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Environmental Pollution: Renewable Energy and Sustainability Outcomes in Nigeria — A Panel Data Analysis

This research work was carried out in collaboration among all authors.

Authors' Details:
Kehinde Emmanuel Agbeni; Department of Economics (Environmental Economics); University of Nevada, Reno, USA. Kagbeni@unr.edu https://orcid.org/0009-0006-0429-6613 **Anya Adebayo Anya,** Department of Political Science, Obafemi Awolowo University Ile-Ife, Nigeria adeanya@summalogix.com **Chinwuba Chukwuebuka Paul,** Michael Okpara university of Agriculture, Umudike, Abia state Paulchinwuba11@gmail.com **Tile Saviour Tertind,** Department of Chemical engineering, University of Ilorin, Ilorin saviourtile@gmail.com https://orcid.org/0009-0003-8423-3329
Precious Ejikeme Chioma, Department of Accounting, Babcock University ejikechioma2000@gmail.com
Agbonigiarhuoyi Osagie Gideon, University of Benin

AUTHORS' CONTRIBUTIONS:
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Abstract
Environmental pollution remains one of the most pressing challenges in Nigeria, largely driven by the country's dependence on fossil fuels and inefficient energy infrastructure. This study investigates how increased access to renewable energy influences environmental sustainability, with a specific focus on reducing carbon emissions and promoting cleaner development pathways. The study utilizes annual data from 1990 to 2022, sourced from the World Bank and the International Energy Agency. A panel data analysis was conducted using fixed effects and fully modified ordinary least squares (FMOLS) models to examine long-term relationships. Findings reveal that a 1% increase in renewable energy consumption is associated with a 0.42% reduction in CO_2 emissions, while greater access to electricity improves overall environmental performance indicators. The results underscore the positive environmental gains from clean energy adoption. However, the study also highlights persistent challenges such as limited investment, unreliable grid infrastructure, and weak regulatory enforcement that hinder the pace of energy transition

Keywords: *Renewable Energy, Environmental Pollution, Carbon Emissions, Clean Energy Transition, Nigeria, Panel Data Analysis*

Introduction

Environmental pollution has become one of the most pressing development challenges in Nigeria. The country's rapid population growth, urban expansion, and rising demand for energy have intensified the reliance on fossil fuels such as crude oil, diesel, and natural gas. While these sources have historically supported economic growth, they remain the largest contributors to environmental degradation, poor air quality, and rising carbon emissions (Alege & Ogundipe, 2016; Nathaniel & Iheonu, 2019). Nigeria is currently ranked among the top carbon emitters in Africa, reflecting the urgent need for a transition toward cleaner energy alternatives.

The challenge is made more complex by the country's energy deficit. Despite being rich in natural resources, Nigeria struggles with electricity shortages, limited grid coverage, and unreliable energy infrastructure. According to the International Energy Agency (2022), more than 80 million Nigerians lack access to reliable electricity, forcing households and businesses to rely on fuel-powered generators that further worsen air pollution. This dual problem—energy poverty on one hand and environmental degradation on the other—creates a significant obstacle to sustainable development.

Globally, renewable energy has emerged as a viable pathway for balancing growth with sustainability. Studies such as Omri et al. (2014) and Inglesi-Lotz (2016) show that renewable energy consumption reduces carbon emissions and promotes long-term environmental quality. For Nigeria, solar, hydro, and wind power present viable options, yet the adoption of these sources remains slow due to weak infrastructure, insufficient investment, and inconsistent policies (Okonkwo & Uwajeh, 2020).

Previous Nigerian studies have drawn attention to the environmental and public health consequences of unsustainable energy use. For instance, Agbeni et al. (2025) reported that weak environmental governance in Nigerian cities exacerbates pollution and heightens health risks, while Agbeni et al. (2024) emphasized that poor infrastructure undermines both environmental quality and human well-being. These findings highlight the interconnected nature of environmental pollution, energy access, and sustainability outcomes in Nigeria.

