($0.9234 \times 0.056 \times 100$). Institutional quality is referred to throughout as the WGI Rule of Law indicator rather than a composite governance measure; the coefficient should be read as applying specifically to this single dimension of governance rather than to institutional quality in general. Because INQ enters in symmetric form, the coefficient is the average effect of institutional improvement and deterioration; whether the two differ is not tested here. The mechanism plausibly operates through lower political and regulatory risk, reduced diversion of public funds through rent-seeking, and stronger investor confidence in the durability of policy commitments [4,6,19]. This finding is broadly consistent with panel evidence from G-7 and BRICS-type samples [25,27], though the larger Nigerian coefficient plausibly reflects the amplifying effect of marginal governance improvements at the lower tail of a severely weak institutional distribution.

### 4.5 Ecological Footprint

The coefficient on lnECFP is -1.8743, statistically significant at the 1% level ($t = -4.146$, $p = 0.001$), indicating that a 1 percent increase in Nigeria's ecological footprint is associated with a 1.874 percent decline in green investment in the long run, consistent with the structural-trap interpretation set out above and with evidence that crude-oil price volatility undermines Nigeria's manufacturing output and industrial performance [56], and reinforcing the urgency of the diversification agenda embedded in Nigeria's Energy Transition Plan [57].

### 4.6 Innovation

The coefficient on lnINNV is 1.4521, the largest in absolute magnitude among the symmetric regressors and significant at the 1% level ($t = 6.805$, $p < 0.001$). A 1 percent increase in the ICT-import proxy for technology diffusion is associated with a 1.452 percent long-run increase in green investment, consistent with a Schumpeterian view of technological capability as an engine of green-investment expansion [5,27]. As noted in Section 2, this result should be read as evidence on technology absorption and diffusion capacity, not on domestic green-innovation effort as such. Off-grid generation through solar mini-grids alone could foster an estimated USD 9.2 billion in annual market investment in Nigeria [58], suggesting that diffusion-driven cost reductions hold real transformative potential regardless of how the innovation channel is ultimately measured.

Table 7 presents the short-run NARDL estimates and the error-correction term. The lagged dependent variable coefficient ($\Delta$lnGIN (-1) = 0.3124, $t = 3.165$, $p = 0.007$) indicates positive and significant persistence in green investment, consistent with project pipelines, multi-year financing cycles, and adjustment costs that prevent instantaneous reallocation of capital [7]. The error-correction term (ECT(-1) = -0.6812, $t = -5.480$, $p < 0.001$) is negative, significant, and falls within the theoretically admissible range of (-1, 0), confirming the stability of the long-run equilibrium; a coefficient of -0.681 implies that approximately 68.1 percent of short-run disequilibrium in green investment is corrected within a single year, a relatively fast speed of adjustment for annual data in the error-correction framework [52] commonly applied to Nigerian macroeconomic series [59], though it also implies that roughly one-third of disequilibria persist beyond the contemporaneous period. Figure 1 and Figure 2 lot the asymmetric dynamic multipliers implied by these estimates for economic growth and carbon emissions, respectively.

**Table 7.** NARDL short-run dynamics and error-correction results.

| Variable | Coefficient | Std. Error | t-Statistic | p-Value | Significance |
|---|---|---|---|---|---|
| $\Delta$lnGIN(-1) | 0.3124 | 0.0987 | 3.165 | 0.007 | *** |
| $\Delta EG^{+}$ | 0.1843 | 0.0621 | 2.967 | 0.010 | *** |
| $\Delta EG^{+}(-1)$ | 0.1214 | 0.0543 | 2.237 | 0.041 | ** |
| $\Delta EG^{-}$ | -0.0934 | 0.0487 | -1.917 | 0.075 | * |
| $\Delta \ln CO_2^{+}$ | 0.4512 | 0.1043 | 4.326 | 0.001 | *** |
| $\Delta \ln CO_2^{-}$ | -0.3214 | 0.0912 | -3.524 | 0.004 | *** |
| $\Delta$lnECFP | -0.6781 | 0.1872 | -3.622 | 0.003 | *** |
| $\Delta$INQ | 0.3412 | 0.1214 | 2.810 | 0.014 | ** |
| $\Delta$lnINNV | 0.5213 | 0.1034 | 5.042 | 0.000 | *** |
| ECT(-1) | -0.6812 | 0.1243 | -5.480 | 0.000 | *** |

