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Assessing the Impact of Green Technological Innovation, Renewable Energy Consumption and Financial Development on Environmental Sustainability in Nigeria

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Abstract

This study employed the novel Dynamic Autoregressive Distributed Lag (DYARDL) model to analyze the impact of renewable energy consumption, green technological innovation and financial development on CO2 emissions in Nigeria. Furthermore, Fully Modified Ordinary Least Square (FMOLS) and Canonical Cointegrating Regression (CCR) approaches are employed for robustness checks. The DYARDL results indicate that green technological innovation, renewable energy consumption and financial development respectively, promote environmental sustainability in the longrun, whereas, in the shortrun, green technological innovation is negatively related to the environmental quality in Nigeria. However, trade openness contributes towards environmental degradation both in the shortrun and the long run. The result of the Dynamic ARDL in this study is in conformity with the findings from both the FMOLS and CCR models. The study therefore, recommends that in order to achieve the target set by Nigeria Renewable Energy Master Plan (REMP) of generating 36% of its electricity from renewable energy sources by 2030, with a primary focus on hydro, Biomass-

based, wind and solar energy sources, government should provide fiscal incentives to private investors in form of tax holidays, capital incentives, moratorium on import duties and loan opportunities for renewable energy projects in the country. Also, policymakers should strengthen policies that encourage green technological investments, in order to promote economic growth while also further reducing environmental emissions.

Key words: Green Technology, environment, Dynamic ARDL, Renewable energy, Nigeria. ***JEL Classification Code:*** C53, O31, O44, Q27

Introduction

In the last few decades, the world has experienced harsh environmental consequences, particularly CO_2 emissions, due to the activities of humans, such as burning fossil fuels, deforestation, and industrial processes (Bergougui, 2024).The energy required for economic growth, dominated by non-renewable energies from fossil-fuel sources pose significant risks to the environment, thus necessitating its recognition as a pressing global issue (Matthew et al., 2023). While, the share of renewable energy has been on the rise in the global energy mix, recent statistics from British Petroleum (BP, 2021) report that fossil-fuel energy accounts for the largest share of 31.22% of global energy consumption (Adewale et al., 2024). The escalation of global warming has been attributed to several factors other than burning fossil fuels, including a rise in industrial waste generation, ongoing depletion of natural resources such as oil, minerals, gas and forests, as well as the persistent adoption of environmentally incompatible financial development strategies and non-sustainable technologies.(Ganda, 2024). As such, there is need on a global scale, for energy transition from nonrenewable energy to renewable energy sources as well as technological advancement that will play a crucial role in addressing climate change and improving energy efficiency (Ganda, 2024).

Additionally, technological innovation over the years has been identified to engender sustainable development in any nation and contributes positively in improving environmental quality by tackling environmental issues (Wenlong et al. 2022). However, given the disparity in development levels of economies, this translates into different global experiences as conditioned by other policy instruments (Udeagha & Ngepah, 2022). Furthermore, based on the continual commitment to improving

environmental quality by governments, the Paris agreement accord was recently reaffirmed in Glasgow. The COP26 occurred at a critical time when extensive decarbonization is being demanded. Post covid countries are engaged in economic recovery strategies, including contextualizing resource utilization under sustainable envelopes (Kwame et al., 2023). With all these efforts, Some countries and regions such as Sub-Saharan Africa though not being major contributors to global Green House Gases (GHGs), are the most vulnerable to climate change hazards, with Air pollution causing 490,000 deaths annually in Sub-Saharan Africa, and lack of access to modern energy sources is also considered as an impediment to the region's wellbeing and development objectives, facing negative effects of climate change in the form of food deficits, extreme weather, water stress, and low economic performance.(Nawaz & Mafizur, 2023).

As the fourth largest fossil fuels consumer and CO_2 emitter in Africa, responsible for 136.98 million tonnes (Global Carbon Budget, 2022), Nigeria has been grappling with the challenge of reducing CO_2 emissions, while still struggling to meet the energy needs of its growing population. Among the west African countries, Nigeria has the greatest biophysical potential for climate mitigation from natural climate solutions, such as increased trees in agricultural lands, reforestation, and improved natural forest management (USAI, 2023). In an effort to combat environmental deterioration, Nigeria has become part of the developing countries that participated in the 2015 Paris Agreement, pledging to reduce approximately 20% of GHG emissions from agriculture, forestry and other land uses by 2030, restore and protect about 380,000 hectares of forest and mangrove (Leddy, 2020). Nigerian government has implemented a number of strategies to find lasting solutions to climate change and meet its emission reduction targets. One of these strategies is the promotion of green technology to tackle environmental challenges through Distributed Access through Renewable Energy Scale-up (DARES) project, a world bank supported program and Other development partners including the United States Agency for International Development (USAID), the German Development Agency (GIZ), SEforAll, and the African Development Bank (AfDB). The main aim of DARES project is to provide new or improved access to electricity through distributed renewable energy solutions to over 17.5 million Nigerians (World Bank, 2023).

Furthermore, possible impact of green technological Innovation (GTI), Renewable Energy Consumption (REC), and Financial Development (FD) on Nigeria's environmental quality is unclear. Although a few studies have examined the effects of fossil fuel energy consumption and foreign direct investment on CO2 emissions, no

study has yet explored the combined impact of green technological, renewable energy use, financial development and CO2 emissions in Nigeria by employing the novel dynamic ARDL simulations. This is a significant gap in the literature because green technological innovation can play a significant role in reducing CO2 emissions. Also, previous studies have used linear models on time series (OLS, VAR, ARDL, and VECM) that only explain the short- and long-run nexus among the tested variables but as the model becomes complex, understanding the short, medium, and long-run effects becomes difficult (Udeagha & Breitenbach, 2023). However, the Novel Dynamic ARDL is strong in its ability to predict, simulate, and immediately plot probabilistic adjustment forecasts on the explained variable in one explanatory variable, other things remain constant (Udeagha & Ngepah, 2022). Nigeria's economy has experienced significant changes in recent decades, including abrupt shifts (economic crises, changes in institutional arrangements, policy changes, civil unrest etc.) and industrial transformations. These changes have led to distinct phases and structural breaks in Nigeria's economy (Ikwor & Otta, 2022). To better understand the impact of GTI, FD, and REC on environment sustainability in Nigeria, it is important to consider these breaks and policy shifts. Motivated by the analysis mentioned above, this study seeks to bridge the existing research gap by employing multiple structural break detecting techniques.

