



Powering Nigeria's future: balancing renewable and non-renewable energy for environmental sustainability

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Abstract

This study examines the role of non-renewable and renewable energy sources in promoting environmental sustainability in Nigeria. It also considers the influence of foreign direct investment (FDI), trade openness, and economic growth on environmental degradation. The analysis covers the period from 1990 to 2021, and the Autoregressive Distributed Lag (ARDL) bound test approach is adopted to establish the long-run relationships among the variables. The empirical results reveal that renewable energy contributes negatively but insignificantly to environmental degradation, implying that an increase in renewable energy consumption does not significantly worsen environmental conditions. On the other hand, non-renewable energy consumption has a positive and significant impact on environmental degradation, indicating that reliance on non-renewable energy sources exacerbates environmental problems. Based on these findings, policy recommendations are put forward to enhance environmental sustainability in Nigeria. These include promoting the adoption and investment in renewable energy technologies, increasing the share of renewable energy in the energy mix, and implementing measures to reduce dependence on non-renewable energy sources. Additionally, efforts should be made to attract sustainable foreign direct investment, foster trade practices that prioritize environmental considerations, and pursue sustainable economic growth strategies that decouple economic development from environmental degradation. By implementing these policy suggestions, Nigeria can move towards a more sustainable and environmentally friendly energy system while maintaining economic growth and attracting foreign investments.

Keywords Non-renewable energy · Renewable energy · Economic growth · Environmental sustainability: time series · Nigeria

Extended author information available on the last page of the article

1 Introduction

The energy transition is the process of downshifting fossil fuels and re-developing whole systems to operate on low carbon energy sources. More generally, an energy transition is a significant structural change in an energy system regarding supply and consumption [1]. Energy consumption not only delivered sustainable development but also establishing environmental relief globally and regionally through its role in economic growth during the previous two decades.

Both renewable and non-renewable energy resources are abundant in Nigeria. Nonetheless, firewood and fossil fuels are essential to the nation's energy source. In 2006, 94% of Nigeria's exports were made up of fossil fuels, and only a small portion of this was used domestically. In Nigeria, only approximately 40% of homes are wired into the main energy system. For the privileged income classes, the supply of energy is generally augmented by private producers, or the usage of individual electrical generators fuelled by fossil fuel. Private generators are used by more than 90% of firms, which increases production costs [2].

The country's current reliance on fossil fuels (petroleum) is insufficient to supply all its energy requirements. The recent increase in oil prices, the lack of power for the bulk of the population, as well as the high cost and energy losses associated with grid expansion, are some of the factors driving interest in the development and distribution of renewable energy in Nigeria. By its numerous power reform initiatives and laws, the government had tried to stimulate private investment and, as a result, the growth of renewable energy sources. Yet, there are obstacles that must be removed for this to become a reality, mostly because of the financial and technological constraints [3].

Renewable energy is energy produced using renewable natural resources like sunshine, wind, rain, tides, and geothermal heat. There have been significant attempts made to address the issues associated with the rising global energy demand, however depending solely on conventional fossil fuels entails a significant danger of contemporary development plans moving backward. This claim is primarily supported by the fact that fossil fuels and other conventional energy sources are not only finite but also losing more and more of their global supplies every day. Overuse of fossil fuels for energy production might contribute to harmful environmental effects like global warming.

Being the sole practical alternative open to man for supplying a solution to energy, renewable energy has gained a very genuine worldwide interest. Widespread popular support for renewable energy sources is the result of environmental concerns over the generation of electric power from traditional sources. Governments all around the globe have responded by offering a variety of financial incentives to encourage the use of renewable energy sources in the production of electricity. Because biomass is found practically everywhere in the globe, developing renewable energy from it is one of the most potential alternative energy resources. Nigeria's access to solar, biomass, and wind energy makes it the most practical solution to the nation's epileptic power supply mess. In line with this, this study examines renewable and non-renewable energy sources and environmental conservation in Nigeria.

Nigeria has signed several agreements on climate change such as the COP27 agreement where the Climate Action agenda discussed during COP27 focused on bringing the world together for implementation to ensure a just and sustainable future for all. In addition, Nigeria agreed on the Kyoto Protocol with the objective to reduce the onset of global warming by reducing greenhouse gas concentrations in the atmosphere. Understanding the impact of both renewable and non-renewable energy sources on environmental sustainability in Nigeria is of paramount importance for several compelling reasons, particularly in the context of climate change and national development. Nigeria, like many other nations, faces the pressing challenge of mitigating climate change. Transitioning to renewable energy sources, which have significantly lower carbon emissions compared to non-renewable sources, is crucial for reducing the country's carbon footprint. Recognizing the impact of both types of energy on climate change is essential for setting realistic and effective emissions reduction targets. Nigeria's heavy reliance on non-renewable energy sources, such as fossil fuels, makes the country vulnerable to energy security risks. Understanding the environmental impact of both renewable and non-renewable energy can inform strategies to diversify the energy mix, reducing dependence on finite and environmentally damaging resources. Sustainable development is inextricably linked to environmental sustainability. By embracing renewable energy solutions, Nigeria can foster technological innovation, create jobs, and improve energy access, ultimately enhancing the quality of life for its citizens. Understanding the environmental implications of energy choices is a prerequisite for making informed decisions in the pursuit of national development goals.

The concentration of GHGs in the earth's atmosphere has been rising steadily since the period of the Industrial Revolution and is directly linked with the rise in the mean global temperature on earth. However, in addition to the direct environmental impact of climate change, it poses serious threats to sustainable national development as a result of the multiplier effects of extreme climate events manifesting in interchanges of droughts and floods and their predilection to increase the likelihood of food insecurity and incidences of communicable and non-communicable diseases.