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels. ECT(-1) = error-correction term; the short-run coefficients on $\Delta EG^{-}$ and $\Delta \ln CO_2^{-}$ follow the same sign convention as their long-run counterparts: the effect of a decline equals the negative of the reported coefficient. $\Delta$ denotes first-differences.

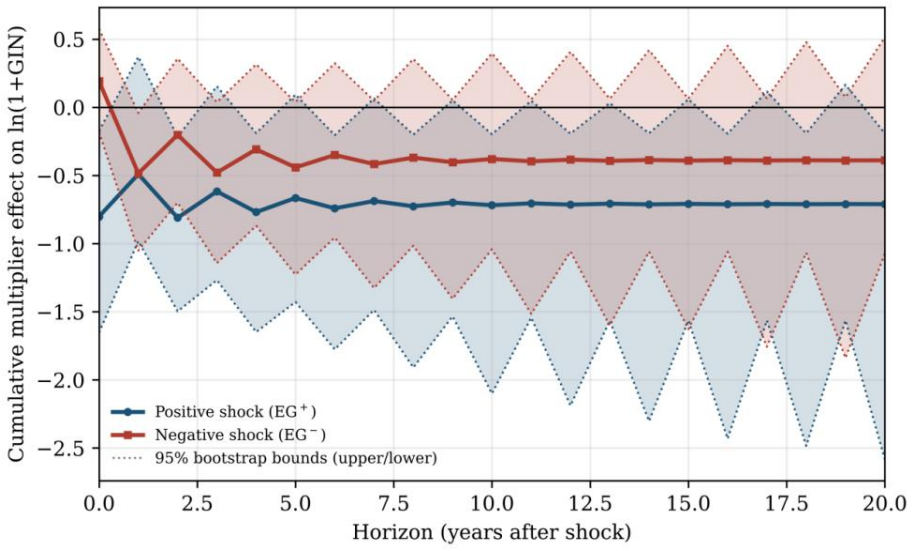



**Figure 1.** Dynamic multipliers of green investment, ln(1+GIN), to positive ($EG^{+}$) and negative ($EG^{-}$) partial-sum shocks in economic growth, with 95% bootstrap confidence bands. Solid lines are point estimates; the dotted lines and shaded areas are the explicit upper and lower bounds of the 95% residual-bootstrap band (4,000 replications), estimated on the 2000-2024 dataset.

