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Advancing Sustainability: Exploring the Impact of Debt, FDI, Finance and Environment in Nigeria

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Abstract

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Nations and international organizations advocate stringent measures to protect biodiversity and promote environmental sustainability. Without these measures. sustainable development becomes unattainable due to unchecked greenhouse gases. This study examined the impact of external debt, foreign direct investment (FDI), financial development, and renewable energy usage on environmental sustainability in Nigeria from 1990 to 2022, using a novel Dynamic Autoregressive Distributed Lag (ARDL)-Simulations Framework. Results showed that external debt, renewable energy usage, and FDI improve environmental sustainability in both the short and long term, while financial development reduces environmental quality. The study recommended that Nigeria manage external debt prudently, ensuring that funds are channeled toward renewable energy investments. This strategy will prevent debt from burdening the economy and harming environmental sustainability.

1. Introduction

The interconnection between external debt, foreign direct investment (FDI), financial development, and renewable energy consumption is a critical nexus influencing nations' economic growth and sustainability strategies, particularly in developing and emerging economies. The impact of external debt on economic growth and environmental sustainability is a double-edged sword. External debt can fuel economic growth by providing the necessary capital for infrastructure development, industrial expansion, and social investments such as education and healthcare. These investments can lead to improved productivity, job creation, and overall economic prosperity. However, the pressure to service external debt can divert resources from critical sectors, leading to fiscal constraints and economic instability (Aladejare, 2023a). High levels of debt may necessitate austerity measures that can stifle economic growth and exacerbate Furthermore, the environmental poverty. implications of external debt are significant. Countries with high debt may prioritize short-term economic gains over long-term environmental sustainability. In their quest to generate revenue, these nations may exploit natural resources unsustainably, leading to deforestation, pollution, and biodiversity loss (Adediyan et al. 2021). The extraction of natural resources to service debt often contributes to environmental degradation, undermining efforts to achieve sustainable development goals (Bese & Friday, 2022).

Foreign direct investment (FDI), financial development, and environmental sustainability linkage are characterized by both synergies and trade-offs. On the one hand, FDI and financial development can be powerful drivers of environmental sustainability if directed toward green industries and projects (Edo, 2024). For instance, FDI can significantly enhance a country's economic development by creating jobs, boosting productivity, and fostering technological innovation. However, the environmental impact of FDI is highly dependent on the sectors in which it is directed and the regulatory environment of the host country. For example, FDI in renewable energy projects can promote environmental sustainability by reducing greenhouse gas emissions and encouraging the adoption of clean technologies (Jamsheed, 2024; Ewane & Ewane, 2023; Yiadom et al., 2023). Financial development also plays a pivotal role in environmental sustainability by enabling the financing of green projects and the development of financial instruments like green bonds and sustainable investment funds. These tools are essential for channeling capital into environmentally sustainable ventures, such as renewable energy, energy efficiency, and conservation projects. Conversely, FDI and financial development in resource-intensive or polluting industries can lead to environmental degradation, including deforestation, pollution, and the depletion of natural resources. Without proper

regulation and incentives, FDI and financial development can exacerbate environmental problems by financing activities that harm the environment, such as the expansion of fossil fuel industries or unsustainable agricultural practices (Saleem et al., 2024).

Furthermore, as countries seek to balance economic growth with environmental stewardship, the transition to renewable energy sources has become a central strategy for improving environmental quality and reducing the adverse impacts of traditional energy consumption (Sadiq et al., 2022 & Qamruzzaman, 2022). The nexus between renewable energy consumption and environmental quality is fundamentally positive, as increased reliance on renewable energy leads to improved environmental outcomes. For instance, replacing coal-fired power plants with wind or solar energy reduces the emission of harmful pollutants such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter (PM), which are associated with respiratory diseases, acid rain, and smog. Moreover, the reduction of carbon dioxide (CO₂) emissions through the use of renewable energy sources is critical for mitigating climate change and its associated risks, including rising sea levels, extreme weather events, and disruptions to agriculture and water supplies (Sadiq et al., 2022). Balancing economic growth with environmental sustainability is a crucial area of focus for Nigeria. As Africa's largest economy, Nigeria faces significant challenges in managing its external debt, attracting sustainable investment. fostering financial development, addressing and environmental degradation (Wudil & Tsauni, 2024). External Debt has been a major component of Nigeria's financial landscape, especially in recent decades, with debt servicing often crowding out spending on environmental management, leading to challenges in addressing issues like deforestation, pollution, and climate change (Alani, 2021). Furthermore, when external debt is used to finance projects that contribute to environmental degradation, such as fossil fuel extraction or unsustainable agricultural practices, it can exacerbate environmental sustainability problems (Boateng, 2024). Also, Foreign Direct Investment

