THE INTERPLAY OF RENEWABLE ENERGY, INSTITUTIONAL QUALITY, AND CONSUMPTION-BASED CO_2 EMISSIONS: AN EMPIRICAL ANALYSIS OF NIGERIA

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ABSTRACT

This study examine the mediating effect of institutional quality on the relationship between renewable energy and consumption-based co_2 emissions in Nigeria. The study utilizes Autoregressive Distributed Lag Model (ARDL) using a time series data from 1996 to 2024. The results show that institutional quality plays a crucial role in strengthening the effectiveness of renewable energy in reducing CO_2 emissions in the long run. Strong institutions ensure better governance, regulatory frameworks, and policy enforcement, which enhance the efficiency of renewable energy projects. Furthermore, the short run interaction term between renewable energy and institutional quality has a negative but statistically insignificant coefficient the negative sign suggests that higher institutional quality may still enhance the effectiveness of renewable energy in reducing CO_2 emissions. The study recommends that, Nigeria should strengthen institutional frameworks, improve policy implementation, and invest in renewable energy infrastructure in order to achieve sustainable emissions reduction. In addition, the long-term benefits of renewable energy can be amplified by addressing governance challenges, improving regulatory enforcement, and ensuring transparency in the energy sector.

Keywords: *Consumption-Based Co_2 Emissions, Institutional Quality, Renewable Energy, ARDL, Gross Domestic Product.*

1. INTRODUCTION

Rising levels of greenhouse gases, particularly carbon dioxide (CO_2), have become a pressing global environmental concern. Energy generation and utilization contribute approximately 75% of greenhouse gas emissions, yet fossil fuels continue to dominate the world's energy supply (IPCC, 2022). Climate change manifests through rising temperatures, extreme weather events, and environmental degradation, threatening food security, healthcare systems, and economic stability.

Renewable energy has gained attention as a sustainable alternative to fossil fuels, while improvements in governance and institutional quality are critical for ensuring effective energy transitions (Sato, 2014).

As Africa's largest economy and most populous nation, Nigeria plays a dual role in the climate crisis as both a significant emitter and a vulnerable country. The nation faces persistent power shortages while attempting to reduce CO_2 emissions. Despite abundant renewable energy resources, including solar, hydropower, and wind, Nigeria relies primarily on fossil fuels, resulting in substantial consumption-based emissions (He & Wei, 2023). Effective governance, transparent policies, and accountable institutions are crucial to mitigating emissions. However, the Nigerian energy sector suffers from institutional weaknesses, corruption, and erratic policy implementation (Adams, Klobodu, & Opoku, 2016).

This study investigates how institutional quality mediates the relationship between renewable energy and consumption-based CO_2 emissions in Nigeria. The focus on Nigeria is justified for two reasons. First, Nigeria is among the largest CO_2 emitters in sub-Saharan Africa due to its dependence on fossil fuels, which account for over 80% of energy production across industrial, transport, and household sectors (Oyedepo, 2019). Rising population and economic growth further increase consumption-based emissions, which account for the carbon embedded in domestic goods and imported products (Sato, 2014). Second, Nigeria's extensive renewable energy potential remains underutilized due to weak institutions, inconsistent policies, and pervasive corruption (Adams et al., 2020).

This study contributes to literature in several ways. It is the first, to the researcher's knowledge, to examine the mediating role of institutional quality in Nigeria's renewable energy–CO_2 emissions relationship. Prior studies, including Fagge et al. (2023) and Dansofo et al. (2024), focus on direct impacts of renewable energy, while Ahmed et al. (2020) and Bokpin (2020) analyze institutional quality effects without exploring mediation. Methodologically, this study employs an Autoregressive Distributed Lag (ARDL) model to capture both short-run and long-run dynamics. Unlike panel data studies (Amuakwa-Mensah & Adom, 2020; Alshubiri & Elheddad, 2020), the ARDL model accommodates variables integrated at different orders (I(0) or I(1)), allowing for robust country-specific insights.

Finally, this study leverages a comprehensive time-series dataset from 1996 to 2024, offering an updated analysis that reflects recent policy developments, energy system changes, and governance measures. Compared with earlier studies (Fagge et al., 2023; Dansofo et al., 2024), this approach provides more relevant and timely insights. The findings are expected to inform policymakers in designing sustainable environmental strategies and improving institutional frameworks to enhance renewable energy adoption while reducing consumption-based CO_2 emissions in Nigeria.