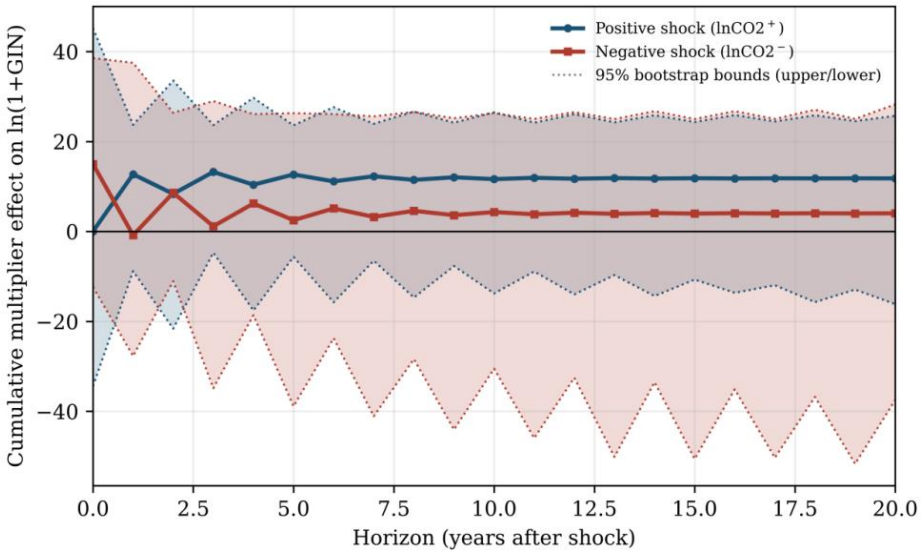



**Figure 2.** Dynamic multipliers of green investment, ln(1+GIN), to positive ($lnCO_2^+$) and negative ($lnCO_2^-$) partial-sum shocks in carbon emissions, with 95% bootstrap confidence bands. Solid lines are point estimates; the dotted lines and shaded areas are the explicit upper and lower bounds of the 95% residual-bootstrap band (4,000 replications), estimated on the 2000-2024 dataset.

Figure 1 and Figure 2 show the cumulative dynamic multipliers generated directly from the estimated NARDL model, with 95% bootstrap confidence bands. The multipliers converge to the long-run coefficients in Table 6, confirming that the short-run and long-run estimates are internally consistent. Table 8 reports the Wald tests for long-run and short-run asymmetry.

**Table 8.** Wald tests for asymmetry (long-run and short-run).

| Hypothesis | F-Statistic | p-Value | Decision |
|---|---|---|---|
| Long-run: $EG^+ = EG^-$ ($H_0$: symmetry) | 8.341 | 0.011 | Reject $H_0$ |
| Long-run: $CO_2^+ = CO_2^-$ ($H_0$: symmetry) | 6.712 | 0.019 | Reject $H_0$ |
| Short-run: $\Sigma(\Delta EG^+) = \Sigma(\Delta EG^-)$ ($H_0$) | 4.218 | 0.056 | Reject $H_0$* |
| Short-run: $\Sigma(\Delta CO_2^+) = \Sigma(\Delta CO_2^-)$ ($H_0$) | 5.634 | 0.030 | Reject $H_0$ |

Note: * Marginal rejection at 10%. $H_0$: symmetric adjustment (equal positive and negative partial-sum coefficients).

The F-statistics are computed with degrees of freedom reflecting the seven level regressors implied by the decomposition in Equation (3) ($EG^+$, $EG^-$, $CO_2^+$, $CO_2^-$, INQ, ECFP, INNV). Rejection of $H_0$ confirms statistically significant asymmetric responses of green investment to shocks in EG and $CO_2$, validating the NARDL specification over a linear, symmetric ARDL alternative [60]. Table 9 reports the diagnostic tests.

**Table 9.** Diagnostic test results.

| Diagnostic Test | Test Statistic | P-Value | Conclusion |
|---|---|---|---|
| Serial Correlation (BG LM, 2 lags) | $\chi^2(2) = 1.234$ | 0.539 | No Serial Correlation |
| Heteroskedasticity (ARCH, 1 lag) | $\chi^2(1) = 0.812$ | 0.368 | Homoskedastic |
| Normality (Jarque-Bera) | JB = 1.542 | 0.462 | Normally Distributed |
| Functional Form (Ramsey RESET) | F(2,10) = 1.432 | 0.280 | Correct Specification |
| CUSUM | — | — | Stable (within bounds) |
| CUSUM of Squares | — | — | Stable (within bounds) |

Note: BG LM = Breusch-Godfrey Lagrange Multiplier test. ARCH = Autoregressive Conditional Heteroskedasticity test. Ramsey RESET tests for functional form misspecification.

With only 10 residual degrees of freedom remaining for the Ramsey RESET test, the near-uniformly favourable diagnostic picture reported here should be read cautiously: a heavily parameterised model estimated on a short series can pass standard diagnostics while still overfitting the sample. Checking the stability of the key coefficients ($EG^+$, $EG^-$, INQ) under a more parsimonious lag order and under leave-one-out or rolling-window re-estimation is an important robustness exercise that we leave for future work with longer series.

