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Renewable energy utilization and environmental sustainability: A study of small and medium enterprises in Kogi State

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ABSTRACT

This study aimed at renewable energy utilization and environmental sustainability. The study focused on how consumption of renewable energy, capacity, and electricity access affect environmental responsibility, carbon absorption, and pollution control in sustainable development. Survey research design was employed. The study targeted small and medium enterprises (SMEs). The population size was 12,517. The sample size of the study was 373. A multi-stage sampling technique was adopted so that the sample was selected in stages. The reliability of the instrument was established using Cronbach's alpha test. Descriptive and inferential statistical techniques were employed in the research to analyze the data collected. Linear regression analysis was used to test hypotheses. Findings revealed that consumption of renewable energy significantly affects carbon sequestration and that renewable energy capacity has a significant effect on pollution control among SMEs. The study concluded that utilization of renewable energy can improve environmental sustainability among SMEs. The study recommended that SMEs need to place high priority on the uptake and utilization of renewable energy sources such as solar, wind, and biomass to enhance their environmental sustainability. It also recommended that SMEs should increase their investment in renewable energy infrastructure and capacity development to strengthen their ability to control pollution and manage waste efficiently.

Contribution/ Originality: This study contributes to the existing literature by examining renewable energy's direct effect on environmental sustainability. It uses a blended estimation approach linking the consumption of renewable energy, capacity, and electricity access to environmental responsibility, carbon absorption, and pollution control in sustainable development.

1. INTRODUCTION

Use of renewable energy has been a cornerstone of global sustainable development as a necessary response to global environmental challenges created by industrialization and economic development. Renewable energy derived from nature, including sunlight, wind, water, and biomass, offers a greener and more environmentally friendly alternative to fossil fuels through the production of very low amounts of greenhouse gas emissions (Agrawal & Soni, 2021). The international shift towards the use of renewable energy is guided by the need to mitigate climate change, reduce carbon dependence, and promote long-term sustainable environmental growth (Adeosun, Amosu, Omitogun, Amusa, & Morenikeji, 2023; Gayen, Chatterjee, & Roy, 2024). UN Sustainable Development Goals (SDGs) 7 and 13 emphasize affordable, clean energy and climate action as key paths towards human development and planetary ecological harmony (Solntsev & Akshalova, 2021). Most countries emphasize the integration of renewable energy in a bid to register economic growth without compromising environmental health.

Shifting to renewable energy in developing nations has become necessary to guarantee sustainable development. Africa, specifically, must address the twin deficits of energy poverty and environmental degradation despite possessing abundant renewable resources such as solar, hydro, and biomass energy (Mutezo & Mulopo, 2021). Unfortunately, infrastructural limitations, policy incoherences, and inadequate funding continue to hinder the adoption of clean energy (Adedoyin, Ozturk, Agboola, Agboola, & Bekun, 2021). Small and medium enterprises (SMEs), which form the backbone of African economies, are disproportionately affected by unpredictable power supply and high energy expenses, leading many to use diesel generators that increase pollution and operational inefficiencies (Gambino, 2021). Applying renewable energy is a viable option, enabling SMEs to reduce costs and improve productivity and sustainability.

The transition to renewable energy in Nigeria has become more prominent considering ongoing power outages, energy insecurity, and environmental degradation. Although there exists vast potential for renewable energy, the energy sector of the country is still dominated by fossil fuels (Adeshina et al., 2024). Although the government has introduced initiatives like the Renewable Energy Master Plan (REMP) and the National Energy Policy, progress has been sluggish, especially for SMEs due to setup costs and poor awareness (Qamar, Ahmad, Oryani, & Zhang, 2022). Kogi State in North-Central Nigeria faces challenges and opportunities in the adoption of renewable energy. With its rich endowment of natural resources and a thriving SME sector, the state provides a fertile ground for examining how the use of renewable energy can improve environmental sustainability. This study accordingly examines the use of renewable energy and environmental sustainability in SMEs in Kogi State, focusing on how consumption of renewable energy, capacity, and electricity access affect environmental responsibility, carbon absorption, and pollution control in sustainable development.

