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Website: <https://www.ecofunai.ng>

ISSN (Print): 2536-6793 | ISSN (Electronic): 2536-6742

Volume 3 (2) August, 2026 (pp 138 - 154)

Submitted June 2026; Published August 2026.

DIGITAL ECONOMY AND GREEN GROWTH IN NIGERIA: THE ROLE OF INTERNET PENETRATION, NATURAL RESOURCES AND RENEWABLE ENERGY

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ABSTRACT

Growing environmental degradation presents a significant challenge to achieving sustainable economic development in Nigeria, where the pursuit of economic growth often conflicts with environmental preservation. Although green growth (GGR) has gained increasing policy attention as a pathway to sustainable development, empirical evidence on the combined effects of digital transformation, natural resource utilization, renewable energy consumption, and trade openness remains limited. This study investigates the influence of internet penetration (ITU), natural resources (NR), renewable energy (RE), and trade openness (TRD) on green growth in Nigeria over the period 1996–2024. The study adopts the Autoregressive Distributed Lag (ARDL) model to estimate both short- and long-run relationships, while Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) are employed to test the robustness of the findings. The empirical results reveal that internet penetration significantly enhances green growth, with a 1% increase improving GGR by 0.08% in the short run and 0.14% in the long run, reflecting gains from digital innovation and efficiency. Renewable energy consumption also exerts a strong positive effect, increasing GGR by 2.2% in the short run and 3.9% in the long run. Conversely, natural resource dependence reduces green growth by 0.11% in the short run and has a weakly significant negative long-run effect, while trade openness exerts no statistically significant influence. The findings consistently support the robustness of the estimated relationships. The study recommends expanding digital infrastructure, accelerating renewable energy adoption, strengthening sustainable resource governance, and aligning trade policies with environmental sustainability objectives to foster inclusive green growth in Nigeria.

Keywords: Green growth; Digital economy; Internet penetration; Renewable energy; Natural resources; Nigeria

JEL Classification: C22, F18, O13, Q42, Q56.

1. Introduction

The increasing severity of climate change, biodiversity loss, environmental degradation, and resource depletion has made green growth a global priority. Conventional growth models reliant on fossil fuels have increased greenhouse gas emissions, threatening sustainability. The United Nations advocates emission reductions to achieve the Paris Agreement and Sustainable Development Goals (United Nations [UN], 2015). The International Energy Agency reported global energy-related CO₂ emissions exceeding 37 billion tonnes in 2023 (International Energy Agency [IEA], 2024). Green growth promotes economic expansion while preserving natural assets through efficient resource use, technological innovation, and environmentally sustainable production (OECD, 2011; World Bank, 2012). Green growth is particularly important for Nigeria due to rapid population growth, urbanization, energy poverty, and environmental degradation. Heavy dependence on crude oil exports exposes the economy to price volatility while contributing to pollution, gas flaring, and ecosystem damage (World Bank, 2024; Cheng et al., 2020). According to the World Bank (2026), natural resource rents remain a significant source of income despite limited economic diversification, constituting about 13.44% of GDP between 1996 and 2021. Agriculture is increasingly vulnerable to climate change, while inadequate electricity access constrains productivity. These challenges make green growth essential for sustainable development, energy security, job creation, and economic resilience.

The digital economy has emerged as a major driver of the green transition. It includes internet connectivity, digital infrastructure, artificial intelligence, e-commerce, cloud computing, and digital finance. Internet penetration is a widely used indicator of digital transformation because it expands access to information, innovation, and digital services. The International Telecommunication Union estimates that about 68% of the global population used the internet in 2024, reflecting the expansion of digital connectivity globally (International Telecommunication Union, 2024). Digitalization promotes green growth by improving efficiency, reducing waste, supporting smart technologies, and facilitating the adoption of green innovations (See Majeed and Sharif, 2024; Neffati and Khemiri, 2025). For Nigeria, where environmental degradation, energy inefficiency, and limited economic diversification remain major development challenges, strengthening the digital economy offers significant opportunities to enhance resource efficiency, accelerate the adoption of clean technologies, improve environmental management, and foster sustainable green growth.

Similarly, natural resources provide the land, energy, minerals, forests, and ecosystem services required for economic development. When efficiently managed through conservation, sustainable extraction, and green investment, they can support environmentally sustainable growth (Lee and He, 2022). However, excessive dependence on extractive industries often leads to pollution, carbon emissions, and weak economic diversification, consistent with the resource curse hypothesis (Cheng et al., 2020; Imran et al., 2025). In Nigeria, oil dependence has generated substantial environmental costs such as greenhouse gas emissions (World Bank, 2026), making effective resource governance, renewable energy investment, and economic diversification critical for achieving green growth.

In addition, renewable energy is seen as a key pillar of the green transition because it generates energy with minimal environmental damage. It includes solar, wind, hydropower, geothermal, and biomass energy (World Bank, 2026). Unlike fossil fuels, renewable energy reduces emissions, improves air quality, enhances energy security, and supports sustainable industrialization (Sohag et al., 2021; Behera et al., 2025;

Amin et al., 2025). According to the International Renewable Energy Agency (IERA), renewable sources accounted for approximately 92.5% of new global electricity generation capacity in 2024 (IERA, 2024). In Nigeria, the abundance of renewable resources offers significant opportunities to improve electricity access and promote sustainable development.