Literature Review

This section presents previous literature that explores the determinants of environmental sustainability in order to justify our research gap. It is noted that importance of research and development in fostering green technological innovation has been confirmed by numerous studies (Bergougui,2024; Tsimisaraka et al. 2023; Ali et al. 2023) and it has also been demonstrated that technological innovation has a favorable influence on environmental sustainability (Ali et al. 2023). According to Erdogan et al. (2023), renewable energy reduces carbon emissions, while being negatively affected by financial development (Parveen et al. 2023).

Wenlong et al. (2022) examined the impact of energy efficiency, technology innovations, trade openness, and institutional quality, on environment in 10 Asian economies over the period 1995– 2018, using Westerlund and Edgerton (2008) and Banerjee and Carrion-i-Silvestre (2017) cointegration techniques and cross-sectionally augmented autoregressive distributed lag (CSARDL) model. The findings revealed that both trade openness and institutional quality have detrimental impact, whereas energy efficiency and technology innovations have favorable impact on environmental

quality in the selected economies. Erdogan et al. (2023) analysed the asymmetric effects of economic growth, renewable energy, and non-renewable energy consumption on carbon emissions in Canada from 1965 to 2017 by employing nonlinear ARDL method. The findings suggest that positive shock in renewable energy reduces carbon emissions. Whereas, negative shock in economic growth greatly deteriorates the quality of the environment; On the other hand, positive shocks in energy consumption have a positive and significant effect on carbon emissions.

Similarly, Monirul-Islam et al. (2022) investigated the contribution of renewable and nonrenewable energies in sustainable development while also taking into account financial development and institutional quality in ASEAN countries from 1980 to 2018. A pooled mean group (PMG) regression technique, fully modified ordinary least square (FMOLS), dynamic ordinary least square (DOLS), and canonical cointegration regression (CCR) techniques in conjunction with other panel-based econometric procedures were applied. The findings revealed a significantly positive influence for renewable energy and a significantly adverse impact for non-renewable energy with respect to sustainable development in ASEAN countries. In addition, the results indicate that institutional quality and financial development have adverse effects on sustainable development. In another study, Bergougui (2024) examined the asymmetric impact of technological innovation, fossil fuel energy, and renewable energy on CO_2 emissions in Algeria by employing nonlinear autoregressive distributed lag (NARDL) model, Quantile Autoregressive Distributed Lag (QARDL) and Quantile Granger Causality (QGC) approaches. The NARDL results indicate that positive shocks in technological innovation decreases CO_2 emissions, whereas negative shocks increase

CO_2 emissions. Positive shocks in renewable energy also decrease CO_2 emissions, while negative shocks have no effect. In contrast, positive shocks in fossil fuel energy increase CO_2 emissions, but negative shocks have an even stronger effect, resulting in almost double CO_2 emissions over time.

Another recent study conducted by Nuta et al. (2024) where the relationship among urbanization, financial development, economic growth, renewable energy consumption, industrial structure, and environmental degradation was examined using Feasible Generalized Least Squares (FGLS) and panel-corrected standard errors (PCSEs) models. The results support that, regardless of the region, economic growth and urbanization are found to be a positive and significant driver of CO_2 emissions, whereas CO_2 emissions declines significantly over time with an increase in renewable energy consumption and financial development. Triki et al. (2023) using data from

1980 to 2020, analyzed the impact of renewable energy, green finance, and public health expenditure on environmental quality in the Kingdom of Saudi Arabia (KSA) using both linear and nonlinear autoregressive distribution models to examine the long- and short-term effects. The results from the ARDL model showed that, all variables have a positive impact on the environment's long-term quality. Furthermore, the NARDL model supports the existence of significant positive or negative shocks that support an unbalanced relationship with the movement of variables over the short and long term.

According to Parveen et al. (2023), there is a significant long-run relationship between the industrial output, the financial development, and the carbon emissions after examinig the impact of industrial output and financial development on carbon dioxide emissions for a panel of 10 newly industrialized countries, covering the period 1982 to 2019 by employing Panel Cointegration Test, Fully Modified OLS and Panel Granger Causality Analysis. The carbon emissions are found to be significantly affected by both domestic income and industrial output, while being negatively affected by financial development. Tsimisaraka et al. (2023) examines the short-term and long-term effects of financial inclusion, information and communication technology, renewable energy, globalization, and economic growth on CO_2 emissions in the top 10 emitter countries in the OBOR region from 2004 to 2019 by employing the CS-ARDL technique. Findings demonstrate that, Renewable energy have been found to have a CO_2 emission reduction effect, both in the long and short term. In the long run, there is a negative connection between globalization and CO_2 emissions; while economic growth (EG) has a positive association with CO_2 emission.

Recent studies from multi-country perspectives also emerged. For example Ali et al. (2023) investigated the impact of financial development, green technological innovation, institutional quality, economic growth, energy consumption, and trade on carbon emissions in Organization of Economic Co-operation and Development, for the period 2003–2019, using two-stage sequential techniques of the linear panel data model and Generalised Method of Moments. Their findings revealed that economic policy uncertainty, financial development, economic growth, energy consumption, and trade decrease environmental quality by increasing CO_2 emissions, while green technological innovation and institutional quality increase environmental degradation by reducing CO_2 emissions. Lasisi et al. (2022) examined the contribution of oil utilization, environmental-related technologies-innovations, and

the moderating role of environmental-related technological innovations in energy-economic output nexus over the period 1990–2020 by employing method of moments

quantile regression approach and Granger causality approaches as robustness. The study found that oil utilization and environmental technologies spur economic growth in the countries while environmental innovations hinder output. Huang, (2024) examined the nexus among natural resources, innovation, globalization, and green growth in BRICS countries from 1990 to 2021 by employing dynamic system panel data estimations and robust random effect GLS regression. The result showed that BRICS countries undergo ecofriendly expansion driven by factors like natural resources, globalization, financial advancement, and research and development.