Energy is an essential ingredient or tool for socioeconomic development and an index of prosperity in any nation. It is one of the basic requirements of human society and vital for human life and for technological advancement. In general, energy can contribute to widening opportunities and empower people to exercise choices. The place of energy and power in the sustenance of economic activities, and their contribution to the standard of living cannot be overemphasized for any nation. As a result, the demand for energy today is far greater than ever in our highly technological world. In Nigeria, energy is the mainstay of growth and development because it serves as a tradable commodity for earning the national income, which is used to support government development programs [4]. Due to population growth, inevitable industrialization, more agricultural production and improving living standards, Nigeria needs more energy to meet the rising demand. It also serves as an input into the production of goods and services in the nation's industry, transport, agriculture, health, and education sectors, as well as an instrument for politics, security and diplomacy. The energy chain

to deliver these cited services begins with the collection or extraction of primary energy, which is then converted into energy carriers suitable for various end-uses.

According to Adedoyin et al. [5], Nigeria intends to achieve net-zero emissions through its Energy Transition Plan by the year 2060. According to the most recent estimates of Nigeria's GHG emissions, the country emits about 2 tonnes of CO₂ equivalent (tCO₂e) per person each year. According to the Intended Nationally Determined Contributions (INDC), overall emissions will increase by 114% to 900 million tCO₂e by 2030 under a "business as usual" (BAU) scenario (approximately 3.4 tCO₂e per capita). According to the high-growth scenario, annual emissions in 2030 will exceed 1 billion tCO₂e. As of 2030, the conditional INDC objective is to stabilize emissions at about 2 tCO₂e per person.

The INDC outlines a number of mitigation objectives to be met by 2030, including the cessation of gas flaring, the deployment of 13 GW of off-grid solar PV generation capacity, the installation of efficient gas generators, the improvement of energy efficiency by 2% annually (30% by 2030), the achievement of a shift from private cars to buses, the improvement of the electricity grid, and the promotion of climate-smart agriculture and reforestation. It is against this backdrop this study seeks to analyse the impact of renewable and non-renewable energy on environmental sustainability targets in Nigeria. Particularly, the study examines the role of renewable and non-renewable energy on environmental sustainability in Nigeria over the period 1990 to 2021. The ARDL bound test approach is adopted to establish the long-run relationships among the variables.

The study empirically contributes to existing literature. The empirical result shows a negative but insignificant impact of renewable energy on environmental degradation suggesting that the use of renewable energy does not have a statistically significant effect on reducing environmental degradation in Nigeria. This finding may seem counterintuitive since renewable energy sources are generally considered more environmentally friendly compared to non-renewable sources like fossil fuels. However, there could be several reasons for this result. Overall, this study highlights the complex relationship between energy sources, foreign direct investment, trade openness, economic growth, and environmental degradation in Nigeria. It underscores the need for comprehensive policies and strategies that promote the use of renewable energy, regulate non-renewable energy sources, encourage sustainable FDI practices, and integrate environmental considerations into trade activities. By addressing these issues, Nigeria can work towards a more sustainable and environmentally responsible development path.

In summary, this study enriches the literature by providing a focused and context-specific analysis of the environmental impact of renewable and non-renewable energy sources in Nigeria. The paper is divided into five sections, section one is the introduction, section two contains literature review and theoretical framework, section three is the methodology, section four is data analysis and interpretation while section five is the conclusion and recommendations.

2 Literature review

On the impact of renewable energy on the environment authors such as Zafar et al. [6], Destek and Sarkodie [7] and Oke et al. [8] found that the stock of carbon emissions is increased by tourism, real GDP per capita, and energy use. The study also supports the decreasing effects of renewable energy on carbon emissions. The studies also discovered that the use of renewable energy is a key predictor of environmental quality. To achieve environmental sustainability, the report recommends raising the threshold for investments in renewable energy and education on the one hand, and planning for renewable energy research and development on the other. Moreover, Su et al. [9] stresses the growing political and market pressures on energy usage in the environmental literature in the context of US oil production. Su et al. [10] expands this claim by establishing further basic connections between geopolitical risk (GPR), oil prices (OPs), and financial liquidity in the context of Saudi Arabia. Egbetokun et al. [11] examines the extent to which the nexuses between disaggregated renewable energy (hydroelectricity, wind, solar, and biomass) consumption and economic growth impact environmental pollution. The main conclusions of the study show that using biomass energy considerably lowers carbon emissions in four nations (France, Germany, Japan, and the USA). Likewise, Destek and Sarkodie [7] analysed the relationship between carbon dioxide emissions, economic development, and the depletion of natural resources in G-20 economies from 1992 to 2013. The study supports the outcomes that are listed below. First, it is stated that cointegration exists for economic development, CO₂ emissions, natural resource depletion, and biomass energy use. Second, the use of biomass energy has contrasting effects on carbon emissions and economic growth.

Focusing on the impact of non-renewable energy on the environment Mahalik et al. [12], Adedoyin et al. [5] clearly make a significant contribution to the energy-environment nexus. They found that the production of non-renewable energy, real GDP, and economic policy uncertainty all increase CO₂ emissions. Yet, the level of carbon emissions is decreased when the generation of renewable and non-renewable energy is combined with uncertain economic policies. They further reveal that non-renewable energy consumption, primary education, total energy consumption, economic globalization, and economic growth increase the volume of carbon emissions. In the same vein, Inglesi-Lotz and Dogan's [13] assessed the effects renewable (RE) and non-renewable energy (NRE) use on carbon emissions. The study showed that RE decreases CO₂ while NRE increases it. This further strengthens the argument that non-renewable energy use has serious environmental consequences.