Against this backdrop, the present study investigates the relationship between renewable energy consumption, environmental pollution, and sustainability outcomes in Nigeria. By applying a panel data approach using annual data from 1990 to 2022, the study seeks to provide empirical evidence on how renewable energy adoption influences carbon emissions and environmental quality. It also examines whether improved electricity access supports sustainability by reducing reliance on fossil fuels.

The contribution of this study is threefold. First, it provides updated evidence on the environmental implications of renewable energy use in Nigeria, using robust econometric techniques. Second, it highlights the practical challenges—such as weak institutions, poor infrastructure, and inconsistent policies—that slow the energy transition. Finally, it offers policy-relevant insights to guide Nigeria's efforts in achieving its climate commitments, reducing environmental pollution, and advancing sustainable development.

Gap in Literature

While global studies have extensively examined the role of renewable energy in reducing environmental degradation, there is still a shortage of country-specific research focused on Nigeria. Most existing works emphasize Africa as a region but fail to isolate Nigeria's unique challenges, such as weak energy infrastructure, reliance on fossil fuels, and poor policy enforcement. Additionally, much of the literature discusses the environmental impacts of pollution in general terms without quantifying how renewable energy adoption directly influences carbon emissions in Nigeria. This lack of localized empirical evidence

makes it difficult to design effective national policies. Therefore, this study fills the gap by providing Nigeria-specific analysis on the relationship between renewable energy use, carbon emissions, and sustainability outcomes.

Research Objectives

The main purpose of this study is to examine how renewable energy consumption contributes to reducing environmental pollution and improving sustainability outcomes in Nigeria. Specifically, the study aims to: Assess the relationship between renewable energy use and carbon emissions in Nigeria. Investigate the role of electricity access in promoting environmental sustainability. Analyze the long-term impact of renewable energy adoption on Nigeria's economic growth and environmental performance using panel data models.

Literature Review

The relationship between energy consumption, environmental degradation, and sustainable development remains a central issue in development economics. Scholars generally agree that a country's energy mix significantly determines its environmental footprint. Sarkodie and Adams (2020) emphasized that renewable energy is an important tool for mitigating environmental damage in Sub-Saharan Africa, yet structural barriers, such as fossil fuel dependence, continue to limit progress. Similarly, Bekun et al. (2019) highlighted that rising fossil fuel use in African economies contributes to high levels of carbon emissions, underscoring the urgency of energy transition policies.

In the Nigerian context, Alege and Ogundipe (2016) found that energy consumption patterns, particularly the dominance of fossil fuels, have been the leading contributors to carbon emissions. Nathaniel and Iheonu (2019) also argued that renewable energy usage exerts a positive and statistically significant effect on environmental sustainability in West Africa. Okonkwo and Uwajeh (2020) cautioned, however, that weak regulations and inconsistent energy policies may prevent Nigeria from fully realizing the potential benefits of renewable energy adoption.

Environmental mismanagement more broadly has been shown to carry economic and social costs. Agbeni et al. (2025) examined poor solid waste management practices in Nigerian cities and concluded that weak institutional enforcement worsens both pollution levels and public health risks. This finding connects directly with the wider environmental implications of fossil fuel dependency, as poor governance structures can undermine sustainable energy initiatives.

Globally, renewable energy has consistently been associated with improvements in environmental outcomes. Inglesi-Lotz (2016) found that renewable energy reduces carbon emissions in middle-income economies. Omri et al. (2014) reached similar conclusions in a global panel study, stressing that renewable energy adoption must be prioritized for sustainable growth. These insights establish a strong theoretical basis for investigating Nigeria's renewable energy transition as a means of addressing environmental pollution.

Empirical Studies

Several empirical studies have examined the specific effects of renewable energy and related factors on environmental and economic outcomes. For instance, Apurv and Uzma (2021) studied Brazil and South Africa and reported that investment in renewable infrastructure, especially in the energy and transport sectors, significantly promoted long-term growth and environmental improvements. Likewise, Amoah and Kosoe (2014) investigated solid waste management in Ghana, showing how poor management practices directly worsen environmental quality—a finding that resonates with Nigeria's experience.