On the group of emerging Market and Developing Economies, Phong and Asumadu, (2020) examined linkage between renewable energy use, nonrenewable energy use, economic growth and environmental quality spanning the period 1990 to 2014. The study employed heterogeneous panel data approach and second generational econometric technique. The findings revealed that variables such government expenditure, capital, and trade openness, non-renewable and renewable energy utilization significantly contributes to the environmental degradation. Mehmood et al.,(2024) applied robust least-squares approach to examine the influence of green industrial transformation in reducing Pakistan's carbon intensity between 1975 and 2020 and the findings support the pollution haven hypothesis in a country. Considering Malaysia, Raihan, (2024)Employed autoregressive distributed lag (ARDL) to examine connection between tourism and carbon emissions as well as environmental sustainability. Using data spanning 1990–2019. The findings demonstrated a negative relationship between renewable energy consumption and carbon emissions. Latif et al., (2023) studied the role of economic growth and renewable energy on environmental quality during the period from 1990 to 2020. The study applied a novel method of moments quantile regression is used. The results demonstrate that financial development and economic growth are positively associated with CO2 emissions, while renewable energy consumption significantly reduce the emissions level and promote a green environment in all quantiles.

Considering high emitters, Yiadom, (2023) Employed various econometric modeling techniques such as dynamic linear regression, dynamic panel threshold regression to investigate the threshold effects of the interplay between finance, development and carbon emissions across 97 countries, including 50 low-income and 47 high-income countries, during the period from 1991 to 2019. The findings showed that low-income countries require a minimum financial development threshold of 0.354 to effectively reduce carbon emissions. Conversely, high-income countries require a higher financial

development threshold of 0.662 to mitigate finance-induced carbon emissions. These findings validate the presence of a finance-led Environmental Kuznet Curve (EKC).

Literature Gap

After carefully assessing the previous studies, this study has concluded that, several studies have taken into account different methodologies to express the relationship among green technological innovation, renewable energy use and environmental quality in terms of the various nations. Previous studies did not take into account the use of the novel dynamic ARDL, which is helpful in sketching out the graphs and area plots which present the positive and negative shocks to the regressors that can impact the explained variable. In addition, the model is highly suitable in case convergence speed is not at par, and that it can be applied irrespective of the order of integration of the variables other than I(2).

In addition, none of the previous studies examined the combined impact of renewable energy consumption, technological innovation, financial development, trade openness and environmental sustainability in Nigeria. According to Inuwa, et al. (2022), incorporating trade openness in environmental studies provides a holistic view of the global environmental consequences of trade policies by enabling the development of policy strategies that can harness the benefits of trade at the same time, minimizing its negative environmental effects, leading to more sustainable economic and environmental outcomes. Similarly, bringing financial development into environmental studies is crucial for understanding the multifaceted nexus between finance and the environment. It plays a significant role in explaining the channel through which financial systems can support sustainable development while protecting the environment. By integrating financial development into environmental research, policymakers and researchers can design more effective strategies to achieve economic growth while preserving environmental quality (Yiadom, 2023).

This study provides a novel contribution to the field of environmental economics by examining the simultaneous impacts of renewable energy consumption, green technology, financial development, and trade on environmental quality in Nigeria by employing additional techniques of Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) models for robustness check, which are known for their unbiased nature, efficient handling of normalization asymptotics, and their effectiveness as optimal estimators in cointegration regressions.

Methodology

Type and sources of Data

This study used annual time series data for the period 1981 to 2022 relating to the renewable energy consumption, technological innovation, financial development, trade openness and environmental sustainability in Nigeria sourced from the World Bank's World Development indicators (WDI).

Table 1. Description of the Variables

Variables	Code	Description	Source
Renewable energy consumption	REC	Renewable energy consumption (% of total final energy consumption) is the share of renewable energy in total final energy consumption.	WDI, WB
Green Technological Innovation	GTI	GI is expressed as a percentage of all technologies, including those that are relevantto the environment.	OECD
Financial Development	FD	Domestic credit to private sector (% of GDP) refers to financial resources provided to the private sector by financial corporations, proxied for financial development.	WDI, WB
Trade Openness	TOP	Trade Openness is the sum of exports and imports of goods and services measured as a share of gross domestic product	WDI, WB
CO_2 emissions	CO_2	CO2 emissions (kt) are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	WDI, WB

Source: The author's elaborations.

Model Specification

In line with the reviewed literature, Ali et al, (2023) model was adapted with slight modifications. Therefore, adapting this pattern, the functional model is specified as follows:

$$CO2 = f(REC, GTI, FD, TOP) \quad (1)$$

$$CO2_t = \beta_0 + \beta_1 REC_t + \beta_2 GTI_t + \beta_3 FD_t + \beta_4 TOP_t + \varepsilon_t \quad (2)$$

Where β_1- β_4 are the parameter coefficients of the explanatory variables. CO2 is the carbon dioxide emissions proxied for environmental quality, REC is the renewable energy consumption, GTI is the Green technological innovation, FD is the financial development, TOP is the trade openness, and ε is the error term which is assumed to be normally distributed.

For the purpose of estimation, there is need to log-linearize the model in equation (2). The log– linear econometrics model has certain advantages of producing both efficient and consistent estimates and also helps in resolving the econometrics issues of heteroscedasticity and multicollinearity (Orzturk et al. 2023).

$$CO2 = \beta_0 + \beta_1 REC_t + \beta_2 LGTI_t + \beta_3 LFD_t + \beta_4 TOP_t + \varepsilon_t \quad (3).$$

Estimation procedure

This research work involves quantitative analysis of the impact of renewable energy consumption, green technological innovation and financial development on environmental sustainability in Nigeria, which employed the novel dynamic Autoregressive Distribution Lag (DYARDL) Model developed by Jordan and Phillips, (2018). The innovative dynamic ARDL simulations method allows for real-time visualization and plotting of graphs to predict variations (both negative and positive) in various factors, investigate the complex interconnections (in both the short term and long term) among the variables under examination, enhance accuracy effectively, and offer potential solutions beyond the complexities encountered with the traditional ARDL approach. Another key benefit of the dynardl framework is its capability to forecast, simulate, and promptly illustrate probabilistic adjustments in forecasts related to the dependent variable based on one explanatory factor, while keeping other variables constant (Udeagha & Ngepah, 2022).