To et al. [14] analysed the impact of international trade and FDI on environmental pollution and found that both factors were positively associated with carbon dioxide emissions in China. In addition, with time series data for the period of 1980 to 2010 for 14 Latin American countries and panel fixed and random effects models, Sapkota and Bastola [15] found that FDI inflow led to environmental degradation in these countries, even when the effects of physical capital,

energy, human capital, population density, and unemployment rate were controlled. Solarin and Al-Mulali [16] analysed the effect of FDI on carbon dioxide emissions, carbon footprint, and ecological footprint for 20 countries and found that FDI increased pollution in the developing countries. With panel data of 25 emerging markets in the Asian region from 1980 to 2016 and panel cointegration fully modified ordinary least squares (FMOLS), To et al. found that the FDI inflows significantly worsened the environmental quality of these countries.

On the impact of economic growth on the environment, Jalil and Mahmud [17] using the autoregressive distributed lag method in their study found that the relationship between carbon dioxide emissions and income per capita for China was an inverted U-shape. A vector error correction model was used by Lean and Smyth (2010) and the results revealed the existence of a non-linear relationship between carbon dioxide emissions and economic growth. Kaika and Zervas [18], and Sanglimsuwan [19] found an inverted U-shaped relationship for CO₂ emissions and economic development in a cross-country analysis. Narayan and Narayan [20] in analyzing EKC for 43 developing countries used both time series and panel data estimation techniques. Their results revealed that in the long run as income increase, CO₂ emission reduces.

Pertaining to the effects of trade openness on the environment, Katircioglu [21] investigate short-run and long-run relationships between trade openness, capita real gross domestic product, and CO₂ emissions between 1961 and 2004 in Tunisia. They argue that trade openness has a positive direct effect on CO₂ emissions both in the short-run and the long-run, but a negative indirect effect occurs at least in the long run. The overall effect is positive both in the short-run and the long run. This highlights the importance of trade reforms along with strong environmental policies. Employing cross-country panel data, Le et al. [22] investigate the link between trade openness and the environment by utilising particulate matter emissions as a proxy variable for environmental quality. They provide significant evidence of a long-run link between particulate matter emissions and trade openness according to the panel cointegration test. An increased trade openness might lead to environmental degradation across the global sample, but this depends on a country's level of income. Trade openness has a harmful effect on the environment in middle-income and low-income countries but has a benign impact in high-income countries. Applying the panel cointegration tests from Pedroni [23] and Westerlund [24], Shahbaz et al. [25] investigates the link between trade openness and CO₂ emissions using data from 105 countries. The paper provides evidence that trade openness reduces environmental quality among countries, but the impact varies widely according to each group of countries.

2.1 Theoretical framework

The environmental Kuznets curve is the foundation of the study. A relationship between environmental quality and economic growth is hypothesized by the environmental Kuznets curve, according to which several environmental degradation indicators tend to deteriorate over time as modern economic growth occurs until

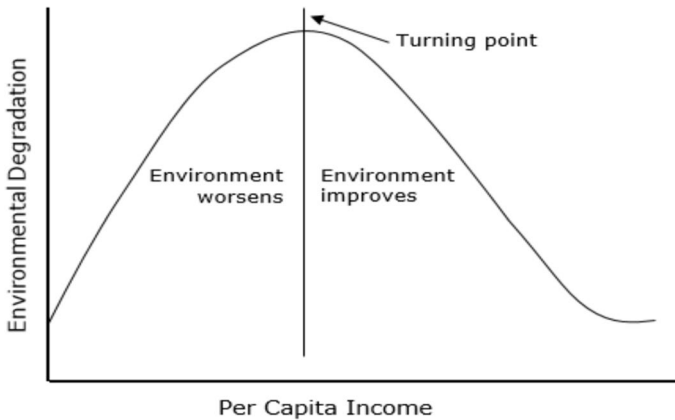


Fig. 1 Kuznets inverted U shaped between environmental degradation and per capita income

average income reaches a particular level over the course of development. There is evidence to support the idea that environmental health indicators, such as air and water pollution, exhibit an inverted U-shaped curve, even though this is still up for discussion. Several environmental contaminants, including sulphur dioxide, nitrogen oxide, lead, DDT, chlorofluorocarbons, sewage, and other chemicals that were formerly discharged directly into the air or water, have been said to be trending in this direction. According to the inverted U-shaped curve in Fig. 1, there is a connection between per capita income and environmental deterioration.

For instance, the number of automobiles and trucks in the nation more than doubled, the total number of miles travelled climbed by 178%, and the inflation-adjusted GDP of the United States increased by 195% between 1970 and 2006. However, during that same time, regulatory changes led to annual emissions of lead falling by more than 98%, particulate emissions falling by 80%, sulfur dioxide emissions falling by 31 million tons, nitrogen oxide emissions falling by 19 million tons, and carbon monoxide emissions falling by 89 million tons.

Nevertheless, there is no proof that the connection holds true for other contaminants, for the use of natural resources, or for the preservation of biodiversity. For instance, resource usage (also known as the "ecological footprint") does not decrease with increasing wealth. In most industrialized nations, overall energy usage is still increasing even while the ratio of energy to real GDP has decreased. Another illustration is the fact that industrialized nations emit far more greenhouse emissions than developing nations. Moreover, several important "ecosystem services" offered by ecosystems, such as the provision and management of freshwater [26], soil fertility, and fisheries, have seen a loss in status in industrialized nations.

Kuznets curves have generally been discovered for some environmental health issues (like air pollution), but not for others (such as landfills and biodiversity). The magnitude of the Kuznets curves may vary for different environmental influences and different areas, according to proponents of the EKC, therefore this does not necessarily rule out the idea. If the idea may be saved by looking for scalar and

local impacts, it can still be the case that a particular location needs more money to experience a drop in environmental pollutants. A thermodynamically enlightened economics, on the other hand, contends that outputs of degraded matter and energy are a necessary byproduct of all uses of matter and energy (according to the second law); some of these degraded outputs will be toxic wastes, and whether and how their production is stopped depends more on the regulatory frameworks and technologies in place than on levels of income or production. Thus, according to one interpretation of the EKC, "the solution to pollution is more economic growth;" however, according to another, pollution is viewed as a regrettable output that should be reduced when the advantages of its production outweigh the disadvantages, such as health consequences and the loss of ecosystem services.