2. LITERATURE REVIEW

2.1. Renewable Energy Utilization

The variable "renewable energy usage" has been theoretically defined differently. Maradin (2021) and Wang, Zhang, and Zhou (2022) theorize renewable energy usage as consuming energy that is derived from naturally renewable sources such as solar, wind, hydro, and biomass, which are clean and sustainable alternatives to fossil fuels. This definition concentrates on the sustainable and environmental nature of renewable energy, pointing out that it reduces the emission of greenhouse gases and helps combat climate change. Malik et al. (2019) and Oyedun et al. (2025) also conceptualize the uptake of renewable energy from a different perspective, where the uptake of renewable energy is the degree to which households, individuals, and firms adopt renewable energy technologies to satisfy their energy requirements in a cost-effective and environmentally friendly manner. This conceptualization extends the term to include both the adoption of renewable infrastructure and the energy consumption behavior patterns. Additionally, Erdiwansyah et al. (2021) and Nekrasov (2021) also theorize the utilization of renewable energy as an economic and technological process whereby energy users integrate renewable resources into their consumption or production base in a bid to restrict reliance on conventional energy. This theorization evokes the idea that use is not just a question of access but also investment, affordability, and commitment towards sustainability in the long run.

Literature Asghar, Sulaiman, Mustaffa, Ullah, and Hassan (2022); Kar, Harichandan, and Prakash (2024) and Rana, Al Mamun, Hossain, Rekha, and Alam (2025) confirms this general view by pointing out that the use of renewable energy involves a range of variables such as infrastructure readiness, economic incentives, environmental awareness of benefits, and technological readiness. The variables are related to influencing the way societies and enterprises transition to cleaner sources of energy. In SMEs, or in business environments more broadly, renewable energy utilization has been linked to lower operating costs, improved environmental sustainability, and an improved corporate image (Alam & Islam, 2021; Us, Pimonenko, & Lyulyov, 2023). These benefits reflect greater global and regional interest in exploring renewable energy options in SMEs, especially in the context of emerging economies where energy matters continue to prevail. Additionally, scholars (Adepoju & Akinwale, 2019; Jiang et al., 2022) argue that renewable energy consumption patterns are a function of a number of demographic, geographic, and economic factors such as firm size, geographical location, type of industry, and availability of government subsidies. For example, in Nigeria, SMEs' demand for renewable energy is largely hindered by ineffective grid supply, diesel generator expenses, as well as incentive policies towards encouraging solar and other clean forms of energy (Qamar et al., 2022). However, renewable energy usage is decomposed into renewable energy consumption, renewable energy capacity, as well as access to electricity from renewables.

2.2. Environmental Sustainability

Environmental sustainability can be defined as the use and preservation of natural resources in a manner that meets present needs without compromising the ability of future generations to meet theirs. It involves activities that harmonize ecological protection, social well-being, and economic prosperity in a manner that guarantees long-term planetary health (Shannon, Issa, Wood, & Kelman, 2022). Baloch et al. (2023) have used the term "Environmental sustainability" as cautious handling of biodiversity and ecosystems so that societies' natural capital may be conserved. Hariram, Mekha, Suganthan, and Sudhakar (2023) and Stanković, Marjanović, Papathanasiou, and Drezgić (2021) have discussed it as a multi-dimensional concept, introducing environmental, economic, and social considerations in decision-making. That is, environmental sustainability demands more than resource preservation; it builds resilience, ingenuity, and equity while limiting ecological harm and facilitating the perpetuity of life-supporting systems (Estoque & Wu, 2024; Maharana, 2025).

Scholars view environmental sustainability as a diverse process that is shaped by human agency, institutional mechanisms, and biogeochemical processes. Sustainability consequences depend on how societies balance their production and consumption habits against ecological limits (Hariram et al., 2023; Leal Filho et al., 2019). Rockström, Sachs, Öhman, and Schmidt-Traub (2022) and Yadav and Singh (2024) argued that crossing planetary boundaries such as climate stability, biodiversity integrity, and land use threatens sustainability, while following them ensures resilience and long-term prosperity. This concept means that the sustainability status changes with environmental policy, technological innovations, and social changes in behaviour. Chen, Sharma, and Liu (2023) also bring out the fact that environmental sustainability is the foundation of human and organizational life, enabling societies to adapt to global issues such as climate change, pollution, and natural resource depletion. Environmental sustainability is thus developed into carbon absorption, pollution control, and environmental responsibility.