(FDI) is a key driver of economic growth in Nigeria, attracting capital, technology, and expertise from foreign investors. FDI has played a significant role in the development of Nigeria's oil telecommunications, sector, and gas and manufacturing industries. However, the environmental impact of FDI in Nigeria has been mixed. While FDI can bring much-needed investment in sustainable sectors, such as renewable energy and environmentally friendly technologies, much of the FDI in Nigeria has historically been concentrated in the oil and gas sector. This concentration has led to significant environmental challenges, including oil spills, gas flaring, and pollution in the Niger Delta. These activities have severe consequences for local communities. biodiversity, and overall environmental quality (Ganda, 2024).

As Africa's largest economy and most populous country, Nigeria faces a complex interplay of factors influencing its energy sector and environmental sustainability (Wudil & Tsauni, 2024). The transition to renewable energy sources represents a critical opportunity for improving environmental quality, but it also requires addressing various barriers and leveraging existing potential. In Nigeria, the potential for renewable energy is substantial due to its geographic and climatic conditions, including abundant sunshine for solar power, significant wind corridors, and numerous rivers for hydroelectric power. However, despite this potential, the country remains heavily reliant on fossil fuels, particularly oil and natural gas, for its energy needs (Matthew et al. 2023).

This study aims to enrich the existing literature by examining the interplay between rising external debt and environmental quality in the context of a large, developing country with substantial renewable energy resources. It seeks to address two main research questions: First, is there a dynamic relationship among external debt, foreign direct investment, renewable energy, and environmental quality in Nigeria? Second, what impact does renewable energy have on Nigeria's environmental sustainability? This research aims to contribute novel insights into these areas. Notably, it is the first study to investigate the connections between external debt, financial development, foreign direct investment, renewable energy, and environment in Nigeria. To address these research questions effectively, the study employs the dynamic autoregressive distributed lag model (DYARDL), which is particularly suited for small sample sizes and is valued for its consistency, unbiased results, and ability to handle endogeneity issues (Inuwa et al., 2024). The findings are expected to offer valuable policy recommendations and advance the field of knowledge. The paper is structured into several sections. including а literature review. methodology, results and discussion, with the final section focusing on conclusions and policy implications.

1.2 Statement of the Problem

Nigeria has witnessed a continuous rise in public debt, particularly external borrowing aimed at addressing budget deficits, infrastructural projects financing, and economy stabilization, and the mounting debt burden is straining government finances, diverting funds away from critical sectors education. and like health. environmental protection and increases the nation's vulnerability global economic shocks and currency to fluctuations (Aladejare, 2023a). Also, while FDI can fuel growth and create jobs, the uneven distribution of investments across sectors and the concentration in extractive industries particularly in the oil and gas sector pose significant challenge to economic sustainability and growth. FDI in resource extraction often leads to environmental degradation and gentrification, and the focus on short-term economic gains rather than sustainable practices results in resource depletion, pollution, and biodiversity loss, which exacerbate long-term environmental challenges (Saleem et al., 2024). Furthermore. Nigeria's financial sector is underdeveloped, and access to sustainable finance remains a challenge particularly for small and medium-sized enterprises (SMEs) and green projects. The high cost of capital, limited financial literacy, and lack of incentives for green finance discourage private investment in sustainable initiatives (Alani, 2021). Another constraint to Nigeria's ability to fund renewable energy projects,

agriculture, sustainable and eco-friendly infrastructure is the limited access to green financing coupled with the nation's heavy dependence on traditional industries that contribute to environmental degradation continues unabated, impeding the transition to a green economy (Matthew et al., 2023). In essence, Nigeria as Africa's largest economy, faces complex and interrelated economic and environmental challenges that hinder sustainable growth, necessitating a study that examines the interplay between debt, foreign direct investment (FDI), finance, and environmental factors in Nigeria, outlining the major challenges that threaten the nation's economic stability, environmental health, and long-term development.