Unit root test

Aside from using the typical unit root tests like augmented Dickey-Fuller (ADF) and PhillipsPerron tests to examine the stationarity of variables, the research also employed the Lee and Strazicich test for detecting structural breaks, which can account for two break points within the series.

Autoregressive Distributed Lag (ARDL) Model

The conventional Autoregressive Distributed Lag (ARDL) Model can be specified as follows:

$$\Delta LCO2_t = \alpha_0 + \alpha_1 LCO2_{t-1} + \alpha_2 REC_{t-1} + \alpha_3 GTI_{t-1} + \alpha_4 FD_{t-1} + \alpha_5 TOP_{t-1} + \alpha_4 + \sum_{I=1}^{q} \beta_1 \Delta LCO2_{t-1} + \sum_{I=0}^{K_2} \beta_2 \Delta REC_{t-1} + \sum_{I=0}^{K_3} \beta_3 \Delta GTI_{t-1} + \sum_{I=0}^{K_4} \beta_4 \Delta FD_{t-1} + \sum_{I=0}^{K_4} \beta_4 \Delta TOP_{t-1} + \mu_t \ldots\ldots\ldots (4)$$

In the above equation, β_i indicates short-term coefficients, while long-term coefficients are denoted by αi with $I = 1 \ldots n$. The immediate effect of independent variables on dependent variables is determined by short-run analysis, while the long-run report notes the speed of adjustment toward equilibrium level.

The ARDL short-run equation estimates the error correction term (ECT), with the speed of adjustment of the model to long-run equilibrium convergence. Equation (4) combines the short and long-run equations. The long- run component is expressed as:

$$\Delta LCO2_t = \alpha_0 + \alpha_1 LCO2_{t-1} + \alpha_2 REC_{t-1} + \alpha_3 GTI_{t-1} + \alpha_4 FD_{t-1} + \alpha_5 TOP_{t-1} + \mu_t \ldots\ldots\ldots\ldots (5)$$

The short-run component of Equation (4) is expressed as:

$$\Delta LCO2_t = \alpha_0 + \sum_{I=1}^{q} \beta_1 \Delta LCO2_{t-1} + \sum_{I=0}^{K_2} \beta_2 \Delta REC_{t-1} + \sum_{I=0}^{K_3} \beta_3 \Delta GTI_{t-1} + \sum_{I=0}^{K_4} \beta_4 \Delta FD_{t-1} + \sum_{I=0}^{K_4} \beta_4 \Delta TOP_{t-1} + \lambda ECT + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Dynamic autoregressive distributed lag (dynamic ARDL) simulations model

Using equation (3) as the baseline model for this study, and following the work of Jordan and Philips (2018), the novel dynamic ARDL simulations framework is expressed as follows:

$$\Delta LCO2_t = \alpha_0 + \alpha_0 LCO2_{t-1} + \rho_1 \Delta REC_t + \varphi_1 REC_{t-1} + \rho_2 \Delta GTI_t + \varphi_2 GTI_{t-1} + \rho_3 \Delta FD_t + \varphi_3 FD_{t-1} + \rho_4 \Delta TOP_t + \varphi_4 TOP_{t-1} + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

