EFFECT OF WOOD FUEL CONSUMPTION ON GREEN GROWTH AND ENVIRONMENTAL SUSTAINABILITY IN NIGERIA (1990-2023)

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Abstract
This study examines the effect of wood fuel consumption on green growth and environmental sustainability in Nigeria from 1990 to 2023 using the Autoregressive Distributed Lag (ARDL) approach. The bounds test result shows the presence of a long-run relationship among the variables, with F-statistics of 5.37 and 5.73, respectively. The empirical findings reveal that wood fuel consumption negatively influences environmental sustainability in both the short and long run, indicating that greater wood fuel consumption worsens environmental sustainability. Conversely, trade openness significantly promotes green growth and enhances environmental quality across both periods, suggesting that trade liberalisation may facilitate environmentally friendly economic activities. The study recommends expanding access to affordable energy alternatives and strengthening environmental governance frameworks. Specifically, policies should provide targeted subsidies and tax incentives for clean cooking technologies such as LPG, solar cookstoves, and improved biomass stoves to reduce household dependence on wood fuel.

Keywords: Clean energy, energy use, environmental sustainability, green growth, wood fuel

1.0 Introduction

Environmental sustainability remains a central concern of the United Nations agenda, particularly highlighted through Sustainable Development Goals (SDGs) 7, 11, 12, and 13, which promote clean energy, sustainable cities, responsible consumption, and climate action. In Nigeria, wood fuel remains a principal energy source for cooking and heating, particularly in rural regions with restricted access to modern energy alternatives (Adekunle et al., 2019). However, the extensive use of wood fuel has substantial implications for the country's green growth and environmental sustainability objectives. High demand for wood fuel has led to rampant deforestation, estimated at a rate of 3.5% annually, exacerbated environmental degradation and threatened biodiversity (Chidumayo & Gumbo, 2010). Moreover, the inefficient burning of wood fuel contributes to indoor and outdoor air pollution, leading to adverse health effects and further environmental degradation (Olaniyan et al., 2019). Hence, understanding the link between wood fuel use and environmental sustainability is therefore vital for guiding policy and advancing Nigeria's sustainable development agenda.

Moreover, the consequences of excessive wood fuel consumption extend beyond environmental degradation to encompass socioeconomic implications, particularly for marginalised communities dependent on forest resources for their livelihoods (Adekunle et al., 2019). Unsustainable harvesting of wood fuel can lead to resource depletion and exacerbate long-term poverty and socio-economic inequalities (Chidumayo & Gumbo, 2010). Additionally, the reliance on wood fuel perpetuates energy poverty, hindering economic productivity and social development (Olaniyan et al., 2019). Thus, understanding the dynamics of wood fuel consumption in Nigeria is essential not only for environmental conservation but

also for promoting inclusive growth and addressing socio-economic disparities across the country.

The study on the effect of wood fuel consumption on green growth and environmental sustainability in Nigeria holds significant importance in understanding the balance between economic development and environmental preservation. With Nigeria's heavy reliance on wood fuel for energy, this research will shed light on the critical need for sustainable alternatives to mitigate the adverse environmental impacts associated with deforestation and indoor air pollution (Adewumi, 2020). By quantifying the environmental costs and exploring sustainable solutions, this study will not only contribute to academic discourse but also provide policymakers and stakeholders with valuable insights to formulate effective strategies for promoting green growth and ensuring long-term environmental sustainability in Nigeria. Therefore, this inquiry will employ a dynamic regression method to assess the connection between wood fuel consumption, clean environment and green growth in Nigeria.

The unsustainable consumption of wood fuel in Nigeria poses a significant threat to both green growth and environmental sustainability. According to the Food and Agriculture Organization (FAO), Nigeria is one of the world's top five countries with the highest rates of deforestation, primarily driven by the demand for wood fuel, which accounts for approximately 63% of total energy consumption in the country (FAO, 2020; Osei et al., 2019). This rampant deforestation not only leads to loss of biodiversity but also exacerbates soil erosion, disrupts water cycles, and contributes to climate change through increased carbon emissions. Furthermore, the reliance on wood fuel for cooking and heating purposes in households results in indoor air pollution, which poses severe health risks, particularly for women and children who are often exposed to harmful pollutants at higher rates (Oluwole et al., 2018).

Despite these alarming statistics and the well-recognised negative impacts of wood fuel consumption, there remains a lack of comprehensive studies examining its specific effects on green growth and environmental sustainability in Nigeria. Much of the existing literature focuses on broader issues such as economic growth,trade, general energy consumption, and environmental degradation, among others, and they concentrated on countries from Asia, BRICS, the Middle East, North Africa, and Sub-Saharan Africa (Razelan et al., 2024; Wei et al., 2023; Destek et al., 2021; Aydin, 2019; Sulaiman and Abdul-Rahim, 2020; Sulaiman et al., 2017). In the Nigerian context, studies by Samaila et al. (2025), Asefon (2024), Abraham et al. (2022), Maina et al. (2020), and Isah and Ahman (2020) mainly explored the relationship between wood fuel use and its implications for sustainable development, without explicitly quantifying its impact on green growth and environmental sustainability.