2. Literature review

2.1 Nexus between External Debt, Foreign Direct Investment and Environmental Quality

The external debt of an economy may exert a significant influence on its economic performance, which in turn may affect its environmental quality. This may require this country to adopt stringent policies to avoid the negative impact of external debt on environmental quality. Several studies have emphasized the association among energy consumption, foreign direct investment, economic growth, and carbon emission, but studies on the direct impacts of external debt on the environment quality are still limited in Nigeria. In this regard, Saleem et al. (2024) examined the effects of renewable energy, FDI, and external debt on the load capacity factor in Brazil over the period 1970-2021 using the novel augmented autoregressive distributive lag (A-ARDL) technique. The findings revealed that an increased external debt hurts ecological sustainability both in the short run and the long run, and renewable energy positively affect ecological sustainability both in the short run and long run. Using autoregressive distributed lag (ARDL) model, Bese and Friday (2022) investigated the link between carbon dioxide emissions, economic growth and ecological footprint per capita for the Republic of Turkey spanning the period 1970-2016. Their results revealed an inverted U shaped

between carbon dioxide emissions and external debt, non-inverted U relationship between ecological footprint and external debt, while there is bidirectional causal relationship between external debt and economic growth.

In a related study, Aladejare (2023a) assessed the impact of external debt on longevity in developing countries in West African countries from 1981 to 2020 using cross-sectional augmented autoregressive distributed lag (CS-ARDL), dynamic common correlated effects (DCCE), and the Driscoll- Kraay (D-K) methods. The study revealed that unsustainable external debt and macroeconomic volatility shorten longevity mainly in the long-term in West African countries. Adediyan et al. (2021) modelled the implications of growth in FDI and external debt on four cases of environmental resources depletion (forestry, solid minerals, fisheries, and crude oil resources productions) in Nigeria over the period 1980 to 2019. Autoregressive Distributed Lag (ARDL) method was applied and the results suggested that the depletion rate of environmental resources like crude oil is largely affected by the movement in FDI inflow in both the long run and short run, while the level of depletion of the forest is affected by external debt. Furthermore, the depletion level of fisheries responds positively only to a change in FDI with in the short run. For solid minerals, the study found a long run positive impact of external debt. Mustafa and Shah (2024) selected 41 countries within the framework of International Monetary Fund (IMF) from 2005 to 2021 and employed System Generalized Method of Moments (GMM) and Difference GMM approach to examine the nexus among GDP growth, external debt, government spending, inflation, and imports. They discovered that high external debt is linked to lower GDP growth, indicating negative correlation.

In a related development, Jamsheed (2024) examined the nexus between foreign direct investment (FDI), external debt, and economic sustainability over the period of 1980 to 2020 in India, Sri Lanka, Pakistan, Nepal, Bangladesh, Bhutan and Maldives. Hausman test's preference for the Fixed Effects (FE) model was applied, and the findings revealed a negative correlation between external debt and economic growth the foreign direct investment is inversely proportional to the economic growth and external debt. Edo (2024) investigated the trend of how foreign aid and external debt in developing countries impacted economic growth over the period 1994-2022 by employing the Generalized Method of Moments (GMM) and Vector Error Correction Model (VECM). The results revealed that growth responded favorably to stable foreign aid and declining external debt, with the response to external debt more robust than the response to foreign aid. Qamruzzaman (2022) gauged the impact of foreign direct investment and public debt in developing renewable energy growth in Bangladesh for the period 1990-2020 by using cross-sectional dependency, Panel -ARDL with symmetry and asymmetry framework. The findings revealed that public debt and FDI coefficients have positive and statistically significant impact on renewable energy growth in the economy, in the long run, Whereas, unidirectional causality running from public debt to renewable energy and bidirectional causality between FDI and renewable energy consumption exist.

In a similar study, Bese, et al., (2021) investigated the effect of external debt on carbon dioxide emissions taking into account the gross domestic product per capita, square of GDP, energy consumption and external debt. The autoregressive distributed lag (ARDL) model and nonlinear ARDL model were applied on time series data in China for the period of 1978-2014. The study discovered that external debt and energy consumption significantly and positively affect emissions. Prah & Ofori, (2022) applied autoregressive distributed lag (ARDL) model to examine inter-relationships among external debt, exchange rate, foreign investments and economic growth in Nigeria from 1981 to 2018. The findings revealed that foreign investment and external debt have positive and an insignificant impact on economic growth in Nigeria. In another study conducted by Karim et al. (2023) using Bayer and Hanck (2013) and Maki (2012) cointegration tests, investigated the interconnection among Renewable energy consumption, public debt, globalization, FDI, and Institutional