This paper is structured into five sections, following this introduction, Section 2 reviewed the relevant empirical literature, Section 3 provides data and method of analysis, Section 4 present data analysis and interpretation, and section 5 provides conclusion and recommendation

2. LITERATURE REVIEW

This section presents a literature review on economic growth, institutional quality, and renewable energy in relation to carbon emissions. It highlights key empirical findings, theoretical perspectives, and research gaps, providing a foundation for this study's analytical framework.

2.1 Economic Growth and Carbon Emissions

Research exploring the relationship between economic growth and carbon emissions largely revolves around the Environmental Kuznets Curve (EKC) hypothesis, which posits that pollution rises during early stages of economic development but declines as nations achieve higher income levels. Studies by Pata and Aydin (2020) and Al-Mulali et al. (2015) highlight that renewable energy, particularly hydroelectric power, reduces carbon emissions in both developed and developing countries such as Vietnam. Dogan and Turkekul (2016) find that economic growth in the USA aligns with the EKC, with financial development and trade openness further reducing pollution. Cross-country analyses by Acheampong (2018) and Saidi and Hammami (2016) indicate that while economic growth has a two-way relationship with emissions in high-income countries, it generally increases emissions in developing economies. Zafar et al. (2020) also argue that American economic expansion increases ecological footprints, challenging the assumption that growth naturally supports sustainability. Recent studies emphasize the role of financial development in mitigating emissions: Shahbaz et al. (2013) and Apergis and Ozturk (2015) show that financial development fosters green investments that reduce carbon emissions, whereas Balsalobre-Lorente et al. (2021) note that industrial sectors like aviation may grow economically while increasing pollution.

2.2 Institutional Quality and Carbon Emissions

Institutional quality is a critical determinant of environmental outcomes. Strong institutions enforce regulations, guide financial investments toward sustainable projects, and reduce carbon emissions, whereas weak governance exacerbates environmental degradation. Ahmed et al. (2020) use asymmetric ARDL co-integration to demonstrate that in Pakistan, stronger institutional systems reduce emissions, while weak institutions cause environmental damage. Bayar and Maxim (2020) find that financial development increases CO_2 emissions in post-transition EU countries, but strong institutions mitigate these effects through sustainable integration. Similarly, Amuakwa-Mensah and Adom (2020) confirm that robust institutions improve forest management and energy regulations in sub-Saharan Africa, reducing carbon emissions. Assa (2020) shows poor governance accelerates deforestation and greenhouse gas emissions, while good governance supports sustainable resource management. Bokpin (2020) highlights that strong institutions channel foreign direct investment into environmentally friendly projects in Africa, decreasing emissions. Alshubiri and Elheddad (2020) report that OECD countries with effective institutions manage foreign investments optimally, promoting green technology adoption and emission reduction. Overall, strong governance and institutional quality are essential to enforcing environmental regulations, guiding sustainable investments, and mitigating carbon emissions.

2.3 Impact of Renewable Energy on Carbon Emissions

Empirical studies show renewable energy consumption significantly affects carbon emissions in both the short and long term. Fagge et al. (2023), using ARDL analysis for Nigeria (1980–2019), find a long-term negative relationship between renewable energy and CO_2 emissions, while short-term deployment may initially increase emissions due to infrastructure demands. Dansofo et al. (2024) emphasize the urgent need to transition from fossil fuels to renewables to reduce environmental degradation in Nigeria. Global evidence supports similar trends: Zafar et al. (2020) show that human capital and FDI help reduce the ecological footprint in the USA, Dogan and Turkekul (2016) confirm that renewable energy decreases US emissions, and Al-Mulali et al. (2015) and Pata and Aydin (2020) validate the EKC hypothesis, noting that renewable energy adoption moderates emissions during economic growth.

Few studies explicitly examine how institutional quality mediates the renewable energy–emissions relationship, especially for Nigeria. Most Nigerian research (Fagge et al., 2023; Dansofo et al., 2024) focuses on direct impacts of renewable energy, neglecting governance effects. Additionally, prior studies largely employ panel data (Amuakwa-Mensah & Adom, 2020; Alshubiri & Elheddad, 2020), limiting country-specific insights. This study addresses these gaps by using an ARDL model (1990–2024) to examine institutional quality's mediating role, providing evidence on how governance shapes renewable energy's effectiveness in reducing consumption-based CO_2 emissions in Nigeria.