Trade in services is a key indicator of global integration and green growth, encompassing financial, digital, telecommunications, transport, education, tourism, and professional services. By facilitating technology transfer, innovation, and knowledge diffusion, it promotes cleaner production and productivity (Huang, 2023). Global commercial services exports exceeded US\$8 trillion in 2024 (WTO, 2024), reflecting the growing role of knowledge-intensive and digital services in facilitating technology transfer, innovation, and cleaner production processes that can accelerate green growth.

Against this background, this study investigates the effect of the digital economy on green growth in Nigeria while accounting for the roles of natural resources, renewable energy, and trade in services. Specifically, the study seeks to determine whether the digital economy promotes green growth, in the presence of natural resource rents, renewable energy, and service trade. By integrating these determinants within a unified empirical framework, the study contributes to the growing literature on sustainable development and provides evidence to guide policies aimed at accelerating Nigeria's transition to a greener, more resilient, and sustainable economy.

Following this section, Section 2 reviews the literature, Section 3 focuses on the methodology, Section 4 presents and discusses the empirical results, while Section 5 concludes the study with policy recommendations.

Research Questions

This study answers the following research questions:

- a) Does internet penetration significantly promote green growth in Nigeria?
- b) What effect do natural resource rents have on green growth in Nigeria?
- c) Does renewable energy consumption enhance green growth in Nigeria?

Objectives of the Study

The broad objective of this study is to examine the effect of the digital economy on green growth in Nigeria. The specific objectives include to:

1. Examine the effect of internet penetration on green growth in Nigeria.
2. Assess the effect of natural resource rents on green growth in Nigeria.
3. Determine the effect of renewable energy consumption on green growth in Nigeria.

2 Literature Review

2.1 Conceptual Clarifications

Green growth connotes economic development that improves income and welfare while conserving natural resources through efficient resource use, technological innovation, and clean energy adoption (OECD, 2011). The digital economy encompasses economic activities driven by digital technologies such as the internet, digital infrastructure, artificial intelligence, and e-commerce. In this study, it is proxied by internet penetration. It promotes green growth by enhancing innovation productivity, information exchange, and energy efficiency, thereby reducing environmental

pollution (Wang et al., 2024; Lu et al., 2025). Natural resources comprise assets such as crude oil, natural gas, minerals,

forests, and water that support economic development. When managed sustainably, they generate revenues for investment in renewable energy, digital infrastructure, and green technologies; however, excessive dependence on resource extraction can increase environmental degradation and hinder green growth (Imran et al., (2025). Renewable energy, obtained from naturally replenishing sources such as solar, wind, hydropower, and biomass, promotes green growth by reducing greenhouse gas emissions, improving energy efficiency, and supporting low-carbon development (Wang et al., 2023). Conceptually, digitalization, sustainable natural resource management, and renewable energy interact to influence green growth.

2.2 Theoretical Literature

This section reviews two theories underpinning the study: Endogenous Growth Theory (Romer, 1986), which explains technology-driven economic growth, and Ecological Modernization Theory (Mol et al., 2000), which emphasizes environmentally sustainable development.

Endogenous Growth Theory posits that sustained economic growth is driven by technological innovation, knowledge accumulation, human capital, and research and development (Romer, 1986). It argues that technological progress is generated internally through investment in innovation and learning. Within this framework, the digital economy promotes growth by improving information exchange, reducing transaction costs, enhancing production efficiency, and facilitating innovation, while trade, renewable energy, and sustainably managed natural resources further support long-run growth.

However, the Ecological Modernization Theory argues that economic growth and environmental sustainability are complementary objectives achievable through cleaner technologies, efficient resource use, renewable energy adoption, and effective environmental governance (Mol et al., 2000). Accordingly, digital technologies, renewable energy, sustainable resource management, and environmentally responsible trade promote green growth by enhancing productivity while reducing environmental degradation and supporting low-carbon development.

In sum, while Endogenous Growth Theory explains how technology increases economic output (without express emphasis on environmental protection), Ecological Modernization Theory emphasizes using technology to increase environmentally adjusted output through cleaner production, efficient resource use, and low-carbon development.

2.3 Empirical Literature Review

The digital economy is increasingly recognized as a key driver of green growth by enhancing production efficiency, technological innovation, and knowledge diffusion. Empirical literature overwhelmingly supports the positive contribution of digitalization to green growth, although the transmission channels differ across countries and regions. For instance, studies by Luo et al. (2022), Liu et al. (2024), Majeed and Sharif (2024), as well as Neffati and Khemiri (2025) consistently identify green innovation, industrial upgrading, economic openness, and technological progress as the principal channels through which the digital economy enhances green innovation and green economic growth. Employing spatial Durbin and dynamic threshold panel models, Luo et al. (2022) examined the effect of the digital economy on green innovation in 278 Chinese cities between 2011 and 2019 and concluded that the digital economy significantly promoted green innovation. Also, Liu et al (2024) applied a fixed-effects technique to examine the effect of the digital economy on green development using provincial data in China. The authors reveal that the digital economy significantly promotes green development by reducing carbon emissions, enhancing technological innovation, and improving trade efficiency. In Europe, Lu et al. (2025) report that the impact of technological innovation on green growth varies with income levels, significantly enhancing green growth in high-income

economies while exerting no significant effect in low-income economies. Focusing on Saudi Arabia from 1996–2022 and utilizing the Bayesian VAR method, Neffati and Khemiri (2025) show that digitization drives long-term green growth. Majeed and Sharif (2024), using internet, broadband, mobile, and telephone subscriptions as proxies for digitalization across 164 countries, applying static methods, system GMM, and panel quantile regression, further demonstrate that the positive impact of digitalization on green growth remains robust across different estimators and quantiles.