This underscores the need for research that not only examines the environmental implications of wood fuel consumption but also identifies feasible strategies to promote green growth and mitigate its adverse effects on environmental sustainability in Nigeria. This study is novel empirically, as it provides a detailed analysis of how wood fuel consumption affects green growth and environmental sustainability in Nigeria. It addresses the gaps left by prior studies that primarily focus on deforestation or general biomass use by explicitly quantifying the relationship between wood fuel use, environmental outcomes, and green economic performance.

2.0 Literature Review

The literature on the effect of wood fuel consumption on green growth and environmental sustainability highlights the significant challenges posed by unsustainable energy practices and the urgent need for coordinated policy actions to address them. Numerous studies have shown that excessive dependence on wood fuel contributes to deforestation, biodiversity loss, and

environmental degradation, which in turn constrain sustainable economic performance. Previous research has focused on the determinants of wood fuel consumption, its socio-environmental impacts, and its relationship with green growth and environmental sustainability at various scales (global, regional, and national).

Wood Fuel Use and Green Economic Growth

Green growth represents an environmentally sustainable form of economic expansion that promotes social inclusiveness while minimising ecological degradation (Sohail et al., 2024). It is based on the premise that long-term economic progress depends on the efficient and responsible utilisation of natural resources. Razelan et al. (2024), using ARDL and dynamic ARDL techniques on data for Malaysia from 1990 to 2021, found that green trade significantly enhances green economic growth in both the short and long run. Similarly, Sohail et al. (2024) employed the CS-ARDL technique on data from 2000-2022 for 33 economies and reported that bioenergy contributes positively to green growth in the long term, although its short-run impact is not statistically significant. Forest trade was also found to promote green growth across both horizons. Javed et al. (2024), using the CS-ARDL model on annual data from 1990 to 2019 for the top ten manufacturing economies, established that green technology, energy efficiency, and human capital improve environmental performance, while trade openness and rapid economic expansion tend to increase environmental pressure. Wei et al. (2023) reached a similar conclusion using data from 1990 to 2018 across leading green-growth economies, showing that renewable energy, green innovation, and green growth collectively enhance environmental quality, though green trade exhibits inconsistent outcomes.

Studies that focus specifically on biomass and wood fuel show mixed results, often depending on each country's economic structure, energy policy, and technological efficiency. For instance, Sulaiman and Abdul-Rahim (2020) analysed data from 1979 to 2017 for Sub-Saharan Africa and found that wood fuel consumption negatively affects economic growth in both the short and long run. Similarly, Danish and Ulucak (2020), using the dynamic ARDL model on China's annual data from 1982 to 2017, observed that biomass energy use has a long-run negative relationship with CO_2 emissions, implying that biomass energy can promote environmental sustainability if supported by appropriate policies. Destek et al. (2021), employing continuously updated, fully modified, and bias-corrected estimators for the U.S., China, Germany, India, and Brazil from 1970 to 2016, confirmed that biomass energy helps reduce CO_2 emissions, thereby supporting environmental sustainability. In the BRICS economies, Aydin (2019) applied the Augmented Mean Group (AMG) estimator on data from 1992-2013 and found that biomass energy consumption positively influences long-term economic growth in all countries except Brazil. Conversely, Sulaiman et al. (2017), using a dynamic Generalised Method of Moments (GMM) data for Sub-Saharan Africa from 2005 to 2013, concluded that wood fuel use accelerates forest degradation. Likewise, Shahbaz et al. (2016), applying panel cointegration analysis for BRICS countries (1991Q1-2015Q4), reported that biomass energy promotes economic growth, while trade openness supports both short- and long-run economic performance.

Wood Fuel Consumption and Environmental Sustainability

Wood fuel production and consumption have emerged as serious threats to environmental sustainability, particularly in developing economies where alternative energy sources remain limited. In Nigeria, Asefon and Adepoju (2024) reviewed the environmental implications of wood fuel use and found that fuelwood remains the most accessible and affordable energy source for many households. They stressed the need for alternative energy options to improve efficiency and protect forest resources. Similarly, Samaila et al. (2025) observed that rising scarcity of fuelwood in Michika, Adamawa State, has driven households to adopt charcoal as

a substitute, reflecting energy insecurity and resource depletion. Asefon (2024) emphasised that excessive wood fuel consumption contributes to deforestation, air pollution, and climate change, while Audu (2023) found that fuelwood collection in Yobe State is a major livelihood activity, underscoring its socio-economic importance. Abraham et al. (2022) reported that massive tree felling in Ganye, Adamawa State, has led to soil erosion, flooding, the loss of biodiversity, and rising local temperatures, thereby worsening environmental vulnerability.