3. METHODOLOGY

This study evaluates how institutional quality mediates the relationship between renewable energy and consumption-Based CO_2 emissions in Nigeria using a 28-year time series data from 1996 to 2024. Data used for consumption-Based CO_2 emissions, renewable energy, Gross Domestic product, and population were obtained from World Development Indicators (https://databank.worldbank.org/source/world-development-indicators). While quality of governance was measured using the Institutional Quality Index provided by the World Bank. The following Table provides the summary of the variables and their measurement.

Table 1 Variables Definition

Variable	Definition	Source
Consumption-Based CO2 Emissions (CCO2)	This refers to the total carbon emissions associated with goods and services consumed within a country, including imported emissions. It is measured in metric tons per capita or total	World Development Indicators

	emissions using input-output models and carbon accounting frameworks.	
Renewable energy (RE)	Renewable Energy (RE) refers to energy derived from naturally replenishing sources like solar, wind, hydro, and biomass. It is measured as the percentage of total energy consumption or electricity generation from renewable sources, typically reported in terawatt-hours (TWh) or percentage terms	World Development Indicators
Gross Domestic product growth rate (GDP)	Gross Domestic Product (GDP) growth rate measures the percentage change in a country's economic output over a specific period. It is calculated using real GDP, adjusted for inflation, and expressed as an annual or quarterly percentage change	World Development Indicators
Population growth rate (POP)	Population Growth Rate (POP) measures the annual percentage increase in a country's population, considering births, deaths, and net migration	World Development Indicators
Quality of governance (IQ)	Measured using the Institutional Quality Index provided by the World Bank	World Bank

3.1 Model Specification

This study adopts the model of Almulhim, Inuwa, Chaouachi, and Samour (2025) on the impact of renewable energy use, institutional quality, and production expansion on consumption based carbon dioxide (CCO2) emissions in BRICS countries, which is specified as;

$CCO2_{it} = f(GDP,\ RE,\ IQ)$..(1)

Where; CCO2 represents consumption-based carbon emissions in million tons, GDP per capita represents economic growth, RE stands for renewable energy consumption, and IQ demonstrates the Index of Institutional Quality. Given that this study is time series focusing on Nigeria, we modified this model and include our interaction variable between institutional quality and renewable energy. In addition, this study provides additional control variable like population growth. Population growth significantly impacts consumption-based CO_2 emissions by increasing energy demand, industrialization, and resource consumption (Wang et al., 2022). The model is specified below;

$$CCO2_t = \lambda + \lambda_1 RE_t + \lambda_2 IQ_t + \lambda_3 (RE_t * IQ_t) + \lambda_4 GDP_t + \lambda_5 POP_t + u_t \ldots \ldots (2)$$

Where; $RE_t * IQ_t$ captures the interaction effect between renewable energy and institutional quality, indicating whether governance quality strengthens or weakens the impact of renewable energy on CO_2 emissions. POP is the population growth rate and u_t is the error term. Λ is the constant term, λ_1, λ_2, λ_3, λ_4, and λ_5 are the coefficients estimated and t is the time period.

3.2 Autoregressive Distributed Lag (ARDL) Specification

Mediating the effect of Institutional Quality on the Relationship between renewable energy and consumption-Based CO_2 emissions in Nigeria was examined using the Autoregressive Distributed Lag (ARDL) model to estimate the model's parameters. Among econometric models the ARDL model stands out for its exceptional characteristics. The ARDL model proves beneficial through its dual capability to examine short-term and long-term variable relationships in economic analysis. The modeling process becomes simpler because the ARDL model avoids requiring precedent unit root or cointegration tests. The model's direct interpretability delivers economic meaning to its coefficients to support policy analysis and model building. The ARDL Bound testing method examined the existence of long-run variable relationships. Due to co-integration analysis's deficient power properties Pesaran and Shin (1999) introduced the ARDL bounds testing methodology which researchers now prefer above methods from Engle and Granger (1987) and Johansen and Juselius (1990). This method maintains its effectiveness when dealing with mixed integration datasets (Shrestha & Chowdhury, 2007).