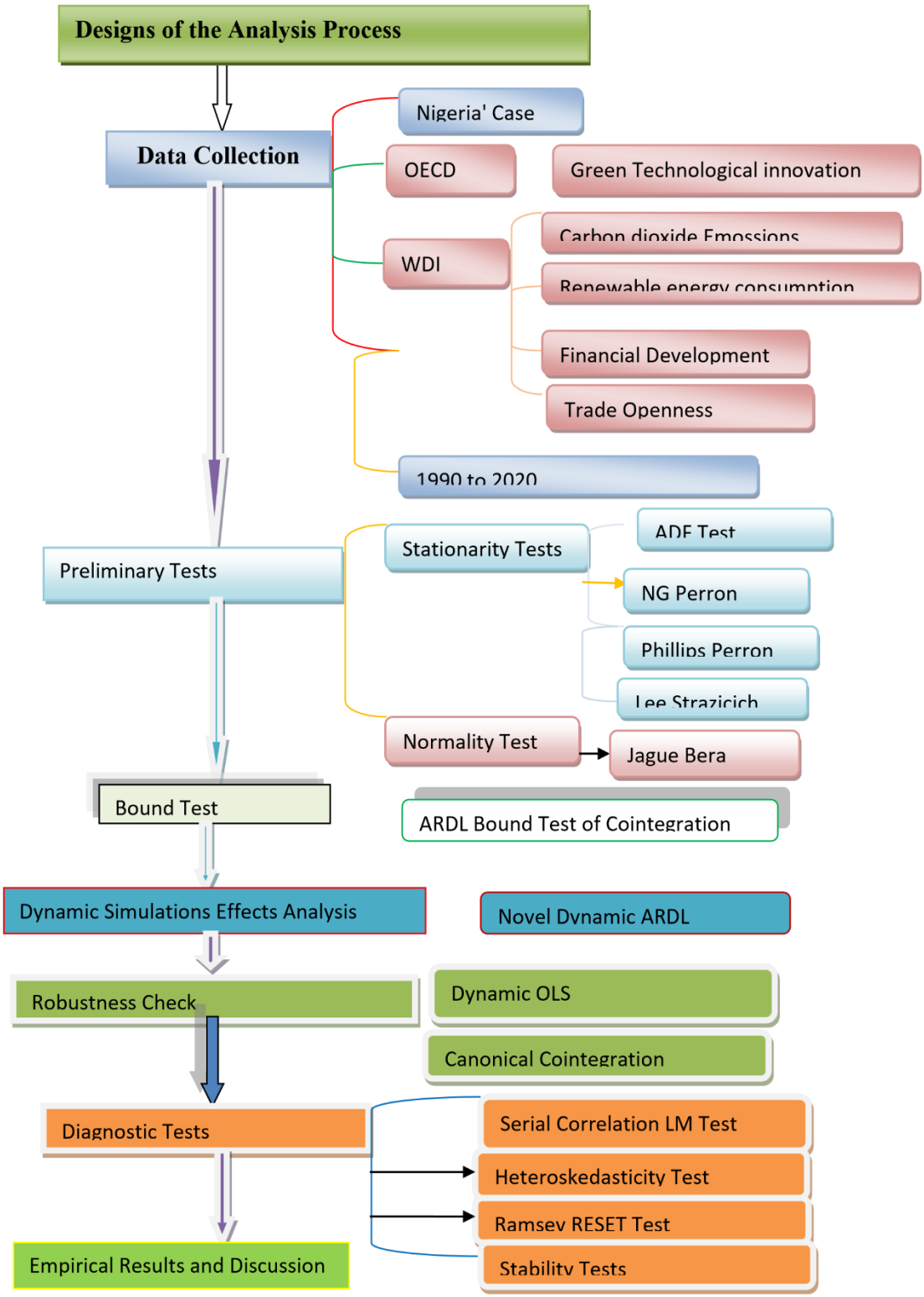


Figure 1: Analysis Flow Chart

Robust Analysis

To ensure robustness, this study utilized both Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) models to investigate the association between the dependent and independent variables. Both FMOLS and DOLS estimators are known for their unbiased nature, efficient handling of normalization asymptotics, and their effectiveness as optimal estimators in cointegration regressions. These models adjust ordinary least squares (OLS) to correct for issues like serial correlation and endogeneity in regressors that arise due to the presence of long-run relationships (Inuwa et al., 2022).

Results and Discussion of Findings

Summary Statistics

The results of descriptive statistics indicated that, the standard deviations analysis revealed higher volatility in GTI, followed by FD, while LREC, LCO2 and TOP recorded lower volatility. To measure the presence or otherwise of multicollinearity in the model, the pair-wise correlation matrix is used, and the results reveals the strength of correlation between a pair of variables. The higher coefficient of correlation ($r \geq 0.8$) shows severe multicollinearity among the variables. The results of the pair-wise correlation matrix statistics in Table 2 indicates that explanatory variables are weakly correlated.

Table 2. **Summary Statistics and Correlation Matrix**

Variables	LCO2	GTI	FD	LREC	TOP
Median	11.46516	8.474576	8.909485	4.438761	0.072185
Maximum	11.69144	40.54054	19.62560	4.485034	1.625906
Minimum	11.25088	0.000000	5.241096	4.389995	-2.168542
Std. Dev.	0.117686	11.89972	3.515000	0.027501	0.794053
Skewness	0.058621	0.878670	1.015760	-0.285314	-0.412635
Kurtosis	2.175813	2.687859	3.599426	2.022691	3.936770
LCO2	1.000000				
GTI	-0.166735	1.000000			
FD	0.062471	0.212305	1.000000		
LREC	-0.715613	0.240952	-0.175034	1.000000	
TOP	0.150375	-0.257584	0.018147	-0.048620	1.000000

Source: Author's computation

Unit Root Tests

To assess the stationarity properties of the data, a number of univariate unit root tests were employed, including the Augmented Dickey and Fuller (ADF) test, Dickey Fuller GLS test, the Phillips and Perron (PP) test, and NG Perron test.

Table 3. Unit Root Tests Results

Variables Level	Dickey Fuller GLS T-statistics	Phillips–Perron T-statistics	Augmented Dickey–Fuller T-statistics	Ng & Perron MZa	MZt	MSB	MPT
LCO2	-2.837951	-2.942633	-2.942633	-9.49976	-2.1794	0.22942	9.59237
GTI	-2.858980	-2.653068	-2.787227	-13.8626	-2.63274	0.18992	6.57344
FD	-3.864131**	-2.110950	-3.759930**	-28.1495	-3.74710	0.13311	3.26331
LREC	-2.621432	-2.527663	-2.527663	-9.30345	-2.15462	0.23159	9.80328
TOP	-1.643748	-1.930248	-3.074423	-4.74294	-1.4935	0.31488	18.9037
Difference							
LCO2	-5.416185***	-6.48496***	-5.549099***	-14.2048***	-2.6499	0.18655	6.50091
GTI	-5.716410***	-5.81901***	-5.509585***	-13.8626***	-2.6327	0.18992	6.57344
FD	-5.160031***	-6.07113***	-5.024767***	-15109.3***	-86.917	0.00575	0.00614
LREC	-5.197526***	-5.19021***	-5.199693***	-14.3986***	-2.63270	0.18284	6.61516
TOP	**-4.674051***	**-4.60105***	**-4.498853***	**-13.8788***	-2.5972	0.18713	6.77350

*****, ** and * show significan ce at 1, 5 and 10% levels respect ively**

Table 4 Unit root t est with structural breaks

Variables	Lee Strazicich LM at Level			Lee Strazicich LM at first difference		
	T-statistics	Break points		*T*-statistics	Break points	
LCO2	-6.198956*	2006	2012	-8.038877***	2002	2007
GTI	-6.420553**	2000	2012	-8.523438***	2006	2014
FD	-6.902381**	2005	2015	-9.571048***	2004	2007
LREC	-8.364109***	2004	2017	-6.464374**	2001	2007
TOP	-6.700921*	2002	2009`	-11.17959***	2006	2012

***, ** and * show significance at 1%, 5% and 10% levels respectively

Source: Authors' computations

All the variables that are not stationary at level become stationary after first differencing, based on the results in table 3 and 4. This suggests that none of the series under consideration are I (2) and that all are either I (1) or I (0). However, the conventional unit root tests described in table 3 do not take structural breaks into consideration. As a result, this study used Lee and Strazicich testing technique that takes into account, two structural breaks in the variables, and the results are presented in Table 4. The empirical findings indicate that, in the presence of two structural

breaks, the variables are integrated. Thus, the variables are qualified to run for dynamic ARDL approach.