Other studies, including Maina et al. (2020) and Isah and Ahman (2020), identified household size and low income as key drivers of wood fuel dependence, which accelerates vegetation loss and environmental degradation. Osei et al. (2019) also highlighted the role of wood fuel demand in driving deforestation across several African regions, consistent with the Food and Agriculture Organization (FAO, 2020), which identifies wood fuel consumption as a major global driver of forest loss. Oluwole, Ogunjuyigbe, and Adefila (2018) further examined the socio-economic implications of wood fuel use, noting that while it provides affordable energy, it undermines efforts toward sustainable livelihood and environmental conservation in Nigeria.

The literature presents mixed evidence on wood fuel's impact on green growth and environmental sustainability. Some studies indicate that biomass and bioenergy can support sustainable growth and reduce environmental degradation under supportive policies and technologies (Razelan et al., 2024; Sohail et al., 2024; Javed et al., 2024; Wei et al., 2023; Destek et al., 2021; Danish & Ulucak, 2020). Conversely, other studies highlight negative outcomes, including deforestation, soil erosion, and reduced economic growth (Sulaiman & Abdul-Rahim, 2020; Sulaiman et al., 2017; Shahbaz et al., 2016; Asefon & Adepoju, 2024; Abraham et al., 2022; Samaila et al., 2025). Household size, low income, and lack of energy alternatives further exacerbate wood fuel reliance, underscoring the trade-off between socio-economic needs and environmental sustainability (Maina et al., 2020; Isah & Ahman, 2020; Osei et al., 2019; FAO, 2020). Collectively, these findings emphasise that while biomass energy can offer benefits, unregulated or excessive wood fuel use threatens environmental sustainability, highlighting the need for context-specific policies, technological interventions, and alternative energy solutions.

Gap Identified

The reviewed literature provides valuable insights into the environmental and socio-economic consequences of wood fuel use. However, most Nigerian studies concentrate on issues of deforestation, household behaviour, and forest resource depletion, with limited focus on how wood fuel consumption affects green economic growth and environmental sustainability at the national level. Moreover, the long-run sustainability implications of continued reliance on wood fuel in Nigeria's energy and economic systems remain unclear. This study therefore bridges this gap by empirically examining the dynamic relationship between wood fuel consumption, green growth, and environmental sustainability in Nigeria using advanced time-series estimation techniques. In doing so, it provides new evidence on whether wood fuel consumption supports or undermines the country's transition toward a green growth pathway.

Theoretical Framework

The Environmental Kuznets Curve (EKC) hypothesis offers a framework for understanding the link between economic growth and environmental quality. It suggests that in the early stages of economic development, environmental degradation tends to increase due to reliance on traditional energy sources and inefficient production methods. However, after reaching a certain income threshold, further economic growth can lead to improvements in environmental quality as societies adopt cleaner technologies, enforce environmental regulations, and shift towards sustainable practices (Grossman & Krueger, 1991; Wang et al., 2022). In the Nigerian context, heavy reliance on wood fuel for cooking and heating, particularly in rural areas,

represents the initial stage where energy consumption contributes to deforestation, air pollution, and biodiversity loss. As income levels rise and access to modern energy alternatives improves, there is potential for a transition toward cleaner energy sources, thereby mitigating environmental pressures and supporting green growth objectives.This framework provides a theoretical basis for examining the effect of wood fuel consumption on green growth and environmental sustainability in Nigeria. It highlights the importance of economic development, energy transition, and policy interventions in achieving a balance between meeting energy needs and promoting environmental sustainability.

3.0 Methodology

Model specification

The theoretical underpinning of this study is based on the EKC (environmental Kuznets curve) hypothesis, which posits that a nation's wealth must surpass a certain threshold to achieve green growth and enhance environmental sustainability (Grossman & Krueger, 1995). Early research such as the empirical work of Ahmad et al. (2015) has explored this relationship. Nevertheless, this study seeks to extend this understanding by employing the linear EKC method, integrating green growth and sustainable environment in the analysis of wood fuel. Hence, the equation is presented as follows:

$$GRG_t = F(WUFL_t, ESTB_t, TRPN_t) \quad (1)$$

$$ESTB_t = F(WUFL_t, GRG_t, TRPN_t) \quad (2)$$

Where *GRG, WUFL, ESTB and TROPN* represent green growth, wood fuel, sustainable environment and openness of trade. Also, the econometric specifications are as follows.

$$lnGRG_t = \gamma_0 + \gamma_1 lnWUFL_t + \gamma_2 lnESTB_t + \gamma_3 lnTRPN_t + u_t \quad (3)$$

$$lnESTB_t = \gamma_0 + \gamma_1 lnWUFL_t + \gamma_2 lnGRG_t + \gamma_3 lnTRPN_t + u_t \quad (4)$$

Where: *ln* represents natural logarithm. The γ_0 are the drift indicators of the models; while $u_t$is the residual term envisaged to be distributed normally. We anticipate γ_2 to be less than 0 in both models whereas$\gamma_1$and γ_3 to be greater than 0.