The generalized ARDL(p,q) model is specified as follows:

$$CCO2_t = \gamma_0 + \sum_{i=1}^{p} \delta_i \boldsymbol{\Delta} CCO2_{t-1} + \sum_{i=0}^{q1} \beta_{1i}\, \boldsymbol{\Delta} RE_{t-i} + \sum_{i=0}^{q2} \beta_{2i}\, \boldsymbol{\Delta} IQ_{t-i} + \sum_{i=0}^{q3} \beta_{3i}\, \boldsymbol{\Delta}(RE \times IQ)_{t-i} + \sum_{i=0}^{q4} \beta_{4i}\, \boldsymbol{\Delta} GDP_{t-i} + \sum_{i=0}^{q5} \beta_{5i} \boldsymbol{\Delta} POP_{t-i} + \lambda_1 CCO2_{t-1} + \boldsymbol{\lambda}_2 RE_{t-1} + \lambda_3 IQ_{t-1} + \lambda_4 (RE \times IQ)_{t-1} + \lambda_5 GDP_{t-1} + \lambda_6 POP_{t-1} + e_t \dots\dots\dots\dots\dots\dots (equ\ 3)$$

Where, the first-difference terms (Δ) capture short-run effects, the lagged level variables capture the long-run relationship and form the basis for the bounds cointegration test, and the coefficients λ, and $\lambda_1 - \lambda_6$ jointly test the existence of a long-run equilibrium.

4. RESULT AND DISCUSSION

4.1 Summary Statistics

The statistics in Table 4.1 reveal key information about how the variables distribute themselves and what traits they possess. The average CO_2 emissions display moderate levels at 105.03 while values reach from 78.03 to 134.43. Renewable energy (RE) demonstrates a low mean value (1.059) along with major distribution towards lower ends as shown by its high skewness (1.33). Institutional quality exhibited a negative overall mean value (-0.957) for the duration of the study period as institutions weakened but the distribution was skewed strongly rightward (1.50).

Statistics on population growth (POP) reveal a steady mean about 2.558 together with small dispersion (Std. Dev = 0.257) and a slightly left-skewed distribution (-0.886). The volatile nature of GDP leads to higher data dispersion (Std. Dev = 3.4529) as it reaches up to 15.329 but falls down to -1.7942 during periods of analysis. RE and IQ demonstrate non-normal distributions based on the Jarque-Bera test results but CO_2 POP and GDP distributions follow normal patterns.

Table 4.1 Summary statistics

	CO2	RE	IQ	POP	GDP
Mean	105.03	1.059	-0.957	2.558	4.6362
Median	102.58	0.4113	-1.00	2.642	4.2300
Maximum	134.43	3.8025	-0.34	2.802	15.329
Minimum	78.033	0.2744	-1.213	2.092	-1.7942
Std. Dev.	14.034	1.1234	0.230	0.257	3.4529
Skewness	0.1220	1.3322	1.4977	-0.886	0.6680
Kurtosis	2.3002	3.3865	4.3977	2.224	4.6313
Jarque-Bera	0.6636	8.7593	13.203	4.5217	5.3728
Probability	0.7176	0.0125	0.0013	0.1042	0.0681
Sum	3046.15	30.734	-27.757	74.192	134.450
Sum Sq. Dev.	5515.43	35.3391	1.4894	1.85193	333.838
Observations	29	29	29	29	29

Source: Generated using EVIEWS 13

4.2 Test of Stationarity

The Augmented Dickey-Fuller (ADF) test found in Table 4.2 shows the stationarity of the variables. The probability values exceeding 0.05 indicate that CO_2 emissions (CO_2) renewable energy (RE) and institutional quality (IQ) are non-stationary at levels. The variables achieve stationary status after first differencing while showing significant p-values which proves their I(1) integration. The tests demonstrate that these variables contain unit roots which need differencing to transform them into stationary data. The results indicate that GDP and population growth (POP) maintain stationary status because their level form p-values are below 0.05. I(0) integration applies to these variables which indicates they do not need to be differenced. The mixed set of I(0) and I(1) variables supports the use of ARDL because it functions well to study relationships between variables that have different integration orders. The findings confirm that I(2) variables do not exist among the sample variables since I(2) status would make the ARDL approach invalid.