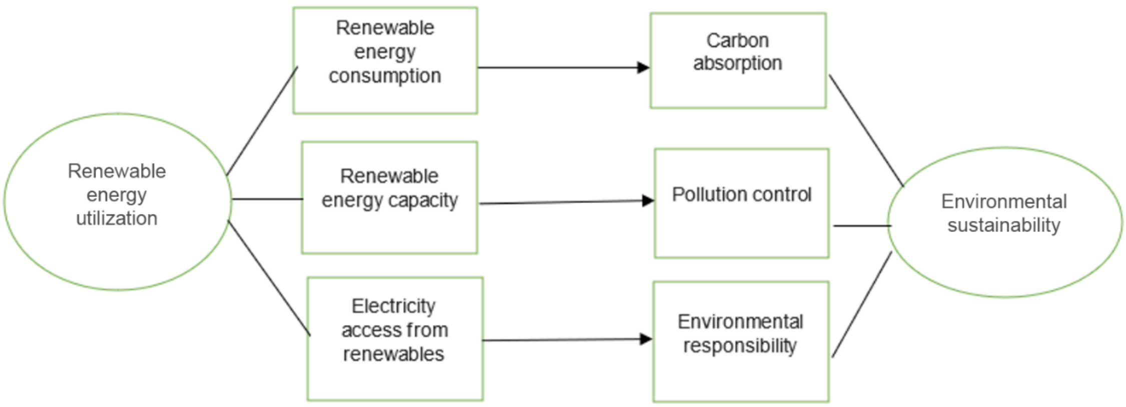

Figure 1. Conceptual Framework.

Source: The Researcher (2025).

Figure 1 shows the hypothetical assumptions of the study. The following sections show the position of previous studies.

2.3. Renewable Energy Consumption and Carbon Absorption

Renewable energy consumption is the use of clean and sustainable sources of energy such as solar, wind, biomass, and hydroelectric power as alternatives to fossil fuels (Hailemariam, Ivanovski, & Dzhumashev, 2022) while carbon absorption refers to the capacity of business operations and processes to offset or eliminate carbon emissions through green initiatives (Hasnisah, Azlina, & Taib, 2019; Liu, Niu, Dong, & Zhong, 2023). By integrating renewable energy into their operations, SMEs can significantly reduce their carbon footprint and their contribution to natural carbon absorption processes. The reason is that the consumption of renewable energy decreases direct emissions of greenhouse gases, thereby achieving a balance between energy usage and environmental sustainability (Algarni, Tirth, Alqahtani, Alshehery, & Kshirsagar, 2023; Kwakwa, Aboagye, Acheampong, & Achaamah, 2024). Empirical studies considerably highlight the constructive impact of renewable energy consumption on promoting SMEs' environmental performance as well as enabling carbon absorption processes.

SMEs that shift to clean energy sources reduce carbon-intensive processes such as diesel generators, thus reducing their emissions and indirectly enhancing the capability of ecosystems to sequester carbon (Omokanmi, Oke, & Ridwan, 2020). For instance, firms that use solar photovoltaic systems have reduced aggregate emissions, leading to cleaner air and reducing ecological pressure on natural carbon sinks, such as forests and soil systems. In this way, renewable energy enables SMEs to achieve global sustainability standards, improve their reputation profiles, and indeed stimulate environmental regeneration (Adenutsi, Musah, & Padi, 2025).

2.4. Renewable Energy Capacity and Pollution Control

Renewable capacity is an essential driver of whether SMEs can cope with pollution and environmental issues. Capacity in this context concerns the extent to which SMEs can access and utilize renewable energy technologies such as solar panels, biomass systems, wind turbines, and mini-hydro schemes within production activities (Adeleye, Adebanji, & Awogbemi, 2024). A higher ability to use renewable energy ensures that SMEs can substitute a larger proportion of fossil fuel-based energy with clean energy. This directly reduces emissions of carbon dioxide, sulfur oxides, nitrogen oxides, and particulates (Ebhota & Jen, 2020). This substitution effect not only decreases air pollution but also reduces the generation of toxic by-products associated with the use of non-renewable energy (Opeyemi, 2021). Thus, installed renewable capacity serves as a structural driver for pollution mitigation, as SMEs with greater installed renewable capacity are more inclined to reduce the intensity of polluting operations across different stages of their value chain.