Lag Length for F- Bound Cointegration Test

The result of the optimal lag length is presented in the table below:

Table 5. Lag Length for F- Bound Cointegration Test Lag

Lag	LogL	LR	EPE	AIC	SC	HQ
0	-78.33352	NA	7.141839	4.796307	5.148200	4.919127
1	-71.60689	10.08995	5.212758*	4.478160*	4.874040*	4.616333*
2	-65.88626	8.263129*	4.026975	4.215903	4.655770	4.369428
3	-63.65386	3.100553	3.779986	4.147437	4.631290	4.316314
4	-63.52088	0.177310	3.991663	4.195604	4.723444	4.379835

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

Table 5 presents the lag order selection by five different criteria. All the lag selection criteria, except LR, suggested that, a lag length of one (1) is optimal for the F-bound cointegration test. Therefore, this study used a lag length of one for the cointegration test.

Bound Test for Cointegration

The results of the cointegration test using the ARDL bound Testing approach are shown in Table 6.

Table 6. **Bound Test for Cointegration**

H_0: *No cointegration*

F-Statistic	Significance Level	Bound Critical Valu	es	K
		I(0) Bound	I(1) Bound	
15.84917	1% 2.5%	3.74	5.06	4
		3.25	4.49	
	5%	2.86	4.01	
	10%	2.45	3.52	

Source: Author's Compilation using Eviews

From the result in table 6, the null hypothesis of no cointegration is rejected because the F- statistics is higher than the upper-bound critical values at all the levels of significance. Therefore, cointegration between the variables under discussion is supported by our empirical results.

Dynamic ARDL Simulations Model Results

Results from the dynamic ARDL simulation model are shown in Table 7.

Table 7 Dynamic ARDL simulations analysis

Variables	Coefficient	Std. error	t-value	P>t	[95%	conf. interval]
cons	17.93958	4.653009	3.86	0.001	8.20072	27.67844
Δ_GTI	.0002424	.0008521	0.28	0.779	-.0015409	.0020258
L1_GTI	-.0022007	.0008794	2.50	0.022	.0003602	.0040413
Δ _FD	-.0049582	.0032398	-1.53	0.142	-.0117392	.0018229
L1_FD	-.003501	.0021576	-1.62	0.121	-.0080169	.0010148
Δ _LREC	-4.064977	.4774135	-8.51	0.000	-5.064215	-3.065739
L1_LREC	-2.397408	.680372	-3.52	0.002	-3.821443	-.9733734
Δ_TOP	.0055027	.0110702	0.50	0.625	-.0176676	.028673
L1_TOP	.0076532	.0076314	1.00	0.329	-.0083195	.0236258
R-squared =	0.8895					
Adj R-squared =	0.8372					
N =	29					
Prob > F =	0.0000***					
Simulations =	*5000*					
Root MSE =	.03453					

Source: Authors' Computation.

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1%levels, respectively.

The results from the dynamic ARDL simulation model are shown in Table 7. The results reveal an inverse relationship between Green Technological Innovation (GTI) and environmental degradation (CO2) in the longrun, whereas, in the shortrun, GTI is positively related to environmental degradation. 1% increase in GTI promote environmental quality by 0.0022% in the longrun, while in the shortrun, 1% decrease in GTI degrades the environment by 0.00024%, confirming the results of Ali et al. (2023), Parveen et al. 2023) and Erdogan et al. (2023). As a result, empirical data reveal that Environmental quality in Nigeria declines throughout the early stages of Green technological innovation, but begins to rise once the country reaches its optimal level in the technological advancement (Udeagha, & Ngepah, 2022). Financial development (FD) is negative but statistically insignificant both in the long run and the shortrun, implying an inverse relationship with CO2. 1% increase in FD reduces environmental degradation by 0.0035% in the longrun, while in the shortrun, 1% increase in FD reduces environmental degradation by 0.0049%, which is in line with the findings of Parveen et al. (2023). Furthermore, renewable energy consumption (REC) is negative and statistically significant both in the shortrun and longrun. 1%

increase in REC promotes environmental sustainability by 4.06% and 2.40% respectively, both in the shortrun and longrun. These findings are consistent with the results from the work of Monirul-Islam et al. (2022) and Bergougui (2024). Finally, Trade Openness is (TOP) is positive but statistically insignificant both in the shortrun and longrun. 1% increase in TOP degrade environmental quality by 0.0076% and 0.0055% respectively, both in the shortrun and longrun. These findings are consistent with the results from the work of Udeagha, & Ngepah, (2022).

The impulse response plot of GTI and CO2 is shown in Figure 2. The graph shows that a 10% increase in GTI demonstrates a positive correlation both in the shortrun, in the long-term with CO2, whereas, a 10% reduction has both a long-term and short-term negative impact on CO2. According to this, increase in GTI increases CO2, while its decrease reduces the CO2 in Nigeria over the long and short terms.

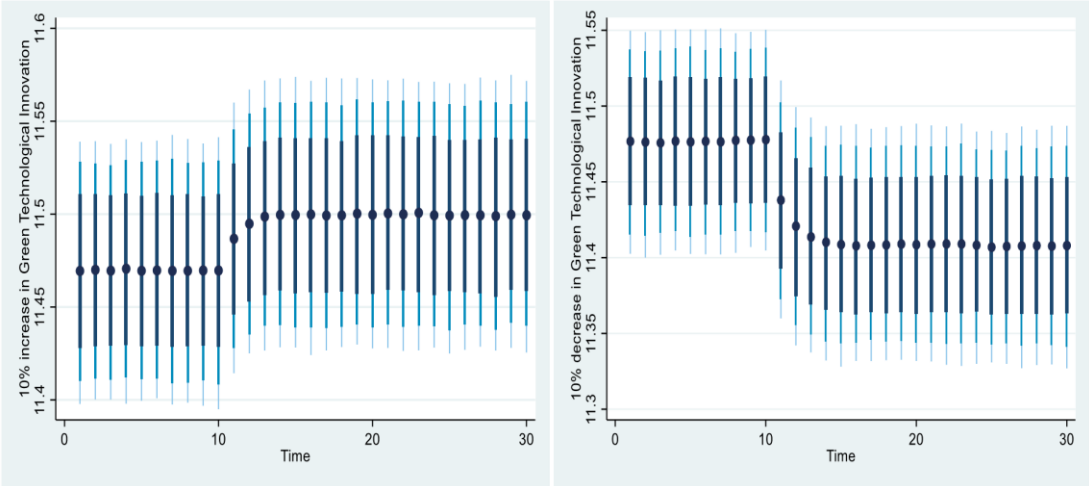


Figure 2. *A 10% increase and a decrease in Green Technological innovation and its influence on environmental quality, where dots specify average prediction value. The dark blue to light blue line denotes 75%, 90%, and 95% confidence intervals, respectively*.