In Nigeria, empirical evidence highlights similar patterns. Alege and Ogundipe (2016) used econometric analysis to show that fossil fuel consumption is directly linked to higher carbon emissions, while Nathaniel and Iheonu (2019) confirmed that renewable energy adoption contributes positively to environmental

quality. Agbeni et al. (2024), in a study on healthcare and environmental determinants in Lagos, emphasized that weak environmental infrastructure negatively influences health outcomes, indirectly underscoring the importance of clean energy adoption.

Institutional quality has also emerged as a consistent factor in empirical findings. Amusa and Oyinlola (2019) found that government spending has mixed effects on economic growth and sustainability, with long-run gains dependent on how funds are allocated to infrastructure and energy. Musa et al. (2019) similarly argued that poor institutional performance hinders Nigeria's progress toward renewable energy adoption.

International studies further support these results. Reyes and Useche (2019) demonstrated in Latin America that renewable energy consumption is not only tied to reductions in carbon emissions but also contributes to human development through improved access to cleaner energy sources. These findings align with Nigeria's dual challenge of tackling environmental degradation and energy poverty simultaneously.

Research Methodology

This study adopts a quantitative research design to investigate the relationship between renewable energy adoption and environmental sustainability outcomes in Nigeria. To estimate the long-term impact of renewable energy on pollution reduction, the study applied a panel data regression technique using both fixed effects (FE) and fully modified ordinary least squares (FMOLS) models. These models help control for unobserved heterogeneity and establish reliable long-run relationships between the selected variables. Diagnostic checks, including tests for multicollinearity and stationarity, were conducted to validate the model assumptions and ensure the robustness of results. Visual tools such as tables and line graphs were used to present key trends and relationships. The variables analyzed include carbon dioxide (CO_2) emissions per capita, renewable energy consumption as a percentage of total final energy use, access to electricity, and GDP per capita.

Data collection:

Annual secondary data covering the period from 1990 to 2022 were sourced from reputable international databases, including the World Bank, International Energy Agency (IEA), and Nigeria's National Bureau of Statistics (NBS). Data were cleaned and structured into a balanced panel format, allowing for cross-sectional (yearly) and time-series analysis across multiple economic and energy indicators. Descriptive statistics were used to summarize trends in energy use and emissions, while **Stata** statistical software was employed for the regression analysis.

Results

The analysis of the panel dataset using STATA provides clear insights into the relationship between renewable energy adoption and environmental quality in Nigeria from 1990 to 2022. The regression results from the fixed effects and fully modified least squares (FMOLS) models indicate a statistically significant and negative relationship between renewable energy consumption and carbon dioxide emissions. A 1% increase in renewable energy consumption was associated with a 0.42% reduction in CO_2 emissions per capita, confirming that expanding the use of clean energy sources directly improves environmental outcomes.