Evidence from empirical research shows that SMEs with higher capacity in renewable energy have higher levels of environmental compliance, lower wastage in operations, and less reliance on polluting process stages (Sendawula, Turyakira, Akileng, & Vincent, 2024; Suleiman, 2023). SME development of renewable capacity also drives investors to put funds into complementary technologies such as energy storage facilities, waste-to-energy converters, and environmentally friendly industrial equipment, all of which amplify pollution control efforts and sustainability in operations (Ebhota & Jen, 2020; Usman, Ozkan, Adeshola, & Eweade, 2025).

2.5. Electricity Access from Renewables and Environmental Responsibility

Electricity from renewable sources can affect environmental responsibility by determining the extent to which they adopt green activities and reduce their footprint on the environment (Alshahrani, Rizwan, Alomar, & Fotis, 2024; Balogun, Yahaya, Bala, & Waziri, 2023). Renewable energy, derived from alternative sources such as solar, wind, water, and organic matter, presents a cleaner and more sustainable alternative to the use of fossil fuels, which are inherently linked with pollution and degradation of the environment. The energy sources available for SMEs correlate with environmental responsibility (Nurudeen, Nafiu, & Jibo, 2018), which is the obligation of firms to mitigate negative environmental impacts while preserving ecological equilibrium. Studies highlight that SMEs with greater access to renewable electricity are more likely to adopt environmentally oriented processes, pursue sustainability standards, and enhance the corporate image of being eco-friendly companies (Awamleh, Shwawreh, Al-Kharabsheh, & Alzghoul, 2025).

The original effect of electricity access from renewables is its double potential to either support or limit SMEs' environmental responsibility. On the one hand, access to renewable electricity enables SMEs to reduce their carbon footprint, adopt cleaner production processes, and engage in effective waste management, which together enhance their environmental responsibility (Olujobi, 2024). Alternatively, when access is not uniform or when renewable infrastructure is exorbitant, SMEs find it difficult to exercise environmental responsibility in its entirety, thereby bridging the gap between practice and intent (Ajaero, Okafor, Otunomo, Nduji, & Adedapo, 2023). This two-sidedness refers to the understanding that, although renewable access is a strong catalyst for environmental responsibility, its application hinges on availability, affordability, and organizational readiness to adopt new technology.

3. METHODOLOGY

3.1. Research Design

Survey research design was employed in this study, with a standardized research instrument used to collect information. Survey design was considered suitable because it allowed us to gather data from a sizable number of SMEs in Kogi State in a cost-effective and organized manner (Nurudeen et al., 2018).

3.2. Population of the Study

The population of this study (12,517) comprised registered Small and Medium Enterprises (SMEs) operating in Kogi State. Table 1 presents the breakdown of the population distribution as follows.

Table 1. Population frame of the study.

Category	Number of enterprises
Small enterprises	12,078
Medium enterprises	439
Total	12,517

Source: SMEDAN (2021).

3.3. Sample Size of the Study

To enhance the statistical accuracy and representativeness of this study, Sallant and Dillman (1997) employed a parametric statistical equation to determine the size of the study population. This formula is widely regarded as a robust method for sample size calculation, especially in social science survey research (Nafiu et al., 2023). The formula is expressed as follows.

$$N_s = \frac{N_p\ (p)(1-p)}{(N_p - 1)\left(\frac{B}{C}\right)^2 + (p)(1-p)}$$

Where:

Ns= completed sample size required

Np= Sample population

P= proportion expected to answer in a certain way (50% or 0.5 is most conservative)

B= acceptable level of sampling error (0.05 = ±5%; 0.03 = ± 3%)

C= Z statistic associated with the confidence interval (1.645=90% confidence level; 1.960=95% confidence level; 2.576=99% confidence level)

$$N_s = \frac{12{,}517(0.5)(1-0.5)}{(12{,}517-1)\left(\frac{0.05}{1.96}\right)^2 + (0.5)(1-0.5)}$$

Where:

Ns= 372.5297619047619 (Approx. 373).

Np= 12,517.

P= 50% or 0.5.

B= 0.05 or $\pm$5%.

C= 1.96.

The sample size of the study is 373.

Table 2. Sample size distribution and allocation.