The impulse-response plot of Financial Development and environmental quality is shown in Figure 3. The graph shows that a 10% rise is strongly correlated with a short- and long-term negative impact of financial development on environmental quality, However, a 10% reduction in financial development has short-term and long-term positive impact on environmental sustainability in Nigeria. This indicates that in Nigeria, a rise in financial development enhances environmental sustainability, but a fall reduces environmental sustainability.

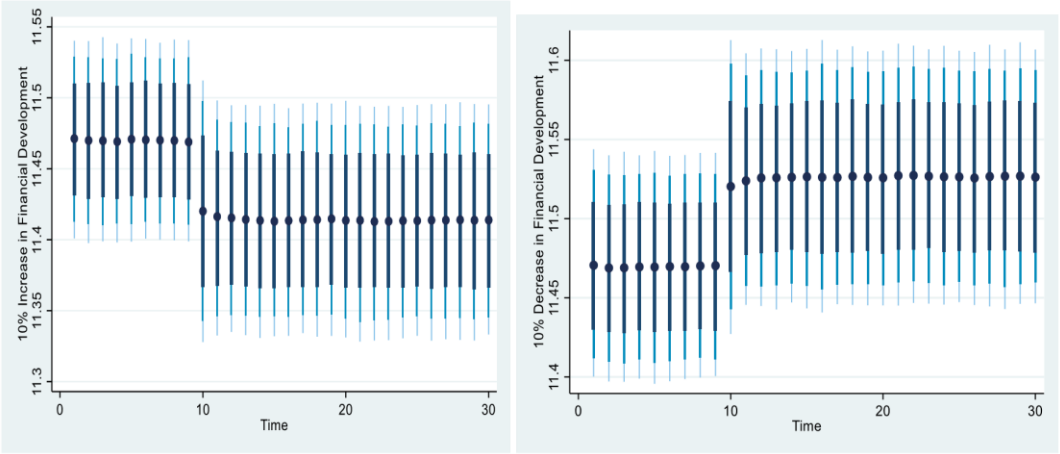


Figure 3. *A 10% increase and a decrease in Financial Development and its influence on environmental sustainability, where dots specify average prediction value. The dark blue to light blue line denotes 75%, 90%, and 95% confidence intervals, respectively.*

Figure 4 depicts the nexus between Renewable energy consumption (REC) and environmental quality using an impulse-response plot. The plot depicts the change in Renewable energy consumption and how it impact environmental quality in Nigeria. A 10% increase in REC indicates a weak long-term and strong short-term positive impact on CO2, while a 10% decrease in REC indicates its negative impact on CO2 in the shortrun, and longrun.

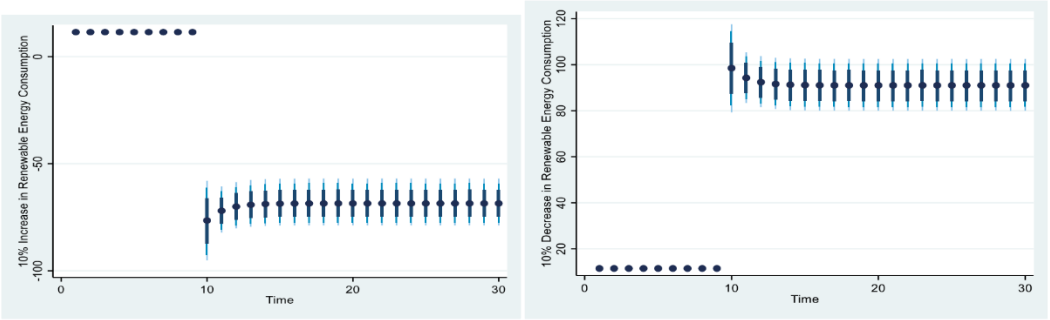


Figure 4. A *10% increase and a decrease in Renewable energy consumption and its influence on environmental quality, where dots specify average prediction value. The dark blue to light blue line denotes 75%, 90%, and 95% confidence intervals, respectively*.

The impulse-response plot relating electricity production from hydroelectric sources and economic growth is shown in Figure 5. The graph demonstrates how a 10% increase in Trade Openness (TOP) has a long-term positive impact on environmental quality but a short-term negative impact. In contrast, a 10% reduction in TOP has a

short-term favorable impact on environmental quality but a long-term negative impact. This shows that, while a rise in TOP temporarily increases environmental degradation in Nigeria, it really makes things better over

time.

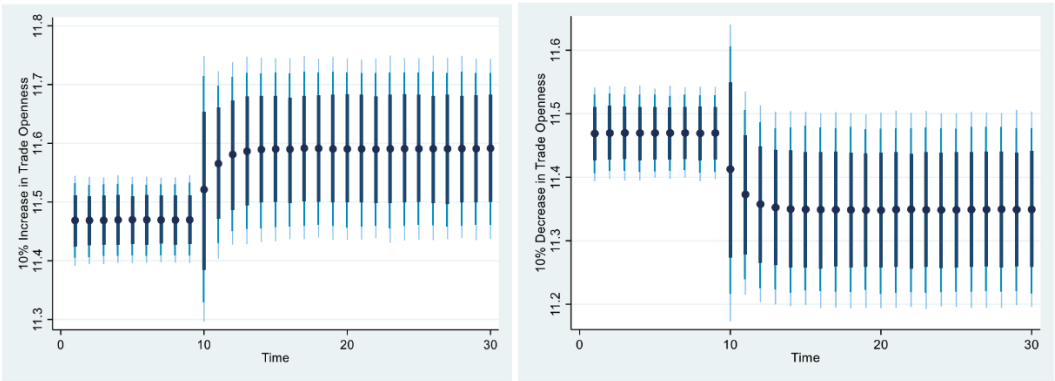


Figure 5. *A 10% increase and a decrease in Trade Openness and its influence on environmental quality, where dots specify average prediction value. The dark blue to light blue line denotes 75%, 90%, and 95% confidence intervals, respectively*.