Similarly, another strand of the literature emphasizes the complementary role of digitalization with other sustainability drivers. For instance, Abubakar et al. (2026) examined the effects of digitalization, financial development, renewable energy, green finance, and corruption on sustainable development, ecological footprint, and human development in twelve West African countries using Method of Moments Quantile Regression and the Driscoll–Kraay estimator. The study reveals that digitalization significantly enhances sustainable and human development while reducing ecological footprints. Likewise, Wang et al. (2024) report that eco-digitalization, alongside green finance, green innovation, and renewable energy, significantly improves environmental sustainability by reducing CO₂ emissions, ecological footprints, and PM_{2.5} pollution across BRICS economies. Furthermore, evidence suggests that digitalization strengthens the effectiveness of other growth-enhancing mechanisms. Yu and Du (2025) show that digitalization positively moderates the relationship between global value chain participation and green productivity, transforming previously negative effects of global value chain positioning into productivity-enhancing outcomes while promoting green technological progress. Collectively, the literature provides strong evidence that digitalization is an important catalyst for green growth through innovation, efficiency improvement, cleaner technologies, and productivity enhancement. Nevertheless, existing studies also indicate that the magnitude of these benefits depends on institutional quality, governance effectiveness, and complementary environmental policies.

Interestingly, Chen et al. (2020) show that the effect of digitalization on the environment could be mixed. In a systematic review of digitalization in manufacturing, Chen et al. (2020) find that Industry 4.0 technologies enhance environmental sustainability by improving resource efficiency and production processes. However, digitalization also increases energy consumption, resource use, and waste generated throughout the technology lifecycle. Consequently, the authors conclude that its overall environmental impact depends on whether these efficiency gains outweigh the associated environmental costs.

Natural resources play a dual role in economic development by generating income and supporting industrial activities, yet their excessive exploitation often undermines environmental sustainability and green growth. The empirical literature generally suggests that abundant natural resources can impede green economic performance through environmental degradation, poor institutional quality, and excessive reliance on extractive industries, although these effects vary depending on governance and market conditions. For instance, studies by Cheng et al. (2020), Xu (2022), Lee and He (2022), and Imran et al. (2025) reveal that natural resource dependence constrains green growth through different transmission mechanisms. Employing the Global Malmquist–Luenberger Index to measure green total factor productivity across 30 Chinese provinces from 2003 to 2016, Cheng et al. (2020) indicate that natural resource abundance significantly reduces green growth by increasing dependence on resource-based industries while crowding out human capital accumulation, technological progress, innovation investment, and institutional development. Likewise, Xu (2022), using the Zivot–Andrews unit root test, ARDL bounds testing, DOLS, FMOLS, and CCR for China over the period 1980–2020, reports that fossil energy resources, particularly natural gas, exert adverse effects on green growth, although green trade moderates these relationships by mitigating the negative impacts of oil and gas while strengthening the contribution of coal.

Conversely, another set of the literature highlights the importance of institutional quality and economic diversification in determining whether natural resources become a blessing or a curse for green development. For instance, Lee and He (2022), employing a finite mixture model for Chinese provinces between 2008 and 2018, identified two distinct development paths in which natural resources either constrain or promote green total factor productivity. The study further argues that stronger market-oriented institutions increase the likelihood of transforming resource abundance into sustainable economic gains. Likewise, Imran et al. (2025), using CADF, Westerlund cointegration, and CS-

ARDL techniques for BRICS countries from 1991 to 2022, document that although fossil fuel consumption stimulates economic growth in both the short and long run, excessive dependence on natural resource and coal rents hinders sustainable development, while inadequate utilization of renewable energy reinforces the persistence of the resource curse. From the foregoing, it is obvious that natural resource endowments contribute to green growth when accompanied by sound institutions, technological innovation, effective resource management, and policy measures that encourage a shift from fossil fuels to cleaner energy sources.

Renewable energy is increasingly recognized as a key driver of green growth by reducing carbon emissions, improving energy efficiency, enhancing energy security, and promoting sustainable production. Empirical literature overwhelmingly supports the positive contribution of renewable energy to green growth, although the transmission mechanisms vary across countries and regions. For instance, studies by Taşkın et al. (2020), Sohag et al. (2021), and Wang et al. (2023) identify renewable energy, technological innovation, trade openness, and environmental policy stringency as the principal channels through which renewable energy promotes green economic growth. Employing panel cointegration, OLS, Dynamic OLS, Fully Modified OLS, system GMM, and Dumitrescu–Hurlin causality techniques, Taşkın et al. (2020) examined OECD countries between 1990 and 2015 and observed that renewable energy consumption and trade openness significantly enhance green growth, with trade exerting a stronger long-run effect. The study also established bidirectional causality between renewable energy and green growth. Likewise, Sohag et al. (2021) applied the CS-ARDL model to OECD countries and reported that renewable energy and technological innovation significantly promote green growth in the long run, whereas militarization hinders sustainable development. Similarly, Wang et al. (2023), using the Method of Moments Quantile Regression (MMQR) for BRICS economies over the period 1990–2019, confirm that renewable energy consumption, environmental policy stringency, human development, and research and development expenditure significantly enhance green growth, with stronger effects observed at higher quantiles.