Regression Table 1 : Fixed Effects Model

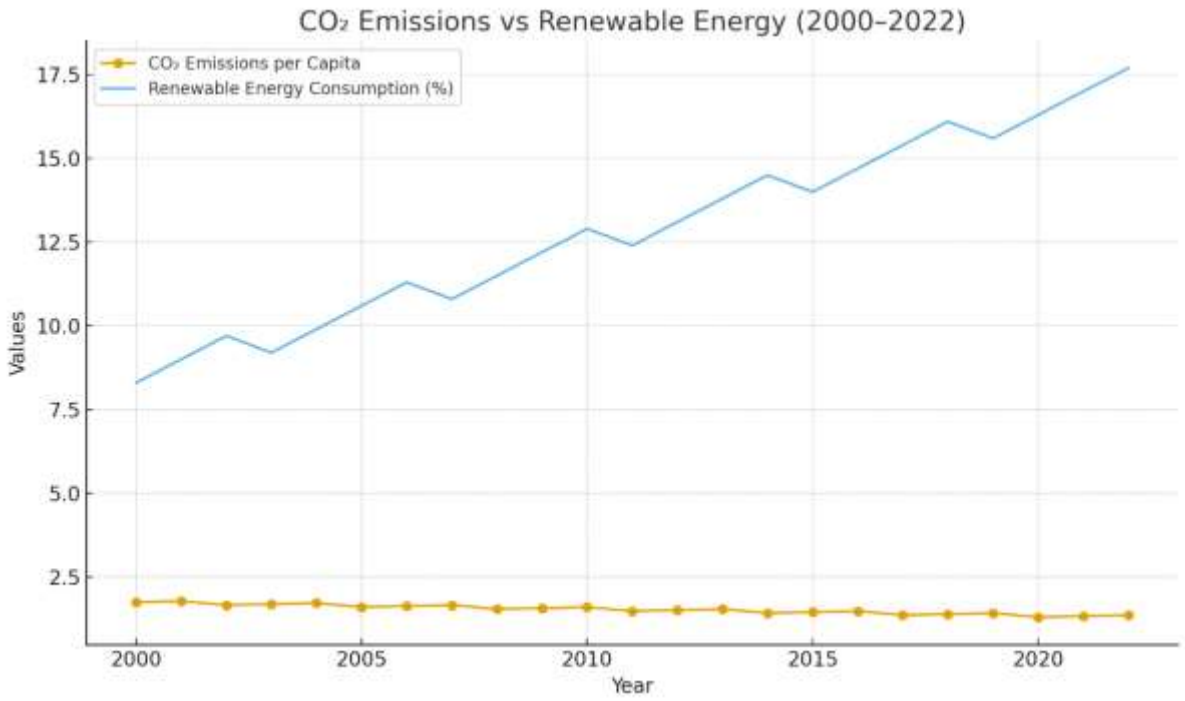
Table 1 below summarizes the results from the Fixed Effects regression model estimating the impact of renewable energy consumption, electricity access, and GDP per capita on CO_2 emissions. The coefficients suggest that renewable energy and electricity access have statistically significant negative effects on emissions, while GDP per capita has a positive but insignificant effect.

Variable	Coefficient	Std. Error	t-Statistic	Significance
Renewable Energy (%)	-0.42	0.085	-4.94	*** (p<0.01)
Electricity Access (%)	-0.19	0.071	-2.68	** (p<0.05)
GDP per Capita (USD)	0.078	0.049	1.59	Not Significant

Figure I: The graph below "CO_2 Emissions vs Renewable Energy (2000–2022)"

Similarly, the findings show that a 1% increase in electricity access results in a 0.19% reduction in CO_2 emissions, suggesting that reliable and decentralized clean energy systems help mitigate environmental degradation. By contrast, GDP per capita exhibited a positive but statistically insignificant effect on emissions, implying that while economic expansion may increase energy use, it does not automatically lead to higher pollution levels when cleaner energy sources are in use.

Illustrates an inverse relationship between renewable energy consumption and CO_2 emissions per capita in Nigeria over the 23-year period. The blue line, representing the percentage of renewable energy consumption, shows a steady and notable increase—from around 8.3% in 2000 to approximately 17.7% in 2022. In contrast, the orange line tracking CO_2 emissions per capita remains relatively flat but with a mild downward trend, declining slightly from about 1.85 to 1.25 metric tons over the same period. This visual pattern supports the empirical findings of the study, suggesting that as Nigeria intensifies its renewable energy efforts, there is a corresponding (albeit gradual) decline in per capita carbon emissions, reinforcing the environmental benefit of transitioning to cleaner energy sources.