Table 4.2 Augmented Dickey Fuller Test (ADF)

Variables	ADF test stat				Oder of integration
	At level	Prob	At first diff.	Prob	
CO2	-0.5736	0.8612	-6.0105	0.0000	Stationary at first Difference I(1)
RE	-2.6244	0.8525	-5.3560	0.0057	Stationary at first Difference I(1)
IQ	-1.3719	0.4565	-5.8487	0.0000	Stationary at first Difference I(1)

GDP	-3.1617	0.0197	-4.6329	0.0000	Stationary at first Level I(0)
POP	-3.3408	0.0764	-7.5778	0.0000	Stationary at first Level I(0)

Source: Generated using EVIEWS 13

4.3 Cointergration Test

Table 4.3 provides the ARDL Bounds Test to determine if the analyzed variables display a long-run relationship. The produced F-statistic stands at 3.45 and crosses both I(0) and I(1) critical values. The result shows that under the 5% significant level the minimum value (I(0)) reaches 2.91 while the maximum (I(1)) touches 4.193. The test results remain ambiguous because the F-statistic exists between the established bounds which prevents establishing either cointegration or exclusion. A long-run relationship among variables becomes plausible through the F-statistic value which exceeds 3.517 at the 10% significance level. There exists a long run relationship between Renewable Energy, Institutional Quality, CO_2 Emissions, GDP, and Population Growth.

Table 4.3 Results of ARDL Bounds Test

Null hypothesis: No levels relationship						
Test Statistic						Value
F-statistic						3.45
	10%		5%		1%	
Sample Size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	2.407	3.517	2.91	4.193	4.1340	5.761
Asymptotic	2.08	3	2.39	3.38	3.06	4.150

Source: Generated using EVIEWS 13

4.4 Mediating Effect of Institutional Quality on the Relationship between Renewable Energy and Consumption-Based CO_2 Emissions in Nigeria

Table 4.4 reveals how renewable energy (RE) affects consumption-based CO_2 emissions (CO_2) through institutional quality (IQ) in Nigeria based on the results of ARDL long-run coefficients. Results from the interaction term (RE*IQ) show that institutional quality helps renewable energy decrease CO_2 emissions significantly in the long term ($p < 0.01$, coefficient=-0.558452). Powerful institutions produce better governance outcomes resulting in effective regulatory systems alongside policy implementation which boosts renewable energy project efficiency. Open and corruption-free institutions lead to increased environmental advantages from renewable energy investments by ensuring maximum resource efficiency and appropriate distribution of resources. The work of Omri and Nguyen (2014) demonstrates that institutional quality creates better emission reductions through renewable energy adoption in developing countries. According to Wang et al. (2021) well-functioning governance systems strengthen renewable energy policy efficiency because they support investments and promote technological adoption and regulatory compliance. Research findings show that inadequate institutions function as barriers for renewable energy to achieve environmental benefits while well-developed frameworks enhance its capability for emission reduction.

The result shows that rising renewable energy (RE) consumption directly lowers CO_2 emissions through its direct effects which amount to -0.310930 ($p < 0.05$). The direct impact of institutional quality coefficient is negative and statistically significance, this shows that a unit improvement in institutional quality will reduce CO_2 emissions by 0.205733 on average. This corroborates the findings of Farhani et al. (2014), who showed that institutional quality is essential in controlling emissions by ensuring proper enforcement of environmental policies.

The analysis reveals that GDP shows a critical role which determines emission levels through its coefficient value of 0.147145 ($p < 0.01$). The findings agree with the Environmental Kuznets Curve (EKC) hypothesis which states that emissions increase alongside economic development until they start to decrease. Al-Mulali and Ozturk (2015) discovered in developing nations a direct positive link between GDP and CO_2 emissions which supports these present findings.

The positive relationship between CO_2 emissions and population growth becomes evident through the value of 0.307464 ($p < 0.05$) which measures the coefficient of population growth (POP). Liddle and Lung (2010) established that demographic expansion leads to higher emissions across both developed and developing economic systems.