Estimation Approach

The research used the ARDL (autoregressive distributed lag) proposed by Pesaran and Shin (1999) for its analysis. This method offers several advantages. Firstly, it can be applied regardless of the stationarity level of the series. The series can be stationary at first difference, level or a combination of both, potentially eliminating the technicality associated with the unit root test. Second, the ARDL method is suitable for small sample sizes, as it can derive long-run impacts from time-series data, even with a limited number of observations. Thirdly, the ARDL enables the simultaneous estimation of both short- and long-run models, allowing for the derivation of error correction mechanisms for long-run convergence. Moreover, to ensure the reliability of the findings, other dynamic regression methods will be utilised for robust verification.

To apply the ARDL approach, the comprehensive functional and econometric equation serves as the basis from which ARDL specifications can be derived. For model 1, using equation 3, the ARDL specification is expressed in equation 5. Whereas, for model 2, equation 4 is used, and the ARDL specification is expressed in equation 6.

$$\Delta GRG_t = \gamma_{0j} + \sum_{i=1}^{n} \gamma_{1j} \Delta GRG_{t-i} + \sum_{i=1}^{n} \gamma_{2j} \Delta lnWUFL_{t-i} + \sum_{i=0}^{n} \gamma_{3j} \Delta ESTB_{t-i} + \sum_{i=0}^{n} \gamma_{4j} \Delta TRPN_{t-i} + \tau_1 GRG_{t-1} + \tau_2 lnWUFL_{t-1} + \tau_3 ESTB_{t-1} + \tau_4 TRPN_{t-1} + \mu (5)$$

$$\Delta ESBT_t = \gamma_{0j} + \sum_{i=1}^{n} \gamma_{1j} \Delta ESTB_{t-i} + \sum_{i=1}^{n} \gamma_{2j} \Delta lnWUFL_{t-i} + \sum_{i=0}^{n} \gamma_{3j} \Delta GRG_{t-i} + \sum_{i=0}^{n} \gamma_{4j} \Delta TRPN_{t-i} + \tau_1 ESTB_{t-1} + \tau_2 lnWUFL_{t-1} + \tau_3 GRG_{t-1} + \tau_4 TRPN_{t-1} + \mu \quad (6)$$

Where: Δ is first difference operator; γ_0 is the intercept; γ_1 is coefficient of the short run; τ_1 is the coefficient of the long-run variables and μ is the error term.

The bounds testing which relies on the Wald test (F-statistics) is employed to test the null hypothesis of no cointegration between wood fuel, green growth and environmental sustainability variables in Nigeria against the alternative hypothesis signifying the existence of cointegration between wood fuel and environmental sustainability variables.

$$H_o: \tau_1 = \tau_2 = \tau_3 = \tau_4 = 0$$
$$H_1: \tau_1 \neq \tau_2 \neq \tau_3 \neq \tau_4 = 0$$

According to Pesaran et al. (2001) long-run cointegration of the variables is implied if the F-statistics value is greater than I (1). Additionally, the cointegration between the variables is absent if the F-statistics value is less than I (0). Finally, the results are questionable if the F-statistics value lies between I (0) and I (1).

The error correction method (ECM) of the study is expressed in equation 7 and 8

$$\Delta lnGRG_t = \gamma_{0i} + \sum_{i=1}^{n} \gamma_{1i} \Delta lnWUFL_{t-i} + \sum_{i=0}^{n} \gamma_{2i} \Delta ESTB_{t-i} + \sum_{i=0}^{n} \gamma_{3i} \Delta TRNP_{t-i} + \partial ECT_{t-1} + \varepsilon_t \quad (7)$$

$$\Delta lnESTB_t = \gamma_{0i} + \sum_{i=1}^{n} \gamma_{1i} \Delta lnWUFL_{t-i} + \sum_{i=0}^{n} \gamma_{2i} \Delta GRG_{t-i} + \sum_{i=0}^{n} \gamma_{3i} \Delta TRNP_{t-i} + \partial ECT_{t-1} + \varepsilon_t \quad (8)$$

Where: Δ represents the first difference operator, γ represents the short-run coefficient, ∂ represents the speed of adjustment, while ECT is the error correction term which ranges between 0 and 1, and most be negative and statistically significant and ε_t is the error term.

Variables and sources of data

Data for this research will be collected from various sources including the World Bank (WDI), FAO, and NBS (national bureau of statistics), spanning from 1990 to 2023. The variables and their proxies are presented in Table 1.

Table 1:
Variables definition and sources

Variable	Definition	Source
Wood fuel consumption	Ratio of wood fuel use/total biomass X100	FOA, 2023
Green growth	GDP growth rate X share of clean energy in total energy	WDI, NBS, 2023
Environmental sustainability	Per capita CO_2 emissions	WDI, 2023
Trade openness	Percentage of trade relative to gross domestic product (export + import/GDP X100).	WDI, 2023

Source: Author`s compilation, 2025.

4.0 Result and Discussions

This research addresses a significant question of whether wood fuel consumption has effects on green growth and environmental sustainability in Nigeria.