quality in Bangladesh for the period 1995-2021. They discovered a positive and significant impact of Renewable energy consumption, public debt, globalization, FDI on institutional quality both in the long-run and short-run. Zaghdoudi (2024) investigated the nexus between external debt and energy access in the Sub-Saharan African countries from 1999 to 2021 using the dynamic panel threshold method. Findings revealed that a statistically negative relationship exists between external debt and energy access above the threshold of 5.04 %, beyond which external debt reduces energy access and that economic growth and trade openness promote access to electricity, Whereas, renewable energy consumption decreases energy access. Sadiq et al., (2022) applied a battery of second-generation estimation approaches to examine the impact of nuclear energy, external debt, and financial globalization in sustaining human development and environmental conditions in BRICS countries covering the period 1990 to 2019. The findings indicated that financial globalization accelerates ecological deterioration, but nuclear energy and external debt promote environmental sustainability. (Mazher & Tramankuti, 2023) employed cointegration techniques, and the VECM method to examine the environmental degradation in Asian economies between 1990 and 2019, with a specific focus on external debt. The findings revealed a robust link between economic growth and CO₂ emissions, and an inverse connection between external debt and net official development assistance (NODA).

2.2. Energy Resources, Financial Development, Foreign Direct Investment and Environmental Quality

A growing body of scientific studies have emerged on the influence of Financial Development, Foreign Direct Investment, economic expansion and renewable energy consumption on ecological quality. For example, Yiadom et al. (2023) investigated whether financial development helps to overturn the negative impact of foreign direct investment (FDI) on the environment using a dynamic panel of 43 economies from 1982 to 2018. They found that financial deepening and efficiency reduce environmental risk and can overturn the negative impact of FDI on the environment. Similarly, Sun et al. (2023) examined the determinants of carbon footprints in selected South Asian countries using Cross-sectional augmentedautoregressive Distributed Lag (CS-ARDL) regression estimator. The findings confirm an inverted U-shaped association between financial development and carbon footprints, technological innovation reduces carbon footprints in the shortand long run, while renewable energy transition exerts negative influence on carbon footprint in the long run. The findings also confirm the pollution haven hypothesis by confirming that net foreign direct investment inflows boost the carbon footprint. Yiadom et al. (2024) utilized the Dynamic Stochastic General Equilibrium (DSGE) model and differenced GMM techniques to investigates the effect of carbon tax adoption on foreign direct investment in Africa with data spanning from 1995 to 2019, covering 43 Sub-Saharan African countries. The findings demonstrated that the unmitigated effect of the carbon tax on FDI is repressive. However, if the revenue from the carbon tax is recycled into the economy, the carbon tax will have a significant positive effect on FDI. Hence, the findings corroborate the double dividend theory. The results further suggest that a carbon tax of around US\$ 8.5 per tonne is reasonable to enhance inward FDI but a carbon tax either above US\$ 25 per tonne or below US\$ 3 per tonne will be detrimental to the African region. Using a quadratic modeling and turning point approach, Ewane & Ewane (2023) examined the effect of trade openness and foreign direct investment (FDI) on environmental degradation using time series data from 1975 to 2020 in Sub-Saharan African countries. The findings revealed that a U-shaped trade openness-emissions and FDI-emission nexus hold given the decrease in trade openness and FDI in the short run and an increase in trade openness and FDI in the longrun; pollution halo hypothesis sets in after the turning point, and that trade openness and FDI reduce CO2 emissions in the short but increase it in the long run.

In another study by Arthur et al. (2024) utilizing the GMM-PVAR model, empirically investigated

the causal nexus between FDI and sustainable development in a panel of 48 African nations spanning the period from 1990 to 2020. They discovered a unidirectional negative causality running from foreign direct investment to sustainable development across African economies, with the magnitude of this adverse impact been more pronounced in low-income countries, while a favorable causal effect of FDI on sustainable development is observed in high-income countries within the region. Shahzadi et al. (2023) analyzed the impact of foreign direct investment, technological innovation, economic growth, and greenhouse gas emission on renewable energy in developing countries from 1991 to 2021. Employing dynamic panel ARDL estimator, the findings confirm that, economic growth, foreign direct investment and technological innovations exert negative effect on renewable sources of energy, whereas, greenhouse gas emissions showed significant positive impact on renewable energy. Li et al. (2019) investigated the impact of foreign direct investment on environmental performance (EP) in 40 countries using panel data from 1990 to 2014 using a directional slack-based model. Their outcomes reveal that, FDI has an insignificant impact on EP for the full sample; the impact of FDI on EP between developed and developing countries exists heterogeneously; in the developed countries, the effect is statistically insignificant at lower quantile of EP, and then turns significantly positive in the middle and high quantile, and the positive effect increases with the rise of quantiles of EP. Le et al. (2022) used annual data covering the period of 1986-2020 and applied the non-linear autoregressive distributed lag (NARDL) to examine the impact of foreign direct investment and economic growth on environmental pollution in Vietnam. The findings support the asymmetric relationship among the study variables and that, economic performance leads to a positive change in environmental, and a decrease in economic performance leads to a negative change in environmental pollution in Vietnam. However, there is a disproportionate impact of foreign direct investment on economic growth in the long run, and disproportionate impact of environmental а

pollution on the economy in both the short and long term.