Similarly, another perspective in the literature suggests a complementary role of renewable energy with other environmental sustainability drivers. For instance, Behera et al. (2025) examined the effects of renewable energy, green technological innovation, ICT, political risk, and green growth on carbon emissions in E-7 countries using the Driscoll–Kraay and CS-ARDL estimators. The study establishes that renewable energy and green technological innovation significantly reduce carbon emissions, highlighting their importance in achieving carbon neutrality. Likewise, Amin et al. (2025), employing wavelet coherence and spectral causality approaches for China from 1990 to 2018, document that renewable energy and green growth significantly reduce carbon emissions, while mineral resource rents, non-renewable energy consumption, technological innovation, and economic growth increase environmental pressures. These findings underscore the critical role of the renewable energy transition in achieving environmental sustainability.

In all, the literature provides strong evidence that renewable energy is an important catalyst for green growth through cleaner energy utilization, reduced emissions, improved energy efficiency, and sustainable resource use. Nevertheless, existing studies also indicate that the magnitude of these benefits depends on technological innovation, environmental policy stringency, institutional quality, and complementary green finance policies.

Gap in Literature

The reviewed literature reveals two major gaps that justify this study. First, most empirical evidence on the relationship between the digital economy and green growth is based on developed and emerging economies such as China, OECD, BRICS, G-20 countries, Saudi Arabia, and multi-country panels (e.g., Luo et al., 2022; Hao et al., 2023; Taşkın et al., 2020; Wang et al., 2023; Majeed and Sharif, 2024; Sun and Mehmood, 2025). Furthermore, existing studies have examined digitalization, renewable energy, natural resources, or trade-related variables

separately or in limited combinations. Consequently, there is limited evidence for Nigeria that jointly examines the effects of internet penetration, natural resources, renewable energy, and trade openness on green growth. This study addresses this contextual and specification gap by providing Nigeria-specific evidence within a unified analytical framework.

3. Methodology

Theoretical Framing

The study is anchored on the Ecological Modernization Theory. Ecological Modernization Theory (Mol et al., 2000) argues that economic growth and environmental sustainability are mutually reinforcing through technological innovation, cleaner production, efficient resource utilization, renewable energy adoption, and sound environmental governance. Within this framework, digitization enhances green growth by improving resource efficiency, facilitating the diffusion of green technologies, and supporting environmentally sustainable production. The theory also posits that renewable energy and environmentally responsible trade promote green growth by reducing carbon emissions, encouraging cleaner technologies, and improving environmental performance. This theory provides a coherent framework for explaining how digitization, renewable energy, trade openness, and natural resource management interact to promote green growth in Nigeria.

Model Specification

Relying on the theoretical foundation and the study of Lu et al. (2025), this study specifies a functional model linking green growth to the digital economy, natural resources, renewable energy, and trade openness as:

$$GGR_t = f(ITU_t, NR_t, RE_t, TRD_t) \quad (1)$$

Where:

- GGR = Green growth (proxy for sustainability or environmentally adjusted-GDP)
- ITU = Internet penetration
- NR = Natural resources
- RE = Renewable energy
- TRD = Trade openness

The econometric model is specified as:

$$GGR_t = \pi_0 + \pi_1 ITU_t + \pi_2 NR_t + \pi_3 RE_t + \pi_4 TRD_t + \varepsilon_t \quad (2)$$

Where $\pi_0, \pi_1 - \pi_4$ represent the intercept and the various coefficients to be estimated. Also, t and ε_t capture the time dimension and the error term, respectively. To separate the short and long-run dynamics of the variables and determine the speed of reversion from any temporal shock, equation (2) is specified in an ARDL framework as follows:

$$\begin{aligned} \Delta GGR_t = & \alpha_0 + \sum_{i=1}^n \alpha_{1i} \Delta GGR_{t-i} + \sum_{i=0}^n \alpha_{2i} \Delta ITU_{1t-i} + \sum_{i=0}^n \alpha_{3i} \Delta NR_{2t-i} + \sum_{i=0}^n \alpha_{4i} \Delta RE_{3t-i} + \sum_{i=0}^n \alpha_{5i} \Delta TRD_{4t-i} \\ & + \alpha_7 GGR_{t-1} + \alpha_8 ITU_{t-1} + \alpha_9 NR_{t-1} + \alpha_{10} RE_{t-1} + \alpha_{11} TRD_{t-1} + \lambda_1 ECM_{t-1} \\ & + \varepsilon_t \end{aligned} \quad (3)$$

Where Δ and ECM_{t-1} , stand for the difference factor and the adjustment speed, respectively.

Variables Definition and Data Sources

Green growth, proxied by the ratio of GDP to CO₂ emissions (GGR), reflects an economy's ability to generate higher output with lower environmental degradation. A higher ratio indicates improved economic efficiency and lower carbon intensity, supporting sustainable development. Digitization (ITU) is captured by the number of internet users per 1,000 population. It is expected to promote green growth by enhancing digital innovation, production efficiency, energy management, and resource utilization while reducing emissions and waste. Natural resource rent (NR) is measured by total natural resource rents as a percentage of GDP, and it is generally expected to hinder green growth because excessive dependence on resource extraction encourages environmental degradation and limits innovation and economic diversification. However, prudent investment of resource revenues in green technologies can offset these effects.

Renewable energy (RE), expressed as renewable energy consumption relative to total energy use, is expected to enhance green growth by reducing fossil fuel dependence, lowering greenhouse gas emissions, and supporting sustainable production. Trade openness (TRD), approximated by trade in services as a percentage of GDP, may either promote or hinder green growth. While it facilitates technology transfer and cleaner production, it may also increase pollution-intensive activities. Therefore, its overall effect depends on institutional quality, environmental regulations, and the composition of trade.