Pre-Estimation Test

The summary statistics (mean, maximum, minimum, standard deviation, skewness, kurtosis, Jarque-Bera, and probability values) and the correlation matrix of the data set considered are displayed in Table 2. As indicated, the probability values computed for the Jarque-Bera distribution are higher than the conventional statistical significance levels, which signifies that all the variables were not normally distributed. In terms of skewness of the distribution, TRPN and WUFL were negatively skewed, whereas ESTB and GRG variables were found to be positively skewed. Also, the kurtosis statistics of the series showed that all the variables (ESTB, TRPN, and WUFL) were platykurtic, except GRG, which was found to be leptokurtic.

Table 2:
Descriptive Statistics

	GRG	ESTB	WFUL	TRPN
Mean	358.6484	0.687554	449499.4	35.36008
Median	360.1836	0.653919	440200.0	34.24085
Maximum	1295.314	0.910979	682466.0	53.27796
Minimum	-175.6308	0.501456	270791.0	16.35219
Std. Dev.	333.6118	0.110600	130160.4	9.482679
Skewness	0.529976	0.306246	0.040026	0.019658
Kurtosis	3.463806	1.846128	1.546971	2.297120
Jarque-Bera	1.896370	2.417636	3.000079	0.702079
Probability	0.387444	0.298550	0.223121	0.703956
Sample	34	34	34	34

Source: Author`s computation, 2025.

Correlation Analysis

The study applied Pearson's correlation coefficients so as to reduce the impacts of multicollinearity in the data set. For multicollinearity to occur, according to Tabachnick et al. (2007), the relationship between two explanatory variables must be more than 0.9.

Table 3:
Correlation matrix for Green Growth

	GRG	WFUL	ESTB	TRPN
GRG	1.000000			
WFUL	-0.023274	1.000000		
ESTB	-0.038940	-0.850640	1.000000	
TROPN	0.409345	-0.276228	0.344880	1.000000

Source: Author`s computation, 2025

The estimated result in Table 3 revealed a negative correlation between WUFL and ESTB with GRG, whereas a positive correlation exists between TRPN and GRG. This makes them more relevant to our estimation model. Additionally, the highest correlation coefficient of our explanatory variables is between GRG and TRPN (0.41), which is slightly below 0.9. Thus, multicollinearity cannot be considered as a significant threat to our regression analysis.

Table 4:
Correlation Matrix for Environmental Sustainability

	ESTB	GRG	TRPN	WUFL
ESTB	1.000000			
GRG	-0.034743	1.000000		
TROPN	0.360595	0.404133	1.000000	
WUFL	-0.871724	-0.058520	-0.330784	1.000000

Source: Author`s computation, 2025.

Similarly, Table 4 revealed a negative correlation between GRG, WUFL, and ESTB. While a positive correlation exists between TRPN and ESTB. Thus, this makes them more relevant to our estimation model. Additionally, the highest correlation coefficient of the explanatory variables is between ESTB and TRPN (0.36), which is slightly below 0.9. Thus, multicollinearity cannot be considered as a significant threat to the regression analysis.

Stationarity Test

The result of the stationarity tests for ADF revealed that ESTB and InWFUL have a unit root at levels but become stationary after taking their first difference. While GRG and TRPN were found to be stationary at levels, this is indicated in Table 5.

Table 5:
Results of the Stationarity Test

Variables	ADF Test		PP Test		Order of Integration
	Level	First Difference	Level	First Difference	
GRG	-3.7823*** (0.0071)	_	-3.9683*** (0.0044)	_	I(0)
lnWFUL	-1.3245 (0.6060)	-3.7604*** (0.0077)	-1.1227 (0.6950)	-3.7114*** (0.0085)	I(1)
InESTB	-1.2921 (0.6214)	-6.2833*** (0.0000)	-1.2377 (0.6461)	-6.4885*** (0.000)	I(1)
TRPN	-2.8535* (0.0619)	_	-2.8450* (0.0630)	_	I(0)
Critical values	-4.273 -3.558 -3.212	-4.394 -3.612 -3.243	-4.273 -3.558 -3.212	-4.285 -3.563 -3.215	

Note: (***), (**), and (*) represent the significant level at (1%), (5%), and (10%) respectively.
Source: Author`s computation, 2025.

The results of the PP-test also indicated that GRG and TRPN were stationary at levels. However, ESTB and InWULF have unit roots at the levels, but after first differencing, they became stationary. Thus, a mixed order of integration exists in both ADF and the PP tests, and this implies that the conditions to apply the Autoregressive Distributive Lag Model (ARDL) are satisfied.

Lag Length Selection Criteria

The lag selection criteria are important and are done by the system automatically; this will enhance robustness and the fitness of the model. Degrees of freedom will not be lost and the model will be free from traps in autocorrelation. In addition, the smaller the lag, the better the model, and the larger the lag, the less fitness the model (Akaike, 1974). The results of the lag order selection is presented in Table 6.