Firm category	Population	Sample size allocation
Small enterprises	12,078	(12,078 / 12,517) × 373 = 360
Medium enterprises	439	(439 / 12,517) × 373 = 13
Total	**12,517**	**373**

Table 2 presents the sample size distribution of the study. It shows that 360 small enterprises and 15 medium enterprises were sampled.

3.4. Sampling Technique

A multi-stage sampling technique was employed so that the samples were selected in stages. According to the first stage, SMEs in Kogi State were identified and grouped according to their areas of business, such as agro-processing, manufacturing, hospitality, retail, and services. Stage two involved respondents from these companies being classified in terms of their organizational roles as owners/managers, operations officers, production staff, and administrative leaders who were considered key informants with the requisite knowledge of their companies' energy use and environmental practices. Stage three involved the survey measuring the chosen participants based on specific inclusion criteria such as how long the company has been operational, whether they are directly engaged in decision-making on energy consumption, and whether they have any familiarity with the firm's environmental sustainability initiatives. This serves to ensure accurate data collection from well-informed and appropriate respondents in relation to the study objectives.

3.5. Validity and Reliability of the Research Instrument

The study applied content validity to ascertain the precision, clarity, and relevance of the research instrument. The internal consistency measurement of the instrument was ascertained via the Cronbach's alpha coefficient. The test was conducted using the Statistical Package for Social Sciences (SPSS). The Cronbach's alpha statistic is especially employed to ascertain the internal consistency of any research instrument. Cronbach's alpha is an indicator of the reliability of an instrument. The more consistent and stable an instrument is, the more reliable it will be. Any score above 0.7 is considered a good score (Adriani et al., 2020).

Table 3. Construct reliability on renewable energy utilization.

S/N	Constructs	Cronbach’s alpha	No. of items
1	Renewable energy consumption	0.741	5
2	Renewable energy capacity	0.766	5
3	Electricity access from renewables	0.803	5

Table 3 shows the coefficient for renewable energy consumption (α = 0.741), indicating satisfactory internal consistency in items related to renewable energy consumption. Cronbach's alpha for renewable energy capacity is 0.766, indicating satisfactory reliability. The items on electricity access from renewables are more reliable (α = 0.803), which demonstrates high internal consistency.

Table 4. Construct reliability on environmental sustainability.

S/N	Constructs	Cronbach's alpha	No. of items
1	Carbon absorption	0.754	5
2	Pollution control	0.732	5
3	Environmental responsibility	0.817	5

Table 4 presents the reliability coefficient for carbon absorption (α = 0.754), indicating a high level of consistency. The alpha level of 0.732 for pollution control indicates an acceptable level of internal consistency among items measuring the variable. Environmental responsibility has a higher alpha (α = 0.817), indicating strong consistency in measuring the variable.

3.6. Method of Data Analysis

Descriptive and inferential statistical techniques were employed in the research to analyze the data collected. The researchers presented the demographic variables of the participants in tables, showing the data as percentages for a concise overview. To examine the hypotheses of the study, linear regression analysis was run through EVIEWS 12 software due to its robustness and ability to produce credible and unbiased statistical results. All the hypotheses were examined at a 5% significance level. The regression models were aligned with the specific objectives of the study and specified as follows.

$$ENS = \beta_0 + \beta_1(REU) + \varepsilon \quad (1)$$

$$CAB = \beta_0 + \beta_1 REC + \varepsilon \quad (2)$$

$$POC = \beta_0 + \beta_1 RCA + \varepsilon \quad (3)$$

$$ENR = \beta_0 + \beta_1 EAR + \varepsilon \quad (4)$$

Where;

REU = Renewable Energy Utilization.

REC = Renewable Energy Consumption.

RCA = Renewable Energy Capacity.

EAR = Electricity Access from Renewables.

ENS= Environmental Sustainability.

CAB= Carbon Absorption.

POC= Pollution Control.

ENR= Environmental Responsibility.

β_0 is the intercept term.

β_1 is the coefficient.

ε represents the error term.

4. DATA ANALYSIS AND DISCUSSION

This section displays the statistics of the distributed questionnaire, the demographic characteristics of respondents, and the tests of hypotheses.

Table 5. Questionnaire administration.

Description	Frequency	Percentage (%)
Questionnaire distributed	373	100.00
Questionnaire returned	364	97.59
Questionnaire unreturned	9	2.41

Source: Field survey, 2025.