Several studies such as Zafar et al. [6], Adedoyin et al. [5]; Mahalik et al. [12] have examined energy utilization and environmental sustainability with mixed results. Most of the studies conducted did not focus on Nigeria, also major energy sources especially renewable energy sources like biomass were not exploited in their analysis, as such this constitutes a gap in study. This study intends to address the gap by focusing on Nigeria in order to analysis the linkages between renewable and non-renewable energy utilization and the environment. In terms of methodology this study is an improvement on other research in this area as it adopts the dynamic time series econometrics approach to identify the short-run and long-run relationships between energy use and environment.

3 Methodology

3.1 Data

To achieve this study stated objective as discuss in Sect. 1, data on renewable energy consumption, carbon emissions, non-renewable energy, trade openness, foreign direct investment (FDI) and economic growth were obtained from the World Bank Database between the period 1990–2021. Besides, the common process of gathering data and looking for patterns to identify trends is known as trend analysis. A technique called trend analysis is used to look at and forecast movements of an item using both recent and previous data. It enables the comparison of data over a specific time frame and the detection of uptrends, downtrends, and stagnation. A trend that is steady and consistent throughout time conveys stability and inspires greater confidence than one that is rapidly shifting positions.

The result of the descriptive statistics as shown in Table 1 shows the measure of central tendencies, i.e., the mean, and median, the measure of dispersion i.e., the maximum, minimum and standard deviation, the measure of distribution i.e., skewness, Kurtosis, and normality test. The result of Skewness shows that most of the variable are positively skewed except renewable energy which skewed negatively under the period of investigation and the result also showed that all the variables have a value greater than one Kurtosis. The result of the Jarque–Bera test indicates that all the variables included in the models are normally distributed at 5% significant level.

Table 1 Descriptive statistics

	CO ₂	ECN	FDI	NREN	OPN	REN
Mean	0.680	2002.065	3.09E+09	19.031	6.469	84.875
Median	0.671	1981.699	2.16E+09	18.518	6.698	84.650
Maximum	0.916	2679.555	8.84E+09	22.844	14.011	88.680
Minimum	0.491	1429.012	3.00E+08	15.854	2.635	80.640
Std. Dev	0.123	464.173	2.61E+09	1.657	2.344	2.327
Skewness	0.316	0.066	0.868488	0.721	0.888	- 0.106
Kurtosis	1.789	1.354	2.555125	2.743	4.603	1.798
Jarque–Bera	2.489	3.633	4.286	2.865	7.641	1.985
Probability	0.288	0.162	0.117	0.238	0.021	0.370
Sum	21.774	64,066.08	9.87E+10	609.001	207.008	2716.004
Sum Sq. Dev	0.473	6,679,162	2.11E+20	85.176	170.445	167.882
Observations	32	32	32	32	32	32

Source: Author's computation, E-views version 10.0

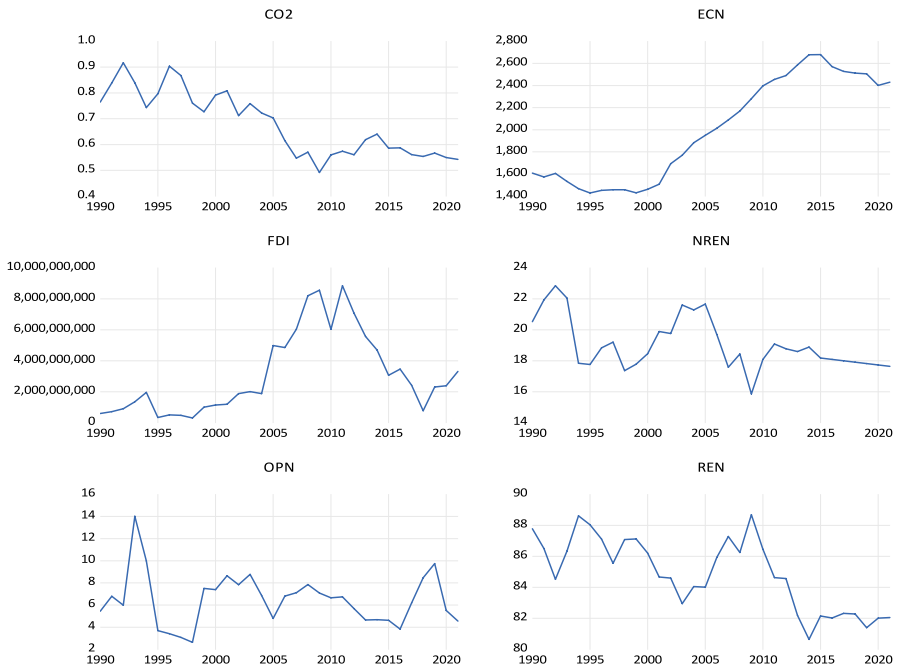


Fig. 2 Trend analysis of the variables (FDI, NREN, OPN, REN, ECN & CO₂) under investigation

Graphically, the trend analyses as presented in Fig. 2 showed that the variables fluctuate at one point or the other during the period under review. This was attributed to the effects of government policy and economic conditions that would have had attendant effects on some of the variables. Based on these outcomes. This study

factored in structural breaks in empirical estimations since time series models are known to suffer from regime shift or structural breaks issues.

3.2 Methodology

The autoregressive distributed lag (ARDL) model equation for CO₂ emissions as a function of GDP, GDP squared (GDP²), FDI, trade openness, non-renewable energy consumption, and renewable energy consumption can be represented as follows:

$$CO2_t = \beta_0 + \beta_1GDP_t + \beta_2GDP_t^2 + \beta_3FDI_t + \beta_4OPN_t + \beta_5NREN_t + \beta_6REN_t + \varepsilon_t \quad (1)$$

where: CO₂ represents the CO₂ emissions. GDP denotes the Gross Domestic Product. FDI refers to Foreign Direct Investment. OPN represents the degree of openness to international trade. NREN represents the consumption of non-renewable energy sources and REN denotes the consumption of renewable energy sources. β_0 , β_1 , β_2 , β_3 , β_4 , β_5 , and β_6 are the coefficients to be estimated and ε represents the error term.