Table 6:
Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-288.8074	NA	3530.108	19.52049	19.70732	19.58026
1	-206.3599	137.4126*	42.59362*	15.09066*	16.02479*	15.38949*
2	-195.5786	15.09377	64.27824	15.43857	17.12001	15.97648
3	-182.8670	14.40644	94.78143	15.65780	18.08654	16.43478
4	-168.4105	12.52897	150.9053	15.76070	18.93675	16.77675

Note: * Indicates lag order selected by the criterion. LR: sequential modified LR test statistic (each test at 5% level). FPE: Final prediction error, AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-Quinn information criterion.
Source: Author`s computation, 2025.

As indicated in Table 6, the Akaike information criteria, the Schwarz information criteria, and the Hannan-Quinn criteria proposed one (1) lag as an appropriate order for the cointegration. The study uses the Akaike information criterion (15.090), which is the lowest value compared to the respective Schwarz information criteria (16.024) and Hannan-Quinn criteria (15.389).

Estimation Test

ARDL bound cointegration test

To determine the possibility of long-term relationship in the models, a bound cointegration test was employed, and the outcome is presented in Table 7. The test results revealed that, the calculated F-statistic for model 1 (5.37) and model 2 (5.73) are way above the upper and lower critical values at the 1% significant level. Therefore, the assumption that there is no cointegration among the series is rejected, meaning there is a cointegration relationship among the variables.

Table 7:

Results for ARDL Bound Test for Cointegration

Model	Dependent Variable	*F*-Stat	10% (0)	10% (1)	5% (0)	5% (1)	2.5% (0)	2.5% (1)	1% (0)	1% (1)
1	F_{GRG} (GRG| lnESTB, InWFUL,	5.37	2.37	3.2	2.79		3.15	4.08	3.65	4.66
2	TRPN)	5.73	2.37	3.2	3.67		3.15	4.08	3.65	4.66
	F_{ESTB} (ESTB| InWFUL, GRG, TRPN)				2.79					
					3.67					
K=4										

Note: k shows the number of explanatory variables. I(0) and I(1) are the Upper and lower critical values

Source: Author's computation, 2025.

In light of the existence of cointegration among the variables in both models, the findings for the long- and short-run relationship among GRG, InWFUL, lnESTB, and TRPN are indicated in Table 7. Both models were estimated by the automatic selection of a maximum lag length of 1. Using Akaike information criteria (AIC) in selecting the ideal lag order for the models and the specification settled on ARDL (1, 0, 0, 1) and (1, 1, 0, 0).

ARDL baseline result

Table 8:

Results of ARDL Long-and Short-run Analysis

Model 1 (GRG) ARDL (1,0,0,1) selected based on AIC				**Model 2** (ESTB) ARDL (1,1,0,0) selected based on AIC			
Variable	Coefficient	Std error	t-stat	variable	Coefficient	Std error	t-stat
Long run results							
lnWFUL	197.309	397.720	0.496	lnWFUL	-0.427***	0.057	-7.439
lnESTB	-324.518	744.115	-0.436	GRG	-4.950	4.791	-1.033
TRPN	25.146***	7.436	3.381	TRONP	0.006**	0.002	2.773
Constant	-3251.92	4934.703	-0.659	Constant	6.600***	0.838	7.872
Short run results							
D(TROPN)	10.65991**	5.132	2.077	D(InWFUL)	-2.063***	0.391	-5.276
CointEq(-1)*	-0.782***	0.141	-5.553	CointEq(-1)*	-0.621***	0.108	-5.747
R^2	0.50			R^2	0.53		
F-stat. p-value	0.000***			F-stat. p-value	0.000***		

Note: (***), (**), and (*) represent the significant level at (1%), (5%), and (10%) respectively.

Source: Author's computation, 2025.

In model 1, the coefficient of wood fuel consumption in the long term is positive but statistically insignificant, indicating that it does not have a meaningful effect on green growth at any conventional significance level. Nevertheless, based on theoretical expectations and a

prior studies, it is anticipated that excessive wood fuel usage could adversely affect green growth by contributing to deforestation, resource depletion, and environmental degradation, which undermine sustainable economic development. This is not similar to the work of Sulaiman and Abdul-Rahim (2020), who found a negative and statistically significant relationship between wood fuel consumption and economic growth. Similarly, the coefficient of environmental sustainability is negative in influencing green growth in both the short and long run, but it is not statistically significant at any conventional level. This indicates that changes in environmental sustainability do not have a meaningful impact on green growth within the study period, although the negative sign suggests a potential inverse relationship that may warrant further investigation. Although the findings conform with the a priori expectation, it is also similar to the findings of Oyebanji et al. (2017), who examined green growth and environmental sustainability in Nigeria.

Additionally, the coefficient of trade openness has a positive and significant influence on green growth at the 5% level. This means a 1% rise in trade openness will lead to about a 25.15% increase in activities that contribute to green growth in the study area. This suggests that trade openness facilitates the transfer of environmentally friendly technologies and green innovations, which can accelerate the transition to a more sustainable and low-carbon economy. However, this is not in tandem with the findings in the work of Sulaiman et al. (2017), who found a negative and statistically insignificant relationship to environment. While, in the short term, trade has a significant positive influence on green growth at a 5% level. The coefficient of trade openness (10.660) implies that a 1% increase in trade will have about a 10.66% influence on green growth. This aligned with the a priori expectation.