4.7. Diagnostic Statistics Tests

The study employed many diagnostic statistical tests, and their empirical results are shown in table 8, in order to confirm the consistency and reliability of the model employed in the study.

Table 8. Diagnostic statistics tests.

Diagnostic Statistics Tests	X^2 (p Values)	Results
Breusch–Godfrey LM test	0.1331	No problem of serial correlations
Breusch–Pagan–Godfrey test	0.2668	No problem of heteroscedasticity
Ramsey RESET test	0.2803	Model is specified correctly
Jarque–Bera Test	0.6750	Estimated residuals are normal

Source: Authors' Computations.

Given that the model in use passed all diagnostic tests, the empirical findings imply that it is well-fitted. The Breusch–Godfrey LM test demonstrates that the model is not affected by serial correlation or autocorrelation problems. The result from the Ramsey RESET test shows that the model is well specified. The Breusch–Pagan–Godfrey test results demonstrates the absence of heteroscedasticity in the model. Finally, the results

of the Jarque–Bera test demonstrates that the model's residuals are normally distributed.

Robustness Check

Fully Modified Ordinary Least Square (FMOLS) and Canonical Cointegrating Regression (CCR) models were employed to check for the robustness, consistency and reliability of the estimated results. The results of Modified Ordinary Least Square are presented in Table 9.

Table 9. Fully Modified Least Squares (FMOLS) Result

Variables	Coefficient	Std. Error	t-Statistic	Prob.
GTI1	-0.001372	0.000558	2.460515	0.0218
FD	-0.005617	0.001799	-3.121402	0.0048
LREC	-4.027055	0.228589	-17.61701	0.0000
DTOP	0.024042	0.007674	3.132801	0.0047
C	29.39375	1.016789	28.90842	0.0000

Source: Author's Computations.

The results of FMOLS shows that increase in GTI reduces environmental degradation in Nigeria, where 1% increase in GTI results in a 0.0014% reduction CO2 emissions, confirming the findings of Ali et al. (2023), Parveen et al. 2023) and Erdogan et al. (2023). The coefficient of the financial development (FD) is negative and significant. 1% change in FD increases economic environmental quality by 0.0056% (fall in CO2 emissions), confirming the findings of Parveen et al. 2023). The coefficient of renewable energy consumption is negative and significant, implying that, 1% change in the renewable energy consumption improves the environment in Nigeria by reducing CO2 emissions by 4.03%. This also support the results of Bergougui (2024). The results of Trade openness shows that a 1% increase in electricity Trade openness increases Co2 emissions by economic growth by 0.024%.

Table 8. Canonical Cointegrating Regression Model Result

Variables	Coefficient	Std. Error	t-Statistic	Prob.
GTI1	-0.001451	0.000574	2.526261	0.0189
FD	-0.005724	0.001753	-3.264334	0.0034
LREC	-4.041336	0.242528	-16.66340	0.0000
TOP	0.026161	0.010145	2.578615	0.0168
C	29.45688	1.079108	27.29743	0.0000

Source: Author's Computations.

The result of the CCR model in this study are consistent with the previous findings from both the Dynamic ARDL and FMOLS, only the coefficient values vary slightly. The results indicated that, 1% change in GTI promotes environmental quality by 0.0015%. The coefficient of the FD is negatively significant, where 1% increase in FD increases environmental quality by 0.0057%. REC is also negatively significant, where, 1% change in REC, reduces CO2 emissions by 4.04%. The coefficient of TOP is positive and statistically significant, where 1% change in TOP, leads to 29.5% fall in environmental quality in Nigeria.

Conclusions and Policy Recommendations

Conclusions

This study employed the newly developed novel dynamic ARDL simulations model, proposed by Jordan & Philips (2018), to examine the impact of green technological innovation, renewable energy consumption and financial development on environmental sustainability in Nigeria over the period of 1990 to 2020. This method allows for the prediction, simulation, and immediately plot the probabilistic forecasts on the environmental sustainability in one of the explanatory variables, holding other regressors constant. The findings of the study revealed that, green technological innovation, renewable energy consumption and financial development respectively, promote environmental sustainability in the longrun, whereas, in the shortrun, green technological innovation is negatively related to the environmental quality in Nigeria. However, trade openness contributes towards environmental degradation both in the shortrun and the long run. The result of the Dynamic ARDL in this study is in conformity with the findings from both the FMOLS and CCR models.

Policy Implications

Based on the empirical results of this study, the authorities in Nigeria should adopt a number of policies to promote green technological innovation, renewable energy, private and public investment, and environmental protection. These policies should include:

First, based on the Nigeria Renewable Energy Master Plan (REMP), Nigeria has set a target to generate 36% of its electricity from renewable energy sources by 2030, with a primary focus on hydro, Biomass-based, wind and solar energy sources. To achieve this, this study recommends that, the government should provide fiscal incentives to private investors in form of tax holidays, capital incentives, moratorium on import duties and loan opportunities for renewable energy projects in the country.

Secondly, the findings of this study revealed that, green technology is a crucial component of achieving the Sustainable environment in Nigeria. Thus, policymakers should strengthen policies that encourage green technological investments, in order to promote economic growth while also further reducing environmental emissions. Also, carbon sequestration technology in power plants can be beneficial to use while applying green technological innovation in promoting green investments in Nigeria, as it become necessary to concentrate on environmentally friendly technologies for transferring the drivers of economic development from fossil fuel energy sources to renewable energy through eco-friendly technologies.

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