In this model, the CO₂ emissions are hypothesized to be influenced by the level of economic development (GDP and GDP²), foreign direct investment (FDI), the extent of international trade (OPN), and energy consumption from both non-renewable and renewable sources. The coefficients β_1 , β_2 , β_3 , β_4 , β_5 , and β_6 indicate the respective impacts of these variables on CO₂ emissions.

It's worth noting that the ARDL model assumes a long-run relationship between the variables and allows for short-run dynamics to be captured by the lagged values of the variables. The specific lag structure and order of integration should be determined through appropriate econometric techniques, such as the bounds testing approach or the Akaike Information Criterion (AIC).

From Table 2, report the correlation coefficient result for the series. Correlation coefficient measures the linear relationship between variables and does not capture other types of relationships, such as nonlinear or causal relationships. Therefore, it is essential to consider other statistical tools and methods in conjunction with the correlation coefficient to gain a comprehensive understanding of the data. To this study, we found that some variables most specifically renewable and nonrenewable are positively associated with environmental degradation while economic growth and foreign direct investment are negatively related with environmental degradation.

4 Results and discussion of findings

In this section, we present empirical results and discuss findings as follows:

4.1 Break-point unit root test

The breakpoint unit root test is a statistical tool used to determine whether a structural break exists in a time series data and whether the data series follows a unit root process before and after the break. The importance of the breakpoint unit root test

Table 2 Correlation analysis

Correlation						
t-Statistic						
Probability	CO2	ECN	FDI	NREN	OPN	REN
CO2	1.000					
t-stat	–					
p-Value	–					
ECN	– 0.862	1.000				
t-stat	– 9.321	–				
p-Value	0.000	–				
FDI	– 0.702	0.615	1.000			
t-stat	– 5.407	4.275	–			
p-Value	0.000	0.000	–			
NREN	0.611	– 0.376	– 0.282	1.000		
t-stat	4.229	– 2.227	– 1.610	–		
p-Value	0.000	0.033	0.117	–		
OPN	0.002	– 0.125	0.009	0.242	1.000	
t-stat	0.015	– 0.695	0.053	1.368	–	
p-Value	0.988	0.492	0.957	0.181	–	
REN	0.372	– 0.687	– 0.044	– 0.052	0.111	1.000
t-stat	2.201	– 5.175	– 0.245	– 0.286	0.612	–
p-Value	0.035	0.000	0.807	0.776	0.548	–

Source: Author's computation

Table 3 Break point unit root test

Variables	Level			FD		
	Coeff.	p-Value	Break date	Coeff.	p-Value	Break date
CO2	– 3.901	0.193	2005	– 7.777	0.01	2009
ECN	– 4.602	0.033	2001			
FDI	– 5.405	0.01	2004			
NREN	– 3.683	0.291	2011	– 6.758	0.01	1994
OPN	– 4.203	0.097	2003	– 7.024	0.01	1995
REN	– 3.757	0.255	2009	– 5.718	0.01	1994

Source: Author's computation using E-views-10

lies in its ability to detect and account for structural changes, which can significantly impact the analysis and interpretation of time series data. By accounting for these breaks, researchers can improve model specification, avoid biased results, enhance forecasting accuracy, and make more informed decisions based on robust statistical inference.

Table 4 ARDL bound test results

F-bounds test		Null hypothesis: no levels relationship		
Test statistic	Value	Signif	I(0)	I(1)
			<i>Asymptotic: n = 1000</i>	
F-statistic	25.25162	10%	1.99	2.94
k	6	5%	2.27	3.28
		2.5%	2.55	3.61
		1%	2.88	3.99

Source: Author's computation, 2023

Unit root results as presented in Table 3 shows that the variables are partially integrated, that is, the stationary of the series are mixture of I(0) and I(1) and are significant at a 5% and 1% level. This means that the null hypothesis will not be accepted. This study, therefore, concludes that the time series model is partially integrated, hence we proceeded to check to co-integration among the variables using the autoregressive distributed (ARDL) bounds testing technique.

4.2 Autoregressive distributed lag (ARDL) bound test result

The ARDL bound testing approach is a valuable tool for analysing time series data and investigating the long-run relationship between variables. By addressing issues of cointegration and endogeneity, it provides insights into the direction of causality and allows for model selection in situations with small sample sizes. It involves estimating an autoregressive distributed lag model that includes lagged values of the dependent variable and the independent variables. The test examines whether the coefficients of the lagged variables are jointly significant, indicating the presence of a long-run relationship.

Based on the empirical outcome presented in Table 3, this study confirms the existence of a long run relationship amongst the variables. This is because, the F-statistic of 25.251 when the (k) is 6 is higher than the upper-bound critical values 3.99 at the 1% significance level. This implies that the null hypothesis of no cointegration among the series is rejected, that is there exist cointegration relationship (Table 4).

4.3 The Chow Test (CT)

The CT is a statistical test used to determine whether there is a structural change or a significant difference between two separate regression models. It examines whether combining the data from two or more separate groups provides a better fit or improvement in the overall model compared to estimating separate models for each group. The test evaluates whether the coefficients of the independent variables are significantly different between the groups.