Table 4.4 Long-run ARDL coefficients, Dependent variable: CO2

Variables	**Coefficient**	**Stand. error**	**t-stat**	**Prob.**
RE*IQ	-0.558452	0.090376	-6.1848	0.0000
RE	-0.310930	0.109810	-2.8315	0.0151
IQ	-0.205733	0.055252	-3.7236	0.0003
GDP	0.147145	0.055032	2.67172	0.0031
POP	0.307464	0.117089	2.6259	0.0221
Constant	-0.307464	0.117089	-2.625906	0.0221

Source: Generated using EVIEWS 13

The short-run results in Table 4.8 reveal the dynamic relationships between consumption-based CO_2 emissions (CO_2) and key determinants, including renewable energy, institutional quality, GDP, population growth, and their interactions. Past CO_2 emissions significantly influence current levels, with a coefficient of 0.511 ($p < 0.01$), indicating persistence over time. Renewable energy reduces emissions in the short run (-0.757, $p = 0.0697$), reflecting early-stage benefits as infrastructure and policies begin to take effect, consistent with Saidi and Omri (2020). The interaction between renewable energy and institutional quality is negative but statistically insignificant (-0.286, $p = 0.1526$), suggesting that higher institutional quality could enhance renewable energy's effectiveness, although short-run impacts are limited due to policy and regulatory lags (Omri & Nguyen, 2014). Institutional quality alone shows a positive yet insignificant effect (0.023, p = 0.0827), indicating that governance improvements primarily influence emissions in the long term (Wang et al., 2021). Economic growth strongly increases CO_2 emissions (0.791, $p < 0.01$), supporting evidence that industrialization drives environmental pressures in developing countries (Sadorsky, 2009; Pata, 2021). Population growth also raises emissions (0.218, $p < 0.01$), aligning with findings that higher energy demand in urban areas contributes to environmental stress (Liddle, 2015). The model demonstrates high explanatory power ($R^2 = 0.963$), passes autocorrelation checks (Durbin-Watson = 2.729), and is significant overall (F = 6.768).

Table 4.8: Short-run coefficients, Dependent variable: CO2

Variables	Coefficient	Stand. error	t-stat	Prob.
D(CO2(-1))	0.510987	0.095628	5.343502	0.0001
D(RE*IQ)	-0.286359	0.195417	-1.465371	0.1526
D(RE(-1))	-0.757401	0.380336	1.991397	0.0697
D(IQ(-2))	0.023014	0.004714	4.931211	0.0827
D(GDP)	0.791091	0.270200	2.927795	0.0062
D(POP)	0.218006	0.049431	4.883133	0.0000
ECM(-1)	-0.415878	0.053674	-7.748170	0.0000
R-Square = 0.962890 Durbin-Watson = 2.729 F-Stat. = 6.768				

Source: Generated using EVIEWS 13

4.5 Post Estimation Diagnostic Tests

Table 4.9 : Heteroskedasticity Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
Null hypothesis: Homoskedasticity			
F-statistic	0.871469	Prob. F(18,12)	0.6153
Obs*R-squared	17.56382	Prob. Chi-Square(18)	0.4847
Scaled explained SS	3.246195	Prob. Chi-Square(18)	0.9999

Source: Generated using EVIEWS 13

The Breusch-Pagan-Godfrey heteroskedasticity test verifies that the assumption of homoskedasticity remains valid. Results from the analysis show an F-statistic value of 0.871469 together with a p-value of 0.6153 while the Obs*R-squared value reveals 17.56382 with a p-value of 0.4847. The scaled explained sum of squares demonstrates a p-value measuring at 0.9999. The model demonstrates no signs of heteroskedasticity through the high values of its p-values exceeding 0.05 thus showing the residuals' variance remains consistent across all observations.