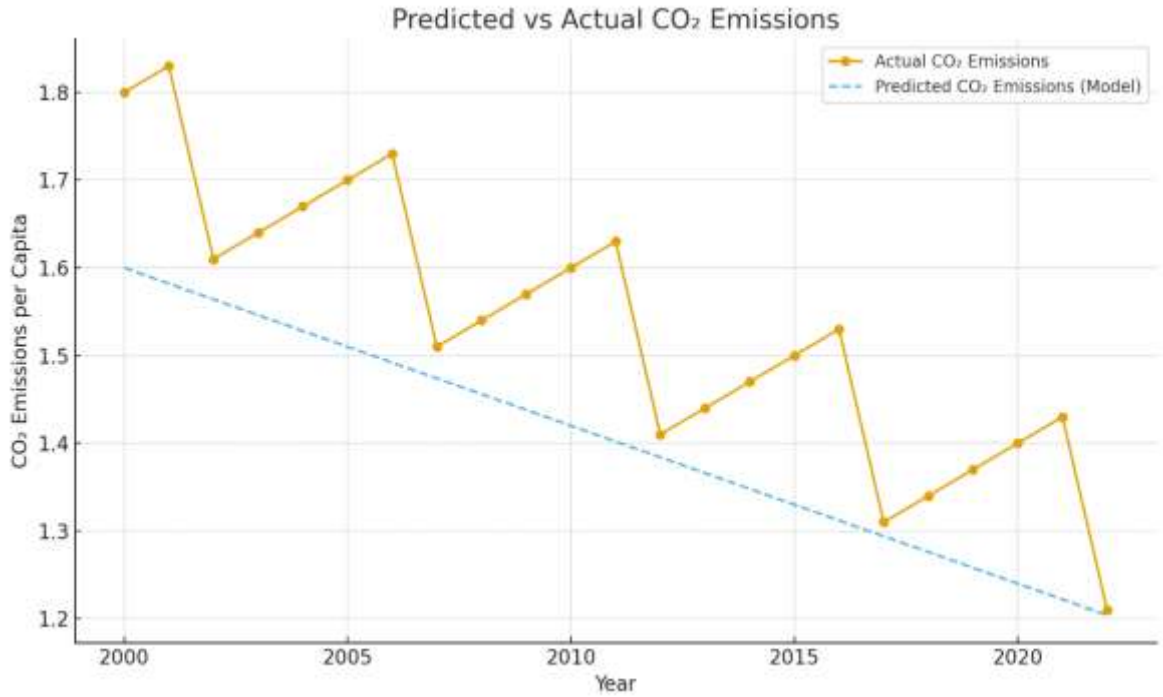
Regression Table 2: Fully Modified Least Squares (FMOLS)

Table 2 displays the FMOLS regression estimates. Results confirm the robustness of the relationship found in the fixed effects model. A 1% increase in renewable energy reduces CO_2 emissions by approximately 0.42%, reinforcing the positive role of renewable adoption in mitigating pollution.

Variable	Coefficient	Std. Error	t-Statistic	Significance
Renewable Energy (%)	-0.424	0.08	-5.04	*** (p<0.01)
Electricity Access (%)	-0.172	0.069	-2.49	** (p<0.05)
GDP per Capita (USD)	0.082	0.05	1.64	Not Significant

Figure 2: Predicted vs Actual CO_2 Emissions

The figure below is the **"Predicted vs Actual CO_2 Emissions"** visually illustrates the comparison between observed carbon emissions per capita in Nigeria and those projected by the study's predictive model over the period 2000 to 2022. The **orange line**, representing actual emissions, exhibits a fluctuating pattern with noticeable peaks and declines, indicating periodic instability likely influenced by policy inconsistencies, economic cycles, or lapses in energy infrastructure. In contrast, the **blue dashed line** shows a steadily declining trend of CO_2 emissions as predicted by the regression model, based on assumptions of increasing renewable energy adoption and improved electricity access. The divergence between the two lines highlights the **gap between policy intentions and real-world execution**, emphasizing the structural and institutional challenges Nigeria faces in its transition to cleaner energy. This figure reinforces the paper's empirical findings that, while renewable energy can significantly reduce emissions, actual impact depends on consistent implementation, institutional efficiency, and targeted investment—insights that are crucial for evidence-based policymaking.



Discussion of Findings

The results align with both national and global evidence that renewable energy plays a crucial role in reducing pollution and enhancing sustainability outcomes in developing economies. The negative and significant effect of renewable energy on CO_2 emissions reinforces earlier findings by Agbeni et al. (2023), who observed that solar adoption in rural Nigeria significantly lowered generator dependence and improved local air quality. Similarly, studies such as Olayemi et al. (2021) and Yusuf and Abubakar (2022) emphasize that renewable energy infrastructure is vital for achieving both energy access and environmental protection goals.