Table 5 Chow Test result

Variables	Coeff.	p-Value
<i>LNCO2</i>	0.619	0.798
<i>LNECN</i>	0.711	0.501
<i>LNFDI</i>	1.06	0.69
<i>LNNREN</i>	0.729	0.624
<i>LNOPN</i>	0.874	0.798
<i>LNREN</i>	0.619	0.255

To interpret the results of a Chow Test, this study typically looks at the test statistic, degrees of freedom, and p-value. The test statistic follows an F-distribution, and a low p-value suggests evidence of a structural change. The null hypothesis (H_0) for the CT is specified under the assumption of no structural change or significant difference between the two groups. While alternative hypothesis (H_1) for the CT is also specified under the assumption of a structural change or significant difference between the two groups.

The test statistic is calculated based on the difference in the sum of squared residuals between the combined model and separate models. A larger test statistic indicates a greater difference between the models. While the degrees of freedom represent the number of restrictions imposed on the models. It is typically equal to the number of parameters estimated in the combined model minus the number of parameters estimated in each separate model. In addition, the p-value indicates the probability of observing a test statistic as extreme as the one calculated under the null hypothesis. A small p-value (e.g., less than the significance level, commonly 0.05) suggests that the null hypothesis can be rejected in favor of the alternative hypothesis.

If the p-value is less than the significance level, you would reject the null hypothesis and conclude that there is a structural change or significant difference between the two groups. Conversely, if the p-value is greater than the significance level, you would fail to reject the null hypothesis and conclude that there is no evidence of a structural change. It is important to note that the interpretation of the Chow Test results should be done in conjunction with other diagnostic tests and a thorough understanding of the data and research context. Additionally, the Chow Test assumes certain assumptions, such as linearity and homoscedasticity, which should be checked before relying solely on the test results.

As reported in Table 5, the CT estimated empirical outcome shows, the break dates are not statistically significant, thus, have no significant impact on the ARDL bound test estimation. This is because the p-Values for all the observed break dates are greater than 1 at all significance levels. This suggests that there is a significant difference in the break dates relationship between the series for the sampled country. In other words, the relationship between environmental degradation and its explanatory variables does not varies significantly in the case of the sampled country. Thus, we proceed with the ARDL estimation without considering the break dates in the empirical estimation.

Table 6 Short- and long-run ARDL bound testing result

Long-run				
Variable	Coefficient	Std. error	t-Statistic	Prob
<i>C</i>	12.730***	2.560	4.972	0.000
<i>LNCO2(-1)*</i>	- 1.034***	0.082	- 12.484	0.000
<i>LNECN**</i>	- 2.017***	0.256	- 7.857	0.000
<i>ECN²**</i>	1.801***	2.958	6.182	0.000
<i>LNFDI**</i>	- 0.003	0.011	- 0.338	0.738
<i>LNNREN**</i>	1.021***	0.106	9.608	0.000
<i>LNOPN**</i>	- 0.056***	0.016	- 3.350	0.002
<i>LNREN**</i>	- 0.326	0.415	- 0.785	0.440
Short run		Coint - 0.341 (0.000)		
Variable	Coefficient	Std. error	t-Statistic	Prob
<i>LNECN</i>	- 1.950***	0.232	- 8.397	0.000
<i>ECN²</i>	1.767***	2.898	6.098	0.000
<i>LNFDI</i>	- 0.003	0.011	- 0.338	0.738
<i>LNNREN</i>	0.988***	0.100	9.871	0.000
<i>LNOPN</i>	- 0.055***	0.016	- 3.372	0.002
<i>LNREN</i>	- 0.315	0.398	- 0.790	0.437
<i>C</i>	12.309***	2.338	5.263	0.000

Source: Author's computation

Having confirmed that the break dates do not have significant impact in the empirical estimation, Table 6 shows the short- and long run ARDL bound test estimation results. This study found that non-renewable energy has direct (positive) and significant impact on environmental degradation both in the long- and short run. Empirical result show that a 1 percent increase in non-renewable energy (such as coal, gas and petroleum) increase environmental degradation at 0.988 and 1.021 percent in the short- and long-run at 1 percent significant level in the case of the sampled country. In terms of renewable energy, this study found that renewable energy has an inverse (negative) but insignificant impact on environmental degradation both in the long- and short run. Empirical results show that a 1 percent increase in renewable energy would decrease environmental degradation at 0.315 and 0.326 percent in the short- and long-run in the case of the sampled country all things being equal. This outcome resonates [27–34] findings.

Foreign direct investment on the other hand has a negative but insignificant impact on economic growth in the short run and long run. This implies that FDI does not necessarily impact on the environmental degradation over the sampled period for the country under observation. However, trade openness has a negative and significant impact on economic growth in the short run and long-run. Results show that a 1 percent increase in trade openness with the rest of the world decreases environmental degradation at 0.055 and 1.056 percent in the short- and

Table 7 Diagnostic test

Variables	Coeff	p-Value
Normality	0.593	0.743
Serial correlation	1.387	0.272
Heteroscedasticity	0.749	0.634

long-run at 1 percent significant level in the case of the sampled country. This outcome is line with Usman et al. [35] and Usman et al. [36]

Lastly, to estimate the turning point between the economic growth measured by the gross domestic product, we estimated Kuznets curve model. This is done by capturing the GDP and level and its squared term in the ARDL model. Result as reported in Table 6 show that, environmental degradation falls when income is at level and increases as the level of income increases. This result confirms the economic growth-led environmental degradation hypothesis for the sampled country. As economic activities increase with the non-renewable and renewable energy sources, environmental degradation also increases and decreases in the short- and long-run at 1 percent significant level in the case of the sampled country resonates [28, 30, 32–34].

The error correction term is an important component in the context of cointegration and error correction models. It plays a crucial role in capturing the long-run equilibrium relationship between variables and ensuring the stability of the model. It is important in econometric modeling to capture the adjustment process towards equilibrium, account for co-integration among variables, maintain model stability, and provide insights into short-run and long-run dynamics. It enhances the understanding of the relationship between variables, enables accurate estimation, and facilitates reliable forecasting and policy analysis.