2.3 Research Gap

The above discussion in the empirical literature focused on carbon emission (CO2) and ecological footprint to capture environmental sustainability using different periods (e.g., 1970 to 2015, 1995 to 2017). These proxies cover the demand part of environmental sustainability and exclude the supply part. Recently, some studies have used LCF to capture environmental sustainability, which takes into account both the supply sides of nature and the demand sides of ecological sustainability. Most empirical literature has ignored the connection between external debt and LCF. Thus, the present study aims to fill the research gap by examining the impact of external debt on the LCF for the first time in the case of Brazil. Likewise, this paper aims to present novel empirical evidence by applying the AARDL approach using two different periods, from 1990 to 2021 and from 1970 to 2021.

3. Data and Methodology

3.1. Data and Tested Model

To empirically assess the impacts of external debt, foreign direct investment, financial development and renewable energy, on environmental quality in Nigeria, this study uses annual time series data from 1990 to 2022. In order to achieve the objective of this study, we specify the model to be tested by taking into account the CO2 emissions indicator to measure environmental quality. The model of this analysis is formulated as follows:

$$LnCO_{2t} = \beta_0 + \delta_1 lnEXTD_t + \delta_2 lnFDI_t + \delta_3 lnFD_t + \delta_4 lnREC_t + u_t \qquad 1$$

Where; CO2t denotes the carbon dioxide emissions, InEXTDt denotes external debt, InFDIt denotes foreign direct investment net inflows FDt denotes financial development and InRECt denotes renewable energy consumption. A description of the selected variables in this study and data sources is presented in Table 1.

Iuble II ful	uble definitions and medsure	, menes	
Sign	Variables	Measurements	Sources
CO2	Carbon Dioxide Emissions	Emissions from burning of fossil fuels and	WDI
		other manufacturing activities, including	
		carbon dioxide produced during consumption	
		of solid, liquid, and gas fuels and gas flaring	
		(Measured in kilo tone).	
EXTD	External Debt	sum of public, publicly guaranteed, and	WDI
		private nonguaranteed long-term debt, short-	
		term debt, and use of IMF credit. (current U.S.	
		dollars)	
FDI	Foreign direct investment	Foreign direct investment, net inflows (BoP,	WDI
		current US\$)	
FD	Financial development	Domestic credit to private sector (% of GDP)	WDI
REC	Renewable energy	Renewable energy consumption (% of total	WDI
	consumption	final energy consumption)	

Table 1. Variable definitions and measurements

3.2 Estimation procedure

This study employs the innovative Dynamic Autoregressive Distribution Lag (D-ARDL) Model. Previous studies often used the traditional ARDL framework developed by Pesaran et al. (2001) and other cointegration techniques, that only explain the short- and long-run nexus among the tested parameter (Udeagha & Breitenbach, 2023). But as the model specification grows in complexity, understanding the short, medium, and long-run effects becomes difficult. In addition to its error-correction form, ARDL models in general may have

complex dynamic specifications, including multiple lags, first differences, and lagged firstdifferences. This makes it more difficult to interpret the effects of changes especially short- and longerrun changes in the explanatory variables. (Jordan and Phillips, 2018).

To overcome the limitations of the traditional ARDL methodology, this study employed the Dynamic Autoregressive Distributed Lag (D-ARDL) model, as introduced by Jordan and Philips (2018). This advanced approach is particularly effective in visualizing and plotting graphs to predict both positive and negative changes in various factors, examining the interconnected short-term and long-term relationships among the variables under study, improving accuracy, and addressing the complexities associated with the conventional ARDL method (Udeagha & Ngepah, 2022). Key advantages of the dynamic ARDL technique include (i) its effectiveness when the speed of convergence varies; (ii) its applicability regardless of the order of integration of the variables, except for I(2); and (iii) its capability to generate graphs and area plots illustrating the effects of positive and negative shocks to the regressors on the response variable (Inuwa et al., 2024).