In model 2, the coefficient of wood fuel usage in the long term is negative and significant at the 1% level of significance. This means a 1% increase in wood fuel consumption will lead to a -0.427% decrease in environmental well-being. This indicates that greater wood fuel consumption worsens environmental sustainability; this conforms with the current situation in the county. This is similar to the work of Sulaiman and Abdul-Rahim (2020), who discovered a negative and significant connection between the use of wood fuel and economic growth. Similarly, the coefficient of green growth is negatively related to environmental sustainability; this implies that a 1% increase in green growth will lead to about a -4.950% decrease in the environment. However, this effect is statistically insignificant at all conventional significance levels, indicating that green growth does not exert a meaningful influence on environmental sustainability in the long run. The negative but insignificant coefficient suggests that Nigeria's green-growth initiatives may be insufficiently developed or ineffectively implemented, resulting in no detectable environmental benefits within the study period. Although the findings conform to the a priori expectation. However, this is not in support of findings in the study by Danish and Ulucak (2020).

Additionally, the coefficient of trade openness is positive and statistically significant at the 5% level. This indicates that a 1% increase in trade openness is associated with a 0.006% improvement in environmental sustainability. The result suggests that greater integration into international markets may promote access to cleaner technologies, renewable-energy infrastructure, and environmentally friendly innovations, thereby supporting ecological preservation. However, this is not in tandem with the findings in the work of Sulaiman et al. (2017), who found a negative and statistically insignificant relationship to environment.

Consequently, in the short term, wood fuel consumption negatively affects environmental sustainability in the study area. The estimated coefficient of wood fuel usage (-2.063) indicates that a 1% increase in wood fuel usage is associated with approximately a 2.063% decline in environmental quality. The negative impact reflects the unsustainable reliance on wood fuel,

which contributes to deforestation, air pollution, and other forms of environmental degradation, particularly in areas lacking access to modern and cleaner energy alternatives. This coincides with the previous study by Nguyen et al. (2023), which stated that any increase in consumption of natural resources will negatively affect the environmental sustainability.

Similarly, the coefficients of the error-correction term for both green growth (model 1) and environmental sustainability (model 2) were negative and statistically significant, implying that there is a long-term link between the variables. The coefficient of ECM of green growth is -0.782 and statistically significant at the 1% level, demonstrating that any departure from the long-term equilibrium between wood fuel consumption and green growth can be corrected and recovered annually at 78%. Whereas the coefficient of ECM for environmental sustainability is -0.621, which is statistically significant at the 1% level, demonstrating that any departure from the long-term equilibrium between the use of wood fuel energy and the environment can be corrected and recovered at 62% annually. The coefficient of the R-squared also suggests that the explanatory variables explained almost 50% of the variation in the dependent variables. The F-statistics' probability value further indicated that the ARDL models are well described.

Post-estimation test

As shown in Table 9, various diagnostic procedures were employed to find the model's shortcomings. There are no problems of heteroscedasticity and serial correlation in the model. However, in model 1 the Jarque-Bera test indicated the model is not normally distributed. The models are correctly specified according to the Ramsey RESET test.

Table 9:
Diagnostic Tests

Tests	Chi-Squared (P-value)	Tests	Chi-Squared (P-value)
Green Growth		Environmental Sustainability	
Breusch-Pagan-Godfrey	1.007 (0.393)	Breusch-Pagan-Godfrey	0.544 (0.695)
ARCH test	0.5566 (0.5416)	ARCH test	0.158 (0.682)
Breusch-Godfrey test	0.2354 (0.7371)	Breusch-Godfrey test	0.701 (0.350)
Ramsey RESET test	1.2787 (0.2685)	Ramsey RESET test	1.020 (0.322)
Jarque-Bera test	9.379 (0.009)	Jarque-Bera test	0.556 (0.757)

Source: Author's computation, 2025.

Furthermore, to assess the stability of the estimated model, the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUM Squares) tests were used. For model 1 (green growth), the coefficients of CUSUM and CUSUM Square as indicated in figure 1 and 2 are clearly within the model's upper and lower critical bounds at the 5% level. Hence, the study concludes that model 1 is reasonably stable during the study period.