From the above discussions, the study expects digitization and renewable energy to enhance green growth directly, while natural resource rents are anticipated to impede green growth if resource dependence dominates productive investment. The effect of trade openness is expected to be conditional, reflecting the balance between technology-driven efficiency gains and the environmental costs associated with expanded economic activity.

Table 1 presents the operational definitions of the study variables, their units of measurement, variable symbols, and corresponding data sources.

Table 1: Variable measurement and data sources

Variable	Measurement	Symbol	Source
Green growth	GDP as ratio of CO2 emissions	GGR	WDI
Digitization	Number of persons using the internet (per 1000)	ITU	WDI
Natural resource rents	Total natural resources rent (% GDP)	NR	WDI
Renewable energy	Renewable energy use (% Total energy)	RE	WDI
Trade openness	Trade in services (% GDP)	TRD	WDI

Source: As compiled by the Author

Estimation Techniques The study employs

The study employs the Autoregressive Distributed Lag (ARDL) model as the baseline estimation technique because it is suitable for variables of different orders of integration provided none is greater than order 1. It is also appropriate for small samples, such as the 1996–2024 period examined in this study, and can simultaneously estimate short-run and long-run relationships while capturing the speed of adjustment to long-run equilibrium. To validate the robustness of the long-run estimates, the study further applies the Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), and Canonical Cointegrating Regression (CCR). These estimators complement the ARDL model by providing robust long-run estimates that address endogeneity and serial correlation, thereby

enhancing the consistency of the empirical findings. DOLS corrects endogeneity and serial correlation using leads and lags of differenced regressors (Stock and Watson, 1993). FMOLS applies non-parametric corrections (Phillips and Hansen (1990), while CCR transforms the data to eliminate these econometric problems before estimation (Park, 1992). Consistent results strengthen the robustness and credibility of the findings.

4. Results and Discussion of Findings

4.1 Presentation of Results

Table 1 presents the descriptive statistics of the variables used in the study. The results indicate that green growth (GGR) has a mean value of 8.043 with a standard deviation of 0.352, suggesting moderate variation over the study period. The minimum and maximum values of 7.349 and 8.393, respectively, indicate relatively stable growth in Nigeria. Digitization (ITU) records a mean of 1.211 and the highest standard deviation (2.737) among all variables, implying substantial fluctuations in internet usage during the period. Natural resource rent (NR) has an average value of 2.457 with a standard deviation of 0.463, reflecting moderate variability. Renewable energy (RE) exhibits the least variation, with a mean of 4.426 and a standard deviation of 0.031, suggesting that renewable energy consumption remained relatively stable throughout the sample period. Trade openness (TRD) has a mean of 1.587 and a standard deviation of 0.687, indicating moderate dispersion across the observations. In addition to Table 1, Figure 1 reveals the evolutionary trend of the variables used in the study.

Table 1: Descriptive Analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
GGR	29	8.043	0.352	7.349	8.393
ITU	29	1.2112	2.737	-4.730	3.719
NR	29	2.457	0.463	1.516	3.216
RE	29	4.426	0.031	4.381	4.478
TRD	29	1.587	0.687	-0.417	2.188

Author’s Compilation 2026.

The figure shows that ITU recorded a remarkable upward trend over the study period, reflecting the rapid expansion of internet penetration in Nigeria. GGR and RE exhibited relatively stable movements with moderate fluctuations, whereas NR and TRD displayed more pronounced variations, indicating changes in resource dependence and trade activities over time. Overall, the observed trends suggest substantial temporal variation across the variables, thereby providing further justification for investigating their dynamic relationship with green growth.