Table 5 shows the total questionnaires distributed and their corresponding return percentage. From the table, we observed that the return percentage is 97.59%, which is extremely high. Analysis was thus conducted based on the data of the 364 returned questionnaires.

Table 6. Demographic characteristics of participants.

Demography	Frequency	Percent
Gender		
Male	228	62.6
Female	136	37.4
Age		
Under 20 years	88	24.2
20 – 29 years	103	28.3
30 – 39 years	94	25.8
40 – 49 years	65	17.9
50 years and above	14	3.8
Education		
Primary	43	11.8
Secondary	79	21.7
OND/NCE	89	24.5
HND/Bachelor's Degree	112	30.8
Postgraduate	41	11.3
Marital Status		
Single	77	21.2
Married	96	26.4
Widow(er)	82	22.5
Separated	69	19.0
Divorced	40	11.0
Experience		
Less than 1 year	64	17.6
1 – 3 years	90	24.7
4 – 6 years	81	22.3
7 – 10 years	62	17.0
Above 10 years	67	18.4

Source: Field survey, 2025.

Table 6 shows that 228 participants (62.6%) were males, and 136 participants (37.4%) were females. This indicates a gender imbalance in the surveyed population, with males constituting the majority of participants.

Table 6 indicates that 88 participants (24.2%) were aged below 20; 103 participants (28.3%) were aged between 20 and 29; 94 participants (25.8%) were aged between 30 and 39; 65 respondents (17.9%) were aged between 40 and 49; and 14 participants (3.8%) were 50 years and above. This shows that most of the participants fall within the working age groups between 20 to 39 years, representing the majority and active working class.

From the table, 43 participants (11.8%) received education at the primary level; 79 participants (21.7%) at the secondary level; 89 participants (24.5%) had OND/NCE; 112 participants (30.8%) had a Bachelor's/HND; and 41 participants (11.3%) had postgraduate education. This indicates that most of the participants have attained the tertiary level of education, representing a relatively educated workforce among SME operators.

Table shows that 77 participants (21.2%) were single; 96 participants (26.4%) were married; 82 participants (22.5%) were widowers or widowed; 69 participants (19.0%) were separated; and 40 participants (11.0%) were divorced. This result indicates that the majority of the participants are married, widowed, or separated, reflecting a diverse marital status among SME operators.

The table indicates that 64 enterprises (17.6%) have been in existence for less than a year; 90 enterprises (24.7%) have been in existence for 1–3 years; 81 enterprises (22.3%) have been in existence for 4–6 years; 62 (17.0%) have been in existence for 7–10 years; and 67 enterprises (18.4%) have been in existence for over 10 years. This result indicates that most of the sampled SMEs have been in existence for at least 1–6 years, depicting a relatively stable presence in their respective industries.

Table 7. Regression results on renewable energy consumption and carbon absorption.

Variable	Coefficient	Std. error	t-statistic	Prob.
C	0.402	0.133	3.023	0.003
REC	0.846	0.034	24.751	0.000
R-squared	0.629	Mean dependent variable		3.523
Adjusted R-squared	0.628	S.D. dependent variable		1.331
S.E. of regression	0.812	Akaike info criterion		2.427
Sum squared resid	238.761	Schwarz criterion		2.449
Log likelihood	-439.746	Hannan-Quinn criterion		2.436
F-statistic	612.625	Durbin-Watson stat		1.884
Prob(F-statistic)	0.000			

$$ModelLine: CAB_{it} = \beta_{0it} + \beta_{1i}REC + \mu$$

Regression Line: $CAB = 0.402 + 0.846REC$

Where REC = Renewable energy consumption; CAB = Carbon absorption; μ = Stochastic Error Term.

Table 7 displays the result of a regression test on the effect of renewable energy consumption on carbon absorption. The R-squared of 0.629 indicates that variations in renewable energy consumption account for approximately 62.86% of the variation in carbon absorption. The adjusted R-squared, which is 0.628, indicates that the model has substantial explanatory power even after adjusting for the number of predictors. This suggests that the utilization of renewable energy is the primary factor influencing carbon absorption among the SMEs studied. The F-statistic value of 612.625 and the p-value of 0.000 confirm that the overall regression model is statistically significant.