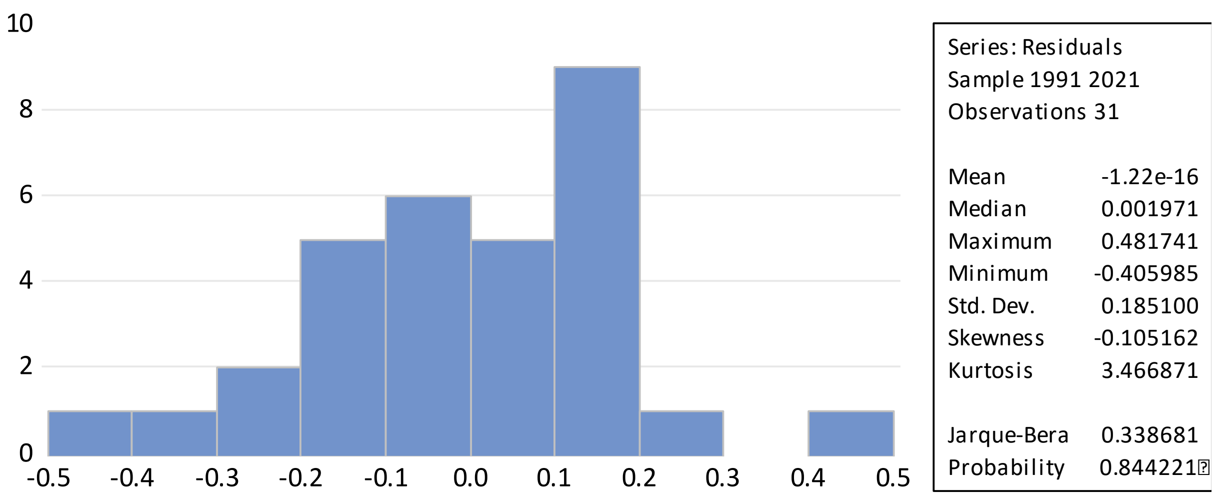
Tabe 4.10: Breusch-Godfrey Serial Correlation LM Test

Breusch-Godfrey Serial Correlation LM Test:			
Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	10.94724	Prob. F(2,10)	0.1985
Obs*R-squared	11.49756	Prob. Chi-Square(2)	0.2132

Source: Generated using EVIEWS 13

The Breusch-Godfrey Serial Correlation LM Test results demonstrate that residuals maintain no significant serial correlation throughout up to two lags in the model. The F-statistic value is 10.94724 along with a p-value of 0.1985 and the Obs*R-squared value stands at 11.49756 with a p-value of 0.2132. The observed p-values exceeding 0.05 allow us to confirm that serial correlation does not exist in the analyzed values. The model demonstrates no substantial autocorrelation among residuals during up to two lags which ensures that serial correlation does not affect the results.

Normality Test



This indicates that the model is stable and normally distributed**.**

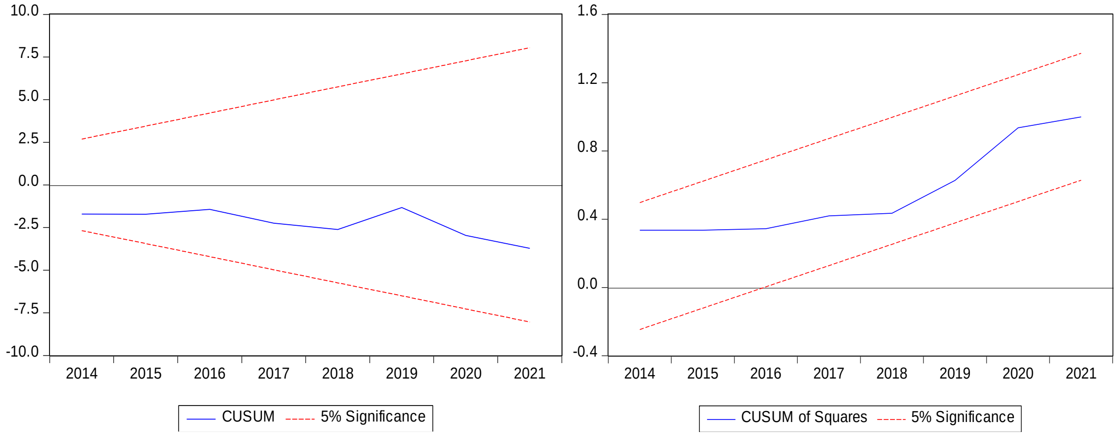


Figure 1: Plots for the CUSUM and CUSUM of Squares

A test using CUSUM and CUSUMSQ methods on recursive residuals analyzes the stability of short-run coefficients following the methodology proposed by Brown et al. (1975). The CUSUM and CUSUMSQ displayed in Figure 4.2 demonstrate test statistics staying within 5 percent confidence limits which implies that coefficients throughout the sample period maintain consistent stability as well as essential statistical properties.