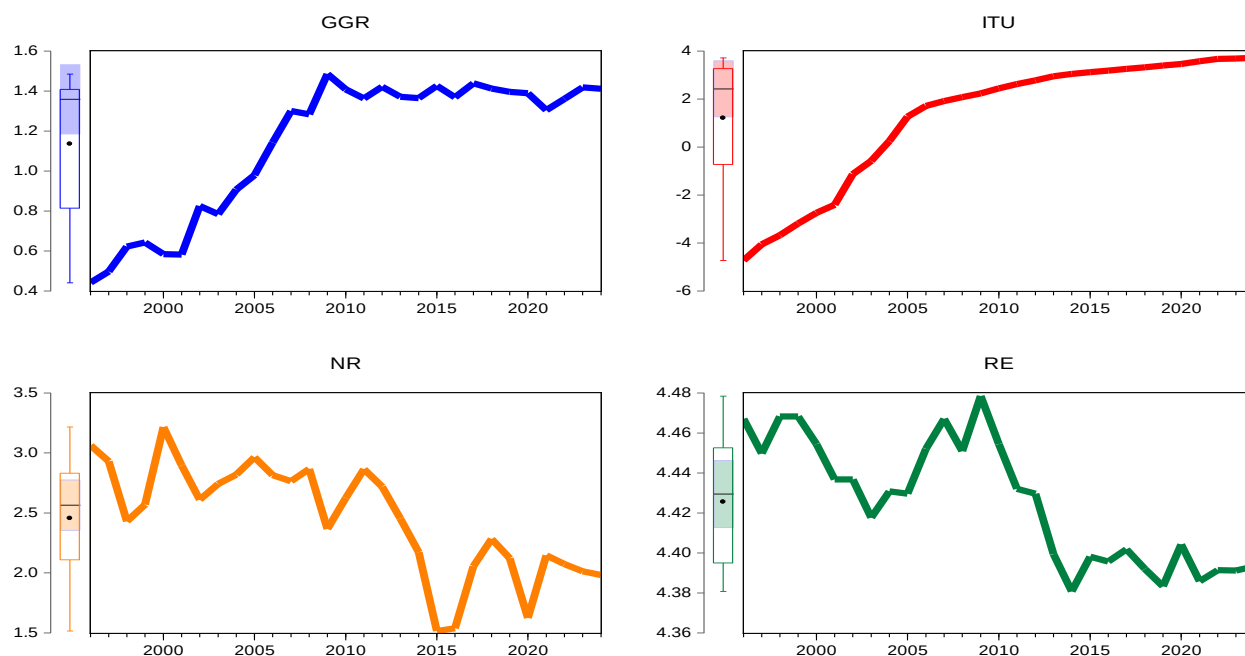


Figure 1: Evolution of Variables Used in the Study

Following the descriptive analysis, the next step is the unit root test. Table 2 reports the results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The findings reveal a mixed order of integration among the variables.

Table 2: Unit-root tests

Series	<u>Augmented Dickey Fuller</u>		<u>Philip Perron Unit Root</u>		Remarks
	At Level I(0)	At Diff. I(1)	At Level I(0)	At Diff. I(1)	
GG	-2.069	-5.716 ***	-2.491	-5.695***	I(1)
ITU	-4.946***	-2.495	-3.777***	-2.357	I(0)
NR	-2.004	-5.180***	-1.867	-5.290***	I(1)
RE	-1.511	-6.196 ***	-1.531	-6.140***	I(1)
TRD	-3.000**	-5.183***	-2.967**	-5.182***	1(0)

*Note: *** = $p < 1\%$, ** = $p < 5\%$, * = $p < 10\%$,*

Specifically, digitization (ITU) and trade openness (TRD) are stationary at levels, I(0), while green growth (GGR), natural resource rents (NR), and renewable energy (RE) become stationary after first differencing, indicating integration of order one, I(1). The consistency of the ADF and PP results confirms that none of the variables is integrated of order two, I(2), thereby satisfying the precondition for applying the Autoregressive Distributed Lag (ARDL) modelling technique.

Table 3: Pesaran, Shin, and Smith (2001) bounds test

Kripfganz and Schneider (2020) critical values and approximate p-values								
H0: no level	relationship							F = 11.859
Case 2								t = -6.33
	10%		5%		1%		P-value	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	2.582	3.661	3.157	4.402	4.603	6.254	0.000	0.000
T	-2.564	-3.672	2.941	-4.123	3.733	-5.066	0.000	0.001

Source: Authors' computation

Once, the issue of unit root test has been addressed, the next is to confirm the existence of a cointegration among the variables. Table 3 presents the Pesaran et al. (2001) bounds cointegration test. The estimated F-statistic of 11.859 exceeds the upper critical bound at the 1 percent significance level (6.254), while the associated p-value of 0.000 confirms statistical significance. Similarly, the estimated t-statistic of -6.330 is more negative than the upper bound critical value of -5.066, with a p-value of 0.001. These results provide strong evidence against the null hypothesis of no long-run relationship, indicating the existence of cointegration among green growth, digitization, natural resource rents, renewable energy, and trade openness. Consequently, the study proceeds with the estimation of the ARDL long-run and short-run models, complemented by FMOL, DOL and CCR techniques.

Having established the existence of a long-run relationship among the variables, the next stage is to examine the magnitude and direction of both the short-run and long-run effects of the explanatory variables on green growth. Table 4 presents the short-run and long-run estimates obtained from the ARDL, FMOLS, DOLS and the CCR models. The ARDL results show that digitization (ITU) has a positive and statistically significant effect on green growth in the short-run. Specifically, a 1% increase in internet penetration increases green growth by 0.08% at the 1% significance level. This positive effect persists in the long-run, where a 1% increase in digitization raises green growth by 0.14% at the 1% significance level. This positive relationship is confirmed by the FMOLS ($\beta = 0.155$), DOLS ($\beta = 0.155$), and CCR ($\beta = 0.142$). The table also reports a short-run negative effect of natural resources (NR) on green economy. That is, a 1% increase in natural resource rent leads to 0.11% reduction in green growth. Similarly, NR exhibit a negative long-run relationship with green growth. Although the long-run ARDL estimate is weakly statistically at 10% ($\beta = -0.08$), however, the FMOLS (-0.250), DOLS (-0.250) and CCR (-0.083) estimates are negative and highly significant at the 1 percent level.

Table 4: Long-run and Short-run Estimates

VARIABLES	(1) ARDL-LR	(2) ARDL-SR	(3) FMOLS	(4) DOLS	(5) CCR
ITU	0.144*** (0.009) [15.225]	0.082*** (0.013) [6.101]	0.155*** (0.006) [24.842]	0.155*** (0.010) [15.300]	0.142*** (0.004) [36.225]
NR	-0.081* (0.056) [-1.445]	-0.110*** (0.034) [-3.279]	-0.250*** (0.037) [-6.677]	-0.250*** (0.061) [-4.112]	-0.083*** (0.029) [-2.880]
Trd	-0.013 (0.029) [-0.453]	-0.007 (0.017) [-0.451]	0.024 (0.017) [1.419]	0.024 (0.027) [0.874]	-0.022* (0.013) [-1.648]
RE	3.920*** (0.856)	2.223*** (0.458)	4.886*** (0.423)	4.886*** (0.686)	2.979*** (0.394)