As expected, the coefficient of ECM_{t-1} is negative and statistically significant at 1 percent significant level. A statistically significant coefficient indicates that the error correction term contributes significantly to capturing the short-run dynamics and restoring equilibrium between environmental degradation and its determinants. We find a speed of adjustment of about 34 percent annually. This implies that environmental degradation adjusts back to the long-run equilibrium more slowly in response to a deviation.

Diagnostic tests are an essential component of statistical analysis and modelling. They help assess the quality of a statistical model and ensure that the underlying assumptions are met. diagnostic tests play a crucial role in statistical analysis by evaluating model validity, verifying assumptions, detecting outliers and influential points, assessing model fit, and analysing residuals. They provide insights into the quality and reliability of statistical models, helping researchers and analysts make informed decisions and draw accurate conclusions from their data. Based on the results reported in Table 7, the estimated model follows a normal distribution pattern and free of serial correlation and heteroscedasticity, since we reject the null hypothesis at various levels.

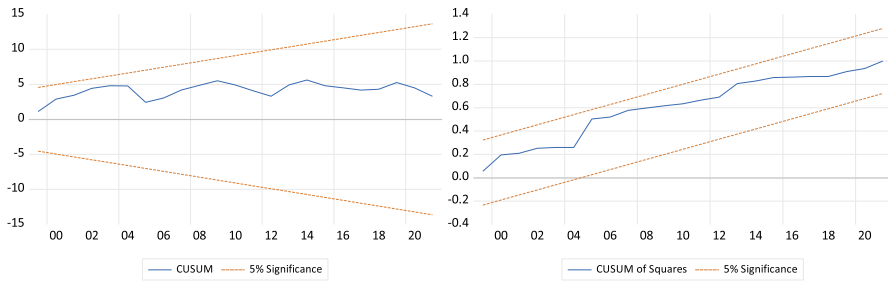


Fig. 3 Stability test (CUSUM and CUSUM Square test) plots

Stability tests as reported in Fig. 3 are crucial for ensuring the reliability of models and systems, improving forecasting accuracy, informing policy decisions, assessing system resilience, designing control systems, optimizing complex systems, and managing risks. They provide valuable insights into the behavior and performance of systems over time, allowing for informed decision-making, risk mitigation, and improved system performance. Result reported in Fig. 3 show that, the cumulative sum (CUSUM) and the CUSUM Squared falls within the critical region. This shows that the parameters are stable over the period and robust for policy decision making.

4.4 Discussion of findings

The negative but insignificant impact of renewable energy on environmental degradation suggests that the use of renewable energy sources, such as solar, wind, or hydroelectric power, does not have a statistically significant effect on reducing environmental degradation in Nigeria. This finding may seem counterintuitive since renewable energy sources are generally considered more environmentally friendly compared to non-renewable sources like fossil fuels.¹ However, there could be several reasons for this result. It is possible that the current level of renewable energy usage in Nigeria is not substantial enough to make a significant impact on environmental degradation. For example, in 2022, renewable energy represented 16.4 percent of Nigeria's total electricity capacity. However, this share has seen a decline in recent years. Additionally, other factors or limitations such as inadequate infrastructure, technological limitations, or policy barriers might be hindering the full potential of renewable energy in mitigating environmental degradation.

The positive impact of non-renewable energy on environmental degradation indicates that the use of non-renewable energy sources, such as fossil fuels (coal, oil, and natural gas), contributes to environmental degradation in Nigeria. This result aligns with the well-known environmental consequences of burning fossil fuels,

¹ This finding resonates the study of Osunmuyiwa and Kalfagianni [37] where they argued that renewable energy adoption in Nigeria has seen a gradual yet consistent rise. However, this adoption is distributed unevenly across the thirty-six Nigerian states, with some leading the way as pioneers and others falling behind as laggards.

such as greenhouse gas emissions, air pollution, and climate change. The positive impact suggests that as the consumption of non-renewable energy increases, so does the level of environmental degradation in Nigeria. This finding highlights the importance of transitioning towards cleaner and more sustainable energy sources to reduce environmental impacts.

The negative impact of FDI on environmental degradation suggests that foreign direct investment in Nigeria may contribute to environmental improvements or mitigation of environmental degradation. This finding could be attributed to several factors: FDI often brings advanced technologies and management practices to the host country. In the context of environmental degradation, this can involve the transfer of cleaner and more efficient production technologies that result in reduced pollution or resource usage. For example, a foreign company investing in Nigeria's manufacturing sector might introduce cleaner production processes or invest in renewable energy technologies, leading to a decrease in environmental degradation.

In addition, multinational corporations operating in Nigeria may be subject to stricter environmental regulations or sustainability standards in their home countries. This can lead to the adoption of better environmental practices when they establish operations in Nigeria. For instance, an international company investing in Nigeria's mining sector might implement rigorous environmental management practices to comply with their home country's environmental regulations. Some foreign investors may prioritize environmentally friendly projects in Nigeria, such as renewable energy infrastructure or sustainable agriculture. These investments can contribute to reducing environmental degradation by promoting clean energy generation, land restoration, or sustainable resource management. It is important to note that FDI can be harnessed for positive environmental outcomes if it is coupled with responsible and sustainable business practices, adherence to environmental regulations, and a focus on green and clean technologies. Governments and regulatory bodies play a critical role in ensuring that FDI projects align with environmental sustainability goals and do not contribute to degradation.

The negative impact of trade openness on environmental degradation suggests that increased international trade in Nigeria is associated with lower levels of environmental harm. Several factors can explain this relationship. For example, increased trade openness can facilitate the exchange of goods and services, allowing countries to specialize in areas where they have a comparative advantage. This specialization can lead to more efficient resource allocation and reduced environmental degradation. For example, if Nigeria specializes in exporting agricultural products, it may rely less on environmentally damaging activities such as deforestation for agriculture, leading to reduced environmental degradation.