3.3 Stationary and Cointegration Assessments

This study applied the Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) unit-root tests to assess the stationarity status of the tested data. However, it is a well-known issue that traditional unit-root tests, such as ADF and PP tests, do not take into consideration structural break dates. To overcome this issue, this study applied the Lee and Strazicich (LM) test. This test takes into account two structural-break dates. The presence of fractional integration in the data examined can cause significant problems in the empirical tests. To fix this, several empirical studies have utilized the ARDL bounds test as introduced by Pesaran et al. (2001). It is specified as follows:

$$\begin{aligned} \Delta lnCO_{2t} &= \alpha_0 + \alpha_1 lnCO_{2t-1} + \alpha_2 EXTD_{t-1} + \alpha_3 lnFDI_{t-1} + \alpha_4 FD_{t-1} + \alpha_5 lnREC_{t-1} \\ &+ \sum_{i=0}^{p} \beta_1 \Delta lnCO_{2t-1} + \sum_{i=0}^{k_1} \beta_2 \Delta lnEXTD_{t-1} + \sum_{i=0}^{k_2} \beta_3 \Delta lnFDI_{t-1} + \sum_{l=0}^{K_4} \beta_4 \Delta FD_{t-1} \\ &+ \sum_{l=0}^{K_4} \beta_4 \Delta lnREC_{t-1} + \mu_t \end{aligned}$$

In the above equation, short-term coefficients are denoted by β_i , while long-term coefficients are denoted by α_i with I = 1... n. The immediate effect of independent variables on dependent variables is measured by short-run analysis, while the long-run

report indicates the speed of adjustment toward equilibrium level in the longrun.

The D-ARDL model in its error correction form is expressed as follows:

$$\Delta lnCO_{2t} = \alpha_0 + \alpha_0 lnCO_{2t-1} + \rho_1 \Delta lnEXTD_t + \phi_1 lnEXTD_{t-1} + \rho_2 \Delta lnFDI_t + \phi_2 lnFDI_{t-1} + \rho_3 \Delta FD_t + \phi_3 FD_{t-1} + \rho_4 \Delta lnREC_t + \phi_4 lnREC_{t-1} + \hbar ECT_{t-1} + \mu_t$$

Here, error correction term (ECT) represents the adjustment factor, which must be negative and significant to ensure convergence in the time series. Post-estimation diagnostics included the Breusch-Godfrey test to assess autocorrelation, the WHITE test to identify heteroscedasticity, the Ramsey RESET test to evaluate model specification, and the Jarque-Bera test to analyze the distribution of errors. Additionally, the CUSUM and CUSUMQ tests were utilized to evaluate the model's stability.

Table 2. Summ	al y Statistics all				
Variables	CO_2	EXTD	FDI	FD	REC
Mean	11.46261	24.30159	21.42076	10.16841	4.437744
Median	11.46516	24.23561	21.41909	8.909485	4.436752
Maximum	11.69144	25.14010	22.90267	19.62560	4.484132
Minimum	11.19504	23.64514	19.51785	4.957522	4.380776
Std. Dev.	0.127342	0.340073	1.007411	3.546446	0.030804
Skewness	-0.130968	0.776318	-0.211429	0.908566	-0.353777
Kurtosis	2.251695	3.662441	1.947987	3.522255	1.920746
Jarque-Bera	0.811903	3.680615	1.660489	4.617349	2.151170
Probability	0.666342	0.158769	0.435943	0.099393	0.341098
Correlation Matrix					
CO ₂	1.000000				
EXTD	0.715956	1.000000			
FDI	0.103360	-0.105192	1.000000		
FD	0.180864	0.016957	0.737792	1.000000	
REC	-0.906415	-0.721156	-0.303537	-0.309342	1.000000

Table 2. Summary Statistics and Correlation Matrix

Source: Author's computation

4. Results

4.1. Descriptive Statistics

The summary of the descriptive statistics of variables of the study are presented in Table 2, including CO2, EXTD, FDI, REC and FD. As suggested, there are negative skewness in terms of CO_2 , FDI and REC, and high kurtosis for EXTD and FD. Based on the results obtained, the mean and median values are approximately the same. However, the volatility in the variables is revealed by the standard deviation as it is high in FD compared to CO2, EXTD, FDI, and REC. The Jarque-Bera statistics indicated that all the variables are normally distributed, suggesting that further empirical investigation is required. Similarly, the results of the correlation matrix are presented in the

Table	3.	Unit	root	test.

lower part of Table 2, revealing that explanatory variables are weakly correlated except for REC.

4.2 Unit Root Tests

In the empirical investigation of the time series modeling, the first important step is the preliminary investigation to reveal the stationary properties of variables through the use of unit root tests. This is because, knowing the stationary properties of the variables will provide a guide in making the right choice of estimation techniques to be employed as well as avoiding spurious results. To achieve these, the study utilized the conventional Dickey Fuller GLS, ADF, PP and NG Perron tests, and the outcomes are displayed in Table 3.