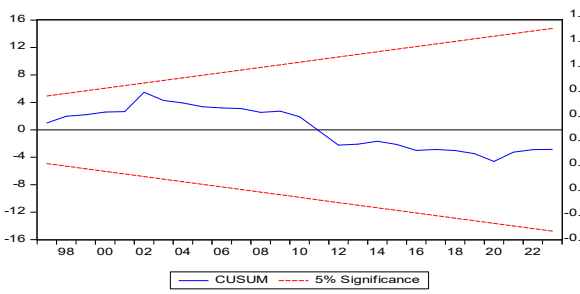


Figure 1: Plot of CUSUM Test

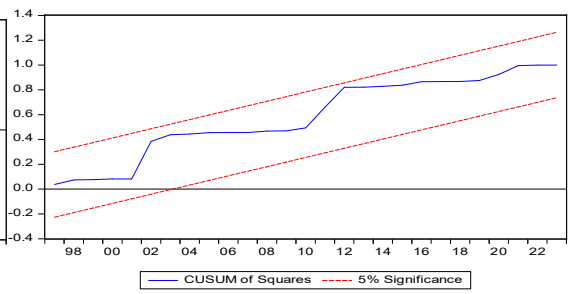


Figure 2: Plot of CUSUM of Squares Test

Similarly, for model 2 (environmental sustainability) the coefficient of CUSUM and CUSUM Square as indicated in figure 3 and 4 are clearly within the model's upper and lower critical bounds at the 5% level. As a result, it is concluded that the model was reasonably stable during the study period.

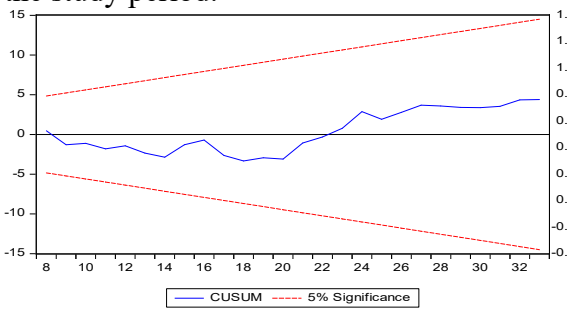


Figure 3: Plot of CUSUM Test

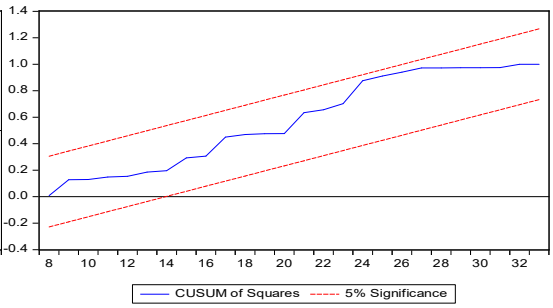


Figure 4: Plot of CUSUM of Squares Test

5.0 Conclusion

This study explores the effect of wood fuel consumption on green growth and environmental sustainability in Nigeria, using annual data from 1990 to 2023. The study employed the ADF and PP tests to investigate the stationarity level of the variables, and the estimation reveals a mixed outcome. The study applied the Autoregressive Distributive Lag (ARDL) model for estimation of the models, and the empirical results for the bound cointegration test show the existence of long-run associations between wood fuel consumption, green growth and environmental sustainability with F-statistics of 5.37 and 5.73 respectively. In the long run empirical result in model 1, only trade openness is found to be positively related to green growth. However, wood fuel and environmental sustainability were not significant in influencing green growth. Similarly, in the short run, an increase in trade openness has a positive influence on green growth. Moreover, in model 2, the study found that an increase in the use of wood fuel energy in the long run has a detrimental impact on environmental sustainability, whereas the influence of green growth on the environment was negative, though not statistically significant. Also, trade openness is found to be positively related to the environment in the long run. Similarly, in the short run, an increase in wood fuel consumption has a detrimental impact on environmental sustainability.

The empirical outcomes provide partial support for the EKC in Nigeria. The insignificance of green growth in improving environmental quality suggests that Nigeria may still be at the early phase of the EKC, where economic expansion driven by resource-based and energy-intensive activities leads to environmental deterioration. The negative and significant impact of wood fuel consumption on environmental sustainability reinforces this interpretation, indicating that traditional biomass use continues to undermine environmental quality and delay the transition toward the downward (improvement) side of the EKC curve. The findings of the diagnostic testing of the ARDL models highlighted that the study is free of serial correlation, heteroscedasticity, and misspecification bias, and the error terms follow a normal distribution for model 2, and model 1 is not normally distributed. The models were stable, according to the CUSUM and CUSUM of squares tests, because they both fell under the 5% limit.

The study recommends expanding access to affordable energy alternatives and strengthening environmental governance frameworks by providing subsidies and tax relief for clean cooking technologies such as LPG, solar cookstoves, and improved biomass stoves to reduce household dependence on wood fuel. Strengthen forest management and enforcement mechanisms to regulate wood harvesting, promote reforestation, and improve coordination among environmental institutions. Trade policy should continue to encourage the importation of clean

energy technologies, renewable-energy infrastructure, and climate-friendly innovations. Households should be educated through an awareness campaign on the health risks of wood fuel use and the benefits of adopting clean energy alternatives. Although the study provides important empirical insights, it is not free from limitations. The analysis depends solely on secondary data obtained from national and international statistical sources. The study employs country-level aggregate indicators, which may obscure substantial regional and household-level variations in wood fuel dependence and environmental conditions across Nigeria. As a suggestion for further studies, there is need for on the causal link between sustainable environment, green growth and wood fuel consumption in Nigeria.

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