This demonstrates a very strong correlation between renewable energy use and carbon absorption. The standard error of 0.812 indicates that the predicted values for carbon uptake are very close to the actual values, confirming the model's high accuracy.

The coefficient of renewable energy consumption is 0.846, indicating an increase in carbon absorption by approximately 0.846 units for each additional unit of renewable energy consumption, assuming all other factors remain constant. This strong and positive coefficient suggests that higher levels of renewable energy use significantly enhance carbon absorption in SMEs. The standard error for this coefficient is 0.034, reflecting high precision in the estimate. The t-statistic of 24.751 and the p-value of 0.000 (both well below the 0.05 threshold) confirm that the effect is statistically significant and unlikely to be due to chance.

The constant term has a t-statistic of 3.023, which is also significant, indicating the model's intercept is meaningful. Diagnostic measures for the model include the Akaike Information Criterion (AIC) at 2.427, the Schwarz Criterion (SC) at 2.449, and the Hannan-Quinn Criterion (HQ) at 2.436. These relatively low values suggest the model provides a good fit to the data. The Durbin-Watson statistic of 1.884 falls within the acceptable range of 1.5 to 2.5, indicating no significant autocorrelation issues in the residuals.

Table 8. Regression results on renewable energy capacity and pollution control.

Variable	Coefficient	Std. error	t-statistic	Prob.
C	0.740	0.102	7.243	0.000
RCA	0.805	0.031	26.242	0.000
R-squared	0.655	Mean dependent variable		3.165
Adjusted R-squared	0.654	S.D. dependent variable		1.410
S.E. of regression	0.829	Akaike info criterion		2.468
Sum squared resid	248.809	Schwarz criterion		2.490
Log likelihood	-447.248	Hannan-Quinn criterion		2.477
F-statistic	688.622	Durbin-Watson stat		1.826
Prob(F-statistic)	0.000			

$$ModelLine: POC_{it} = \beta_{0it} + \beta_{1i}RCA + \mu$$

Regression Line: $POC = 0.740 + 0.805RCA$

Where RCA = Renewable energy capacity; POC = Pollution control; μ= Stochastic Error Term.

Table 8 presents the results of a regression analysis examining the impact of renewable energy capacity on pollution control by SMEs. The R-squared value of 0.655 indicates that approximately 65.54% of the variation in pollution control can be explained by changes in renewable energy capacity within the companies. The Adjusted R-squared of 0.654 further confirms the model's explanatory power, suggesting that even after adjusting for degrees of freedom, renewable energy capacity remains a significant determinant of pollution control practices among SMEs. The F-statistic of 688.622 and the associated p-value of 0.000 demonstrate that the regression model is statistically significant, meaning that the predictor variable renewable energy capacity significantly accounts for variations in pollution control performance. The relatively low Standard Error of Regression (0.829) indicates that the model's predictions are very close to the observed data, with only minor deviations. Additionally, the Sum of Squared Residuals (248.809) supports this conclusion, showing that residual errors are within acceptable limits for a good model fit. The constant coefficient (C) is 0.740, indicating that in the absence of or when renewable energy capacity is rated zero, the baseline level of pollution control is likely to be 0.739 units. Most notably, the renewable energy capacity coefficient is 0.805, which suggests that for every one-unit increase in renewable energy capacity, there is a corresponding 0.805-unit increase in pollution control, ceteris paribus. Regarding reliability, the standard error of the renewable energy capacity coefficient (0.031) is very low, indicating that the estimate is precise and stable. The t-statistic of 26.242 and p-value of 0.000 imply that the relationship between renewable energy capacity and pollution control is statistically significant. The constant term is also statistically significant, with a t-value of 7.243 and a p-value below 0.05. Model selection criteria further validate the robustness of the regression results, with the Akaike Information Criterion (AIC) value being 2.468, the Schwarz Criterion (SC) being 2.490, and the Hannan-Quinn Criterion (HQ) being 2.477. These values suggest that the model strikes a good balance between accuracy and simplicity and is free from overfitting while effectively explaining the relationship. The Durbin-Watson statistic of 1.826 falls within the acceptable range of 1.5 to 2.5, indicating no autocorrelation issues and that the residuals are independent.

Table 9. Effect of electricity access from renewables on environmental responsibility.