Variables	ADF	Phillips Perron	Lee Strazicich Un	it Root Test
Level	Test Statistics		Break Year	Test Statistics

LCO2	-2.942633	-2.942633	2006 2012	-6.198956
LEXTD	-1.084324	-1.229828	2001 2006	-6.968035
LFDI	-2.864507	-2.064151	2003 2017	-5.592286*
FD	-3.691574***	-2.077189	2004 2009	-7.933864***
LREC	-2.563224	-2.629323	2004 2017	-7.145371***
First Differen	се		Critical value (1%, 5	5%, and 10%)
LCO2	-5.549099**	-6.484956***	2002 2007	-8.038877***
LEXTD	-6.791774***	-4.813348***	1995 2007	-9.628696***
LFDI	-7.932322***	-6.787627***	2004 2016	-6.937358***
FD	-5.214266***	-6.588783***		
LREC	-5.673722***	-5.681663***		

Note: ADF = Augmented Dickey Fuller. ***, ** and * show significance at 1%, 5% and 10% levels respectively. *Source*: Authors' computations

The results from Table 3 reveal that all the variables have unit root at their level values when tested with intercept and trend with the exception of FD. However, the variables were subjected to first difference and they became stationary. The results from all the unit root tests showed that the stationary properties of the variables are I(0) and I(1), hence, satisfying the condition for the application of the novel dynamic ARDL cointegration.

4.3 Lag Length for F- Bound Cointegration Test

The result of the optimal lag length is presented in the table below. Table 4 presents the lag order selection by five different criteria. All the lag selection criteria except LR and SC, suggested that a lag length of one (1) is optimal for the F-bound cointegration test.

4.4 Bound Test for Cointegration

The results of the bound test for cointegration using ARDL approach are shown in Table 4. From the result in table 4, the null hypothesis of no cointegration is rejected at 5% because the F-statistics is higher than the upper-bound critical values.

Table 4. Lag Length for F- Bound Connegration fest
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Lag	LogL	LR	FPE	AIC	SC	HQ
0	15.84196	NA	3.26e-07	-0.747722	-0.511981	-0.673890
1	81.16770	103.6201*	2.08e-08*	-3.528807*	-2.114363*	-3.085821*
2	95.37097	17.63165	5.19e-08	-2.784205	-0.191058	-1.972064

**Indicates lag order selected by the criterion Source:* Author's Computation

Table 5. Bound Test for Cointegration H₀: *No cointegration*

 e: Boana ie	se for connegration	1100 110 2 000008.000		
F-Statistic	Significance	Bound Critical Valu	ies	Κ
	Level			
		I(0) Bound	I(1) Bound	
4.969296	1%	3.74	5.06	4
	2.5%	3.25	4.49	
	5%	2.86	4.01	
	10%	2.45	3.52	

Source: Author's Compilation using Eviews

4.5 Findings of dynamic ARDL simulations approach

Results from the dynamic ARDL simulation model are shown in Table 7. Having confirmed the existence of cointegrating relationship among the variables, the study applied dynamic ARDL estimator, and the results are presented in Table 6. The results reveal that in both the short and long run, external debt contributes significantly to rising CO2 emissions at 5% and 10% levels of significance respectively. This shows that any 1% increase in external debt will escalate environmental pollution by 0.009% and 081% respectively. This may be connected to the fact that, these countries in their quest to generate revenue to service their foreign debt, may over-exploit natural resources, resulting to excessive deforestation, pollution, and loss of biodiversity (Adediyan et al. 2021).

Variables	Coefficients	Std. Err	t- Stat	Prob.
D-LEXTD	.0097321	.0441663	2.022	0.048
L-LEXTD	.0814217	.0459641	1.77	0.092
D-LFDI	0136943	.012939	-1.05	0.303
L-LFDI	0124885	.0131796	-2.95	0.035
D-FD	.0007738	.0038312	2.20	0.041
L-FD	.0025161	.00336	2.75	0.036
D-LREC	-3.808662	.4391942	-8.67	0.000
L-LREC	-1.014424	.7625103	-2.33	0.039
Cons	8.497058	5.49248	1.55	0.138
ECT(-1)	-0.501729	0.092590	-5.418858	0.0000
R-squared	0.887914		Adjusted R-squared	0.874981
F-statistics	68.65469(0.0000)			
Simulations	5000			

Table 6. Findings of dynamic ARDL simulations approach

Source: Author's Computation.