	[4.581]	[4.855]	[11.556]	[7.117]	[7.556]
ECT	-0.567*** (0.089)				
Constant	-16.147*** (3.730)	-16.147*** (3.730)	-20.157*** (1.791)	-20.157*** (2.907)	-11.987*** (1.699)
	[-4.329]	[-4.329]	[-11.258]	[-6.933]	[-7.057]
Observations	28	28	26	26	28
R-squared	0.790	0.790	0.992	0.992	0.976

Source: Authors' Computation. Note: * = sign. at 10%, ** = sign. at 5% , *** = sign. at 1%

Further, the results reveal that in the short-run, RE increases GGR by 2.2% for every 1% increase in renewable energy consumption. In the long-run, RE maintains a strong positive and statistically significant impact on green growth across all estimation techniques. For instance, the ARDL long-run coefficient ($\beta = 3.920$) and the probability ($p < 0.01$) show that a percentage increase in RE consumption leads to a corresponding 3.9% improvement in GGR. Finally, trade openness (TRD) shows insignificant effect in both the long-run and short-run ARDL models. This result is robust across FMOLS, DOLS and CCR estimates.

The error correction term (ECT) is negative (-0.567) and highly significant ($p < 0.01$), confirming the existence of a stable long-run equilibrium relationship among the variables. The coefficient suggests rapid convergence to long-run equilibrium following short-run shocks suggesting that approximately 56.7% of deviations from the long-run equilibrium are corrected annually. Furthermore, the ARDL model explains about 79.0% of the variation in green growth ($R^2 = 0.790$), indicating a good model fit. The robustness estimators also exhibit high explanatory powers, with R^2 values of 0.992 for both FMOLS and DOLS and 0.976 for CCR, further reinforcing the reliability and robustness of the estimated long-run relationships.

Table 5: Diagnostic Analysis

Test	F-stat.	Prob.	Remarks
JBNorm	0.196	0.91	Normal
BPGHet	0.62	0.77	Homoskedasticity
RESETomv	1.5	0.24	No omitted variable
CUSUM&CUSUMQ	With the 5% region	-	Stable

Source: Author's calculation

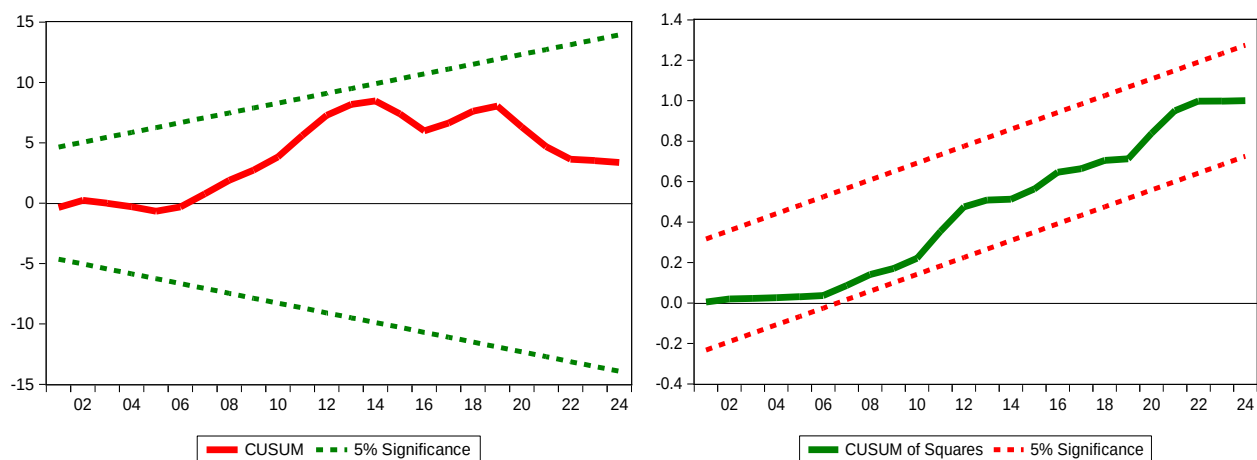


Figure 2: Stability Graph

Table 5 contains the diagnostic analysis which shows that the model passed all diagnostic tests as the probability values are higher than the 5 percent threshold. This is further validated by the CUSUM tests whose graphs (Figure 2) lie within the 5% region. This implies that the model has no econometric issues and can be relied upon for policy inferences.

4.2 Discussion of Findings

The discussion of results focuses on the effects of digitization, natural resource rents, renewable energy consumption, and trade openness on green growth in Nigeria in both the short run and the long run. The result shows that digitization has a positive and increasing effect on green growth in Nigeria. A percentage change in ITU raises green growth by 0.08% in the short run and 0.14% in the long run, respectively. This suggests that increased internet penetration promotes digital innovation, improves resource efficiency, and supports environmentally sustainable economic activities in Nigeria. In the Nigerian context, this may occur because wider internet access facilitates the adoption of digital financial services, e-commerce, smart agricultural practices, remote working arrangements, and online public services, all of which can reduce transportation-related emissions, improve energy utilization, and minimize waste associated with traditional business and administrative processes (Liu et al (2024; Lu et al., 2025; Abubakar et al., 2026). Furthermore, digital technologies enhance access to information, environmental awareness, and the diffusion of green technologies among households and firms. This finding is consistent with the theoretical expectation of the Ecological Modernization Theory (Mol et al., 2000), which posits that technological advancement and digital transformation drive environmentally adjusted economic growth by improving production efficiency, reducing resource intensity, and encouraging cleaner methods of economic activity. Empirically, the result also aligns with the findings of Luo et al. (2022), Majeed and Sharif (2024), and Neffati and Khemiri (2025), who demonstrate that digitalization significantly promotes green innovation and green economic growth through improvements in technological progress, efficiency, and innovation. However, the result contrasts with the finding of Chen et al. (2020) who conclude that the effect of digitization on the environment could be positive or negative.