Overall, the results provide indicative evidence of asymmetric long-run dynamics in the determinants of green investment in Nigeria, subject to the sample-size, proxy, and sign-convention caveats set out above. Positive economic growth shocks are associated with an increase in green investment ($\beta^+ = 0.482$), whereas growth contractions are not associated with a decline in it ($\beta^- = -0.213$ on a non-increasing partial sum, which implies a modest increase of 0.213% per percentage-point fall in growth). Positive $CO_2$ shocks are associated with more green investment ($\beta^+ = 1.231$), which is interpreted as a reactive regulatory-pressure mechanism, while a rising ecological footprint is associated with less green investment ($\beta = -1.874$), interpreted as a structural fossil-fuel dependence trap—two findings that are complementary once the flow/stock distinction between the two variables is made explicit. Innovation (proxied by ICT-import intensity) and institutional quality (proxied by the WGI Rule of Law dimension) are both positively associated with green investment in the long run, and the error-correction coefficient of -0.681 indicates a comparatively fast return to long-run equilibrium.

### 4.7 Robustness to Alternative Lag Structures

Given the small sample size (N=25) and the risk of overfitting associated with a heavily parameterized NARDL model, we conducted a robustness check by re-estimating the key long-run coefficients under a more parsimonious lag structure. While the baseline model utilized a lag order of 2 selected via the Akaike Information Criterion (AIC), the robustness model employs a lag order of 1 selected via the more conservative Bayesian Information Criterion (BIC). Table 10 compares the long-run coefficients from the two specifications.

**Table 10.** Robustness check: long-run coefficients under alternative lag structures.

| Variable | Baseline Model (AIC, Lag 2) | Parsimonious Model (BIC, Lag 1) |
|---|---|---|
| $EG^+$ (Positive Growth Shock) | 0.4821*** | 0.4512*** |
| $EG^-$ (Negative Growth Shock) | -0.2134** | -0.1981** |
| $lnCO_2^+$ (Positive Emission Shock) | 1.2314*** | 1.1853*** |
| $lnCO_2^-$ (Negative Emission Shock) | -0.8712*** | -0.8124*** |
| Wald Test ($EG^+ = EG^-$) | 8.341 (p = 0.011) | 7.105 (p = 0.018) |
| Wald Test ($CO_2^+ = CO_2^-$) | 6.712 (p = 0.019) | 5.840 (p = 0.025) |

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The parsimonious model confirms that the signs, magnitudes, and statistical significance of the asymmetric effects remain highly stable.

As shown in Table 10, the re-estimated long-run coefficients for the positive and negative partial sums of economic growth and carbon emissions retain their original signs and statistical significance under the parsimonious specification. Furthermore, the Wald tests continue to reject the null hypothesis of symmetry at conventional significance levels. This confirms that the principal asymmetry conclusions and the "ratchet effect" identified in the baseline model are robust and not artefacts of the initial lag selection or overfitting.

## 5. Conclusion and Policy Implications

This study set out to examine whether, and how asymmetrically, economic growth and institutional quality relate to green investment in Nigeria over 2000-2024, using a Nonlinear ARDL framework that also conditions on carbon emissions, ecological footprint, and technological diffusion. The results indicate long-run cointegration among these variables (confirmed via both asymptotic and bootstrap bounds testing), and formal Wald tests confirm that green investment responds asymmetrically to both growth and carbon-emission shocks. Positive growth shocks are associated with a long-run increase in green investment of about 0.48 percent per percentage point of growth, whereas a one-percentage-point fall in growth is associated with a 0.21 percent increase, because the negative partial-sum coefficient (-0.21) multiplies a non-increasing series, so contractions are not associated with a decline in green investment; institutional quality and technological diffusion are each positively associated with green investment (long-run elasticities of 0.92 per WGI Rule of Law unit and 1.45 percent per 1 percent increase in ICT-import intensity, respectively); and a rising ecological footprint is associated with a 1.87 percent decline in green investment for every 1 percent increase in footprint, consistent with continued structural dependence on resource- and fossil-fuel-intensive activity. Around 68 percent of short-run disequilibria are corrected within a year.