Trade openness often necessitates compliance with international environmental regulations and standards. To access global markets, Nigerian industries may need to meet environmental requirements set by importing countries. This can promote the adoption of sustainable practices, pollution control measures, and cleaner technologies. It creates opportunities for exporting environmentally friendly products or services. For instance, Nigeria may export sustainably sourced agricultural products or eco-tourism services, which contribute positively to the environment and promote conservation efforts. Lastly, increased trade openness allows Nigerian agricultural

producers to export organic products to international markets, encouraging the adoption of sustainable farming practices. This shift reduces the use of synthetic fertilizers and pesticides, thereby decreasing soil and water pollution and lowering overall environmental degradation.

5 Conclusion and policy suggestions

5.1 Conclusion

Overall, this study highlights the complex relationship between energy sources, foreign direct investment, trade openness, economic growth, and environmental degradation in Nigeria. It underscores the need for comprehensive policies and strategies that promote the use of renewable energy, regulate non-renewable energy sources, encourage sustainable FDI practices, and integrate environmental considerations into trade activities. By addressing these issues, Nigeria can work towards a more sustainable and environmentally responsible development path.

Empirical results show a positive relationship between economic growth and CO₂ emissions in Nigeria, where CO₂ emissions initially decrease at lower levels of GDP but start to increase as GDP reaches a certain threshold, it implies several implications for Nigeria's environmental and developmental challenges. The positive relationship suggests that as Nigeria undergoes industrialization and experiences economic growth, there is an increasing demand for energy. Energy production relies heavily on fossil fuels; thus, it contributes to higher CO₂ emissions. This indicates a challenge in balancing economic development with environmental sustainability. As the country's GDP grows, there is a need for infrastructure expansion, including power plants, transportation systems, and buildings. The construction and operation of these infrastructure projects can be carbon-intensive, leading to an increase in CO₂ emissions. Rising CO₂ emissions have implications for climate change, contributing to global warming and its associated effects. Nigeria may experience adverse consequences such as increased temperatures, altered rainfall patterns, and impacts on ecosystems and biodiversity. In addition, higher CO₂ emissions often correlate with increased air pollution, which can have detrimental effects on public health. This includes respiratory diseases, cardiovascular issues, and other health complications associated with poor air quality.

5.2 Policy suggestions

The positive relationship between non-renewable energy and environmental degradation highlights the need for robust environmental regulations and policies to address the challenges posed by increasing CO₂ emissions. Nigeria may need to strengthen emission control measures, set emission reduction targets, and enforce sustainable practices across sectors. The findings underscore the importance of transitioning towards cleaner and renewable energy sources. Nigeria can

prioritize investments in renewable energy infrastructure, promote energy efficiency measures, and encourage the adoption of sustainable practices in various sectors.

Nigeria's policymakers can focus on integrating environmental sustainability into their development strategies. This includes aligning with the United Nations Sustainable Development Goals (SDGs), particularly Goal 13 (Climate Action) and Goal 7 (Affordable and Clean Energy). The results suggest a need for Nigeria to strike a balance between economic growth and environmental sustainability. It is crucial to explore pathways that decouple GDP growth from CO₂ emissions, such as adopting green technologies, promoting sustainable consumption and production, and implementing circular economy principles. Addressing these implications requires a comprehensive and integrated approach that involves collaboration between the government, private sector, civil society, and international partners. Nigeria can leverage sustainable development strategies, promote green investments, and pursue low-carbon development pathways to mitigate the environmental impacts associated with GDP growth and CO₂ emissions.

Empirical results indicate that trade openness has a negative impact on environmental degradation in Nigeria, policymakers should consider strengthen and enforce environmental regulations to ensure that trade openness does not lead to environmental degradation. These regulations can set standards for emissions, waste disposal, and sustainable resource management and negotiate trade agreements that prioritize sustainability and environmental protection, while encouraging trading partners to adopt and adhere to environmentally friendly practices, such as sustainable sourcing of natural resources.

While empirical results indicate that FDI has a negative but statistically insignificant impact on environmental degradation in Nigeria, policymakers should consider a nuanced approach to address this issue. Government should maintain and strengthen existing environmental regulations and enforcement mechanisms. The insignificance of FDI's impact on environmental degradation should not be interpreted as a green light for lax environmental oversight. Policymaker should ensure that FDI projects align with Nigeria's commitment to achieving the United Nations Sustainable Development Goals (SDGs), which include environmental sustainability targets. The statistical insignificance may suggest a less direct relationship, the potential environmental consequences of FDI should not be overlooked. Balancing economic growth and development with environmental sustainability remains a critical goal for Nigeria.

Given the negative impact, albeit statistically insignificant, of renewable energy on environmental degradation, policymakers should continue to support and promote the adoption of renewable energy sources. The key takeaway is that while renewable energy may have a negative but statistically insignificant impact on environmental degradation, this should not deter policymakers from continuing to promote renewable energy adoption. Instead, it should serve as a reminder that the environmental impact of renewable energy technologies needs careful management and continuous improvement to maximize their benefits for sustainable development.

5.3 Area for future studies

Further research into the transition to renewable energy sources in Nigeria is essential. Researchers could investigate the economic, social, and environmental impacts of increasing the share of renewables in the energy mix, along with the barriers and solutions for effective implementation. Future studies could explore strategies and policies for climate change adaptation specific to Nigeria, including measures to mitigate the impacts of extreme weather events, rising sea levels, and shifting climate patterns. Study water resource management, including the impact of industrial activities, agriculture, and urbanization on water quality and availability. Research innovative solutions for water conservation and pollution control. Lastly, study could be conducted on sustainable agricultural practices and technologies in Nigeria to improve food security while minimizing environmental impacts, including soil degradation, water use, and deforestation. These research areas can help inform policies, practices, and strategies for promoting environmental sustainability and addressing the unique environmental challenges facing Nigeria in the twenty-first century.

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Declarations

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