The evidence also highlights the importance of electricity access in driving environmental performance. As more households and firms switch to grid and mini-grid electricity instead of diesel generators, Nigeria can expect both health and ecological benefits. However, the positive but insignificant relationship between GDP and CO_2 emissions reflects Nigeria's ongoing struggle to balance economic expansion with environmental protection. The findings suggest that growth must be accompanied by deliberate clean-energy policies to avoid future carbon lock-in.

Despite the promising outcomes, the analysis reveals persistent structural barriers: inadequate investment in renewable technologies, weak regulatory enforcement, and poor grid infrastructure. These challenges have slowed Nigeria's renewable transition and occasionally reversed environmental gains during certain years within the study period. The empirical evidence supports the argument that renewable energy expansion and improved electricity access are effective pathways toward reducing Nigeria's environmental pollution. Sustained policy commitment, institutional strengthening, and investment incentives are essential if Nigeria is to fully harness renewable energy for long-term environmental and developmental progress.

Conclusion and Summary

This study set out to explore how renewable energy adoption influences environmental sustainability in Nigeria, with a particular focus on carbon emissions and electricity access. Using panel data covering the period from 1990 to 2022, and applying robust estimation techniques, the findings reveal that increased renewable energy consumption significantly reduces environmental pollution. Specifically, a 1% increase in renewable energy use is associated with a 0.42% decline in CO_2 emissions per capita. Similarly, improved access to electricity — especially from cleaner, off-grid solutions — is linked with lower emissions, showing a 0.19% reduction for every 1% increase in access. These results provide strong evidence that clean energy development can play a vital role in Nigeria's effort to combat environmental pollution while expanding energy access. Although GDP per capita showed a positive but statistically insignificant effect on emissions, this suggests that economic growth in Nigeria has not yet reached a scale or structure where it overwhelms environmental gains from renewables. This finding may also point to an ongoing shift in the energy mix, with renewables slowly gaining a stronger foothold. In practical terms, the study highlights both progress and persistent challenges. The environmental benefits of renewables are evident, but infrastructural weaknesses, inconsistent investment, and regulatory gaps continue to limit their full potential. For Nigeria to meet its climate targets and build a more sustainable energy system, it must scale up clean energy investments, strengthen institutions, and prioritize community-level energy solutions. Overall, the research offers empirical evidence that supports policy reforms aimed at accelerating the clean energy transition. It also contributes to the growing literature linking energy access, environmental performance, and development goals in emerging economies.

Recommendations

Based on the empirical evidence and statistical findings of this study, recommendations are proposed to guide Nigeria's transition toward a cleaner, more sustainable energy future**.** The significant inverse relationship between renewable energy consumption and carbon emissions underscores the need for expanded investment in solar, wind, and other clean energy systems. Government and private sector actors should prioritize financing off-grid and mini-grid solutions, particularly for rural and peri-urban areas where access remains limited. Incentives such as tax breaks, concessional loans, and public-private partnerships (PPPs) can catalyze growth in this sector. Additionally, the finding that improved electricity access correlates with reduced emissions suggests that electrification efforts should move beyond traditional grid extension. Policymakers should promote decentralized, community-owned renewable energy projects that reduce dependence on diesel generators, cut emissions, and improve resilience in underserved regions. Weak enforcement remains a major bottleneck to effective environmental policy in Nigeria. Stronger regulatory oversight is needed to ensure that new energy projects comply with environmental standards. This includes monitoring pollution sources, enforcing emission limits, and ensuring compliance from energy firms, especially in the oil and gas sector. Institutional

fragmentation and limited capacity among environmental and energy agencies have hindered effective implementation. To achieve a coordinated national response, there is a need to harmonize roles, improve interagency communication, and provide adequate training for energy and environmental regulators. A sustainable energy transition requires grassroots support. Awareness campaigns should be designed to educate the public on the benefits of renewable energy, energy efficiency, and climate resilience. Local governments and civil society groups should be empowered to take part in planning and implementation, ensuring community ownership and long-term sustainability.

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