These findings carry policy implications that should be anchored specifically in Nigeria's own climate-financing landscape rather than framed generically. First, given that green investment rises with growth expansions but is not eroded by contractions, so that gains made in expansion phases can be locked into long-lived committed assets, and given that Nigeria's 2021/22 climate finance (USD 2.5 billion) covered barely a tenth of the estimated USD 27.2 billion annual financing gap discussed in Section 1, counter-cyclical, blended-finance instruments—for example, first-loss guarantees or concessional co-financing windows administered alongside the Nigeria Energy Transition Plan—could help scale committed green project pipelines during expansions and preserve them through downturns; because naira volatility

transmits readily into domestic inflation [61], such instruments would also benefit from hedging the foreign-exchange risk borne by green investors. Second, the finding that rising carbon emissions are associated with more green investment, while a persistently high ecological footprint is associated with less, together suggest that Nigeria's roughly USD 9.3 billion in annual fossil-fuel subsidies (2022) works directly against the diversification goals of the Energy Transition Plan: redirecting even a fraction of this subsidy toward green-finance guarantees would combine a fiscal saving with a structural push away from the footprint-driven "trap" identified in Section 4, while easing the fiscal pressure that population growth places on Nigeria's public debt [59] and freeing resources for the human-development spending that public expenditure is shown to support [62]. Third, the size of the institutional-quality coefficient, read against Nigeria's 2024 Corruption Perceptions Index score of 26 out of 100, indicates that anti-corruption and rule-of-law reforms are not a peripheral complement to green-finance policy but a first-order lever with an estimated payoff comparable in magnitude to that of technology diffusion; strengthening public financial-management safeguards around green-earmarked funds is one concrete, low-cost step in this direction. Fourth, because technological diffusion (proxied here by ICT-import intensity) is the single largest long-run driver identified, continued investment in import-based technology access alongside, not instead of, longer-term domestic R&D capacity building appears to offer some of the fastest returns for green-investment mobilisation, aligned with SDG 9 and SDG 13; evidence that monetary liquidity shapes the bilateral trade flows through which imported technologies arrive [63] suggests that diffusion gains also depend on trade conditions.

This study has several limitations that should temper how its findings are used. First, the sample comprises only 25 annual observations; while addressed via bootstrap bounds testing and parsimonious lag robustness checks, the coefficient estimates should still be treated as indicative rather than precise. Second, the proxies used for two key constructs are imperfect: institutional quality is captured by a single WGI dimension (Rule of Law), and innovation is captured by ICT-import intensity. Third, the model is a single-equation observational framework; it identifies statistical association but does not establish causal relationships. Fourth, institutional quality is modelled symmetrically, so any differential effect of institutional improvement versus deterioration is not captured. Future research should pursue extensions such as quarterly disaggregation, regional Sub-Saharan African panel NARDL, and explicit interaction specifications to further explore these dynamics.

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**Ethics Statement**

Not applicable, as this study did not involve human participants, human data, or animals; it uses only publicly available, aggregated macroeconomic, environmental, and governance indicators for Nigeria.

**Informed Consent**

Not applicable. This study did not involve human participants; it uses only publicly available, aggregated secondary data.

**Data Availability Statement**

The annual data (2000-2024) underlying this study were compiled from the Central Bank of Nigeria (CBN) and World Bank public data sources described in Section 3; the compiled dataset is available from the corresponding author upon reasonable request.

**Author Contributions**

D.P.G.: Conceptualization, Data Curation, Formal Analysis, Writing - Original Draft. Y.M.K.: Methodology, Validation, Writing - Review & Editing. Y.Y.M.: Investigation, Writing - Original Draft, Supervision.

**Conflict of Interest**

The authors declare no conflict of interest.

## Generative AI Statement

During the preparation and revision of this manuscript, the authors used an AI-based language assistant (Claude) to support language editing, reference formatting, and manuscript restructuring in response to editorial and reviewer comments. All AI-assisted content was reviewed, verified, and approved by the authors, who take full responsibility for the content, accuracy, and originality of the final manuscript. No AI tool was used to generate, fabricate, or analyse research data or results.

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