This outcome is in line with what Saleem et al. (2024) discovered in Brazil, and Bese and Friday (2022) in Turkey. Conversely, the coefficient of FDI promotes environmental quality both in the short run and long run. This implies that any 1% increase in FDI will reduce CO2 emissions by 0.13% in the short run, 0.12% in the long run, corroborating with the findings of Adediyan et al. (2021) in Nigeria and Qamruzzaman (2022) in Bangladesh. In the words of Jamsheed (2024) and Yiadom et al., (2023), FDI renewable energy projects preserves in environment by reducing greenhouse gas emissions and stimulating the adoption of clean technologies. However, financial development positively and significantly affects CO2 emissions in both periods at 5% levels of significance. This suggests that a 1% appreciation in FD reduces environmental quality by 0.0007% and 0.0025% in the short and long run. respectively. This result is supported by the work of Sun et al. (2023) in selected South Asian countries. Finally, renewable energy consumption significantly reduces CO2 emissions both in the short run and in the long run. This suggests that increase in the adoption of REC immediately reduces carbon emissions, thereby promoting environmental quality in Nigeria. 1% appreciation in REC adoption promotes environmental quality by 3.80% and 1.01% in the short and long run, respectively. This findings is confirmed by the works of Raihan et al.,(2024) and Farhan et al., (2024) in the newly industrialized countries.

4.4.3 Diagnostic Statistics Tests

The series of diagnostic checks have been employed in the form of normality, serial correlation, heteroscedasticity, and functional misspecification, and the results are displayed in Table 8. As evidenced from the Jarque-Bera test, Breusch-Godfrey serial correlation LM test, and Ramsey RESET test, the estimated model has passed all the post-estimation tests. Similarly, the results of the CUSUM test displayed in Figure 1 suggests the constancy and stability of residuals and models, respectively.

Table 8. Diagnostic statistics test	ïS.
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Diagnostic Statistics Tests	X ² (p Values)	Results
Breusch-Godfrey LM test	0.0866	No serial correlations
Breusch-Pagan-Godfrey test	0.5594	No heteroscedasticity
Ramsey RESET test	0.3881	Model is correctly specified
Jarque–Bera Test	0.1686	Normal estimated residuals
1		

Source: Author's Computations.



Figure 1 Plot of CUSUM Plot

To further reveal the impact of the explanatory variables on the explained variable, this research work used the impulse response functions generated from the dynamic ARDL estimations, and the outcomes are shown in Figure 2–5. The plot displayed in Figure 2 unmask the positive and negative response of external debt (EXTD) and establish stimulating effect on environment in Nigeria at a 10% level of significance. The effect of the positive and negative shocks in FDI depicts an escalating effect on CO_2 emissions as displayed in Figure 3. However, the rise in financial

development slows down environmental quality in Nigeria, while its fall raises the quality of the environment as clearly seen in Figure 4. Figure 5 depicts the linkage between REC and CO_2 emissions using an impulse-response plot. The plot depicts the change in REC and how it impacts environmental quality in Nigeria. A 10% increase in REC indicates a weak short-term and strong longterm negative impact on CO_2 emissions, while its 10% decrease indicates a positive impact on CO_2 Emissions in the shortrun, and longrun.



Figure 2. The above figure signifies a 10% increase or decrease external debt and its effect on environmental quality.in Nigeria



Figure 3. The above figure signifies a 10% increase or decrease FDI and its effect on environmental quality.in Nigeria.



Figure 4. The above figure signifies a 10% increase or decrease financial development and its effect on environmental quality.in Nigeria.



Figure 4. The above figure signifies a 10% increase or decrease REC and its effect on environmental quality.in Nigeria.

5 Conclusion and Policy Recommendations

This research established the dynamic impact of external debt, foreign direct investment, financial development and renewable energy consumption considering data from 1990 to 2022 for Nigeria, using credible econometrics estimators including the classical and structural breaks unit root tests, the novel dynamic ARDL simulation model and post estimation techniques. Findings revealed as follows: increase in external debt escalates environmental degradation both in the short and long run, respectively. Contrarily, a rise in FDI promotes environmental sustainability both in the short run and long run. However, financial development reduces environmental quality both in the short and long run, respectively. Finally, an increase in renewable energy consumption promotes environmental quality both in the short run, and long run.

This paper presents important policy recommendations for Nigeria's sustainable development, that Nigeria manage external debt prudently, ensuring that funds are channeled toward renewable energy investments. This strategy will prevent debt from burdening the economy and harming environmental sustainability. Also, to address Nigeria's energy deficit and to capitalize on its abundant natural resources, particularly solar and wind energy, the country should implement green finance incentives and establishing policies to promote FDI in renewable energies. This wold

significantly expand its energy production capacity and investment in renewables over the next decade. This strategy aligns with global climate change goals and leverages Nigeria's natural advantages.

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