4.6 Discussion

The relationship between institutional quality (IQ) and renewable energy (RE) is crucial in determining the dynamics of CO_2 emissions, especially in Nigeria, where environmental sustainability is greatly influenced by governance structures. The short-term results show that although the interaction term (D(RE*IQ)) has a negative coefficient, it is not statistically significant, indicating that the efficiency of renewable energy in lowering CO2 emissions is not immediately improved by institutional quality. This is consistent with the findings of Omri and Nguyen (2014), who noted that institutional reforms have gradual effects that become more noticeable over time. The long-term results show that institutional quality enhances renewable energy's capacity to reduce emissions, notwithstanding the short-term insignificance. This supports the claim that stable policies, strong regulations, and secure investments are all facilitated by good governance, all of which maximize the environmental advantages of renewable energy (Wang et al., 2021). Corruption and ineffective regulations frequently impede the shift to sustainable energy sources in nations with weak institutions, which lowers the efficacy of renewable energy policies (Farhani et al., 2014).

Like many developing economies, Nigeria has governance issues that may affect how well investments in renewable energy work. The potential of renewable energy sources to reduce CO_2 emissions is frequently limited by the existence of corruption, lax enforcement of environmental regulations, and inconsistent energy policies (Adebayo et al., 2022). In order to diversify its energy sources, Nigeria, for example, adopted the Renewable Energy Master Plan (REMP); however, because of a lack of institutional capacity, implementation is still proceeding slowly (Ibrahim et al., 2021). In order to ensure that money allotted for renewable energy projects is used efficiently, strengthening institutions can increase accountability and transparency in energy-related investments (Adegbite et al., 2023).

The direct impact of renewable energy on CO_2 emissions in the short run, though negative, suggests that increasing renewable energy consumption has an immediate effect on emissions reduction. However, the magnitude of this effect is smaller compared to the long run, which is consistent with Saidi and Omri (2020), who found that renewable energy deployment takes time to scale up and replace fossil fuel-based sources. In Nigeria, the renewable energy sector remains underdeveloped, with limited infrastructure and high dependence on fossil fuels, making short-term impacts less pronounced (Aliyu et al., 2018).

Nigeria needs to concentrate on long-term plans that incorporate institutional reforms and investments in clean energy infrastructure in order to optimize the advantages of renewable energy. An environment where renewable energy effectively contributes to the reduction of CO2 emissions can be created by improving regulatory transparency, lowering bureaucratic bottlenecks, and improving policy consistency.

5. CONCLUSION

This study investigated the role of renewable energy (RE) and institutional quality (IQ) in reducing consumption-based CO_2 emissions in Nigeria. The long-run results indicate that institutional quality significantly enhances the effectiveness of renewable energy in lowering emissions, highlighting the importance of robust governance, effective regulation, and anti-corruption measures. Countries with stronger institutional frameworks are better able to optimize the environmental benefits of renewable energy investments. In contrast, the short-run interaction between RE and IQ was not statistically significant, suggesting that improvements in governance and institutional reforms take time to translate into measurable reductions in emissions. The findings also reveal that economic growth and population increases contribute to higher CO_2 emissions, consistent with the Environmental Kuznets Curve (EKC) hypothesis, which shows that environmental pressures initially rise with development before declining at higher levels of income and governance maturity.

The study concludes that strengthening institutions ensures that renewable energy initiatives are effectively implemented and maintained, maximizing their long-term impact on environmental sustainability. The results further emphasize that while renewable energy adoption is essential, it is insufficient on its own; governance structures, regulatory enforcement, and policy consistency are equally necessary to translate renewable energy potential into meaningful reductions in consumption-based CO_2 emissions in Nigeria.

Based on the study findings, the study gives the following recommendations;

First, policymakers should strengthen institutional quality by improving governance, enhancing transparency, and enforcing environmental regulations to maximize the impact of renewable energy. Additionally, investments in renewable energy infrastructure, incentives for private sector participation, and continuous monitoring of energy policies are recommended to ensure sustainability.

Future research should explore sector-specific institutional reforms, incorporate technological advancements in renewable energy, and undertake cross-country analyses to better understand how governance and energy efficiency jointly contribute to achieving broader sustainability goals.

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