From the results, natural resource rent (NR) has negative effect of on green economy (GGR) both in the short-and long-run. That is, a 1% increase in natural resource rents leads to 0.11% reduction in green growth. Similarly, NR exhibit a negative long-run relationship with green growth, reducing it by 0.08%. These results are consistent across all the techniques applied. This indicates that excessive dependence on natural resource exploitation undermines green growth by encouraging environmentally harmful production activities, increasing pressure on natural ecosystems, and

limiting economic diversification into more sustainable and environmentally friendly sectors. This finding is consistent with the empirical evidence of Cheng et al. (2020), Xu (2022), and Imran et al. (2025), who argue that natural resource dependence hinders green growth and sustainable development by reinforcing reliance on extractive industries, increasing environmental degradation, and constraining technological progress. However, the result contradicts the findings of Lee and He (2022), who indicate that natural resources can promote green economic growth under strong market-oriented institutions, and Sun and Mehmood (2025), who show that green growth and environmental sustainability can be enhanced when natural resource utilization is complemented by green finance, fintech, and sound institutional quality.

Further, renewable energy consumption (RE) exerts a positive effect on green growth (GGR), increasing it by 2.2% in the short-run and 3.9% in the long-run. The result is validated by other the other estimation techniques employed, showing the importance of renewable energy in promoting green growth in Nigeria. This outcome reinforces the evidence provided by Taşkın et al. (2020), Sohag et al. (2021), and Wang et al. (2023) who report that renewable energy stimulates green growth by reducing dependence on fossil fuels and improving environmental sustainability. However, this result contrasts with the findings of Sun and Mehmood (2025) and Amin et al. (2025), who observe more conditional or mixed environmental effects of renewable energy. Finally, trade openness (TRD) shows insignificant effect in both the long-run and short-run ARDL models. This result is robust across FMOLS, DOLS and CCR estimates. The insignificant coefficients across all estimation techniques indicate that the contribution of service trade to green growth in Nigeria is limited. This suggests that the environmental impact of trade depends largely on the composition of traded goods, the adoption of cleaner technologies, and the effectiveness of environmental regulations.

5. Conclusion and Recommendations

5.1 Conclusion

This study examines the effects of digitization, natural resource rents, renewable energy, and trade openness on green growth in Nigeria from 1996 to 2024 using the ARDL model, employing FMOLS, DOLS, and CCR for robustness analysis. The ADF and Phillips–Perron unit root tests confirm a mixed order of integration, while the ARDL bounds test reveals the existence of a long-run relationship among the variables. The ARDL estimates show that digitization and renewable energy significantly promote green growth in both the short and long run, indicating that greater internet penetration and increased adoption of renewable energy enhance environmentally sustainable economic growth. Specifically, a 1% increase in internet penetration raises green growth by 0.08% in the short run and 0.14% in the long run. Similarly, a 1% increase in renewable energy consumption increases green growth by 2.2% in the short run and 3.9% in the long run, underscoring its critical role in promoting environmental sustainability. Conversely, natural resource rents exert a negative effect on green growth, reducing GGR by 0.11% in the short run and 0.08% (weakly significant at the 10% level) in the long run, suggesting that excessive dependence on natural resource exploitation undermines environmental sustainability.

Trade openness, however, exhibits no statistically significant effect on green growth, implying that its environmental impact depends on the nature of trade and the prevailing institutional framework. The findings are robust across FMOLS, DOLS, and CCR techniques. Furthermore, the ARDL model explains about 79.0% of the variation in green growth ($R^2 = 0.790$), revealing that independent variables jointly account for 79% of the changes in GGR. Finally,

the diagnostic tests confirm that the estimated model is stable and free from heteroskedasticity, serial correlation, non-normality, and model misspecification, indicating that the results are reliable for policy inference.

5.2 Recommendations

The empirical findings have important policy implications for promoting green growth in Nigeria. First, greater investment should be directed toward expanding digital infrastructure and improving internet access, as enhanced digitization supports green growth by fostering innovation, resource efficiency, and sustainable economic activities. Efforts should also be intensified to increase the adoption of renewable energy through supportive policies, financial incentives, and increased investment in clean energy technologies, given its strong positive contribution to green growth in both the short and long run. Furthermore, strategies should be implemented to reduce excessive dependence on natural resource rents by promoting economic diversification and ensuring that resource revenues are invested in productive sectors such as renewable energy, digital infrastructure, and green industries. Such measures would lessen the adverse environmental effects associated with resource dependence while fostering sustainable economic development. Although trade openness does not exert a significant influence on green growth, trade policies should be aligned with environmental sustainability objectives by encouraging the transfer of clean technologies and strengthening environmental standards. Finally, continuous investment in green innovation, research and development, and institutional capacity should be sustained to reinforce the complementary roles of digitization and renewable energy in achieving long-term green growth and supporting Nigeria's transition to a low-carbon and environmentally resilient economy.

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