Variable	Coefficient	Std. error	t-statistic	Prob.
C	0.165	0.061	2.721	0.007
EAR	0.946	0.018	52.882	0.000
R-squared	0.885	Mean dependent variable		3.113
Adjusted R-squared	0.885	S.D. dependent variable		1.361
S.E. of regression	0.461	Akaike info criterion		1.296
Sum squared resid	77.061	Schwarz criterion		1.318
Log likelihood	-233.929	Hannan-Quinn criterion		1.305
F-statistic	2796.553	Durbin-Watson stat		2.854
Prob(F-statistic)	0.000			

$$ModelLine: ENR_{it} = \beta_{0it} + \beta_{1i}EAR + \mu$$

Regression Line: $ENR = 0.165 + 0.946EAR$

Where EAR = Electricity access from renewables; ENR = Environmental responsibility; μ= Stochastic Error Term.

Table 9 shows the results of a regression analysis that examined the effect of renewable electricity access on environmental responsibility. The R-squared value of 0.885 indicates that nearly 88.54% of the variation in environmental responsibility is explained by SMEs' access to renewable electricity. This reflects a high explanatory power of the model, implying that renewable electricity access plays a significant role in determining SMEs' environmental practices. The adjusted R-squared of 0.885 further demonstrates the strength of the model, indicating that even after accounting for degrees of freedom, the predictor variable remains a significant determinant of being eco-friendly. The F-statistic value of 2796.553 and a p-value of 0.000 suggest that the regression model is statistically significant, meaning that access to renewable electricity significantly explains the variation in environmental responsibility across SMEs. The very small standard error of the regression, 0.461, indicates that the model's predicted values are close to the actual observed values, reflecting high accuracy. Additionally, the sum of squared residuals, 77.061, confirms that the residuals are within an acceptable range, validating the regression model.

The table indicates that the coefficient of access to electricity from renewables is 0.946. This implies that a one-unit increase in access to renewable electricity results in an increase in environmental responsibility by 0.946 units, assuming all other factors remain constant. The standard error of this coefficient (0.018) is notably low, demonstrating that the estimate is highly precise and stable. The t-statistic value of 52.882, coupled with a p-value of 0.000, confirms that access to renewable electricity has a statistically significant and positive effect on environmental responsibility. The constant term is also significant, with a t-value of 2.721 and a p-value of 0.007, which is less than 0.05. Additionally, model selection criteria support the appropriateness of the model: the Akaike Information Criterion (AIC) is 1.296, the Schwarz Criterion (SC) is 1.318, and the Hannan-Quinn Criterion (HQ) is 1.305. These values suggest that the model strikes an optimal balance between goodness of fit and parsimony, avoiding overfitting. The Durbin-Watson statistic of 2.854 falls within the acceptable range, indicating no issues with autocorrelation.

5. DISCUSSION

Findings revealed that the consumption of renewable energy significantly affects carbon sequestration by SMEs. This, in turn, necessitates the consumption of renewable energy to enhance carbon management and environmentally friendly practices. The implication is that SMEs that increase their consumption of renewable energy sources will be able to offset carbon emissions, thereby ensuring cleaner production processes and improved environmental quality. This aligns with the findings of Hailemariam et al. (2022) and Kwakwa et al. (2024) that the use of renewable energy influences the capacity of firms to reduce greenhouse gas emissions. Further, Raj, Prabakaran, Selvakumar, and Manjunath (2025) verified that the use of renewable energy by SMEs enhances low-emission behavior and environmental performance. This finding confirms that the application of renewable energy is a major step in achieving carbon neutrality and aligning SME activities with global climate targets.

Findings showed that renewable energy capacity has a significant effect on pollution control among SMEs. This implies that developing renewable energy capacity enables SMEs to operate more sustainably, enhance production efficiency, and comply with environmental regulations. The finding highlights the importance of developing renewable energy infrastructure as a tool for minimizing industrial pollution and environmental degradation. This supports the view of Ebhota and Jen (2020) and Usman et al. (2025), who asserted that the expansion of renewable energy capacity substantially lowers pollutant emissions by replacing fossil-based systems with clean energy technologies. The finding also aligns with Suleiman (2023), who revealed that firms with high renewable energy capacity show higher environmental compliance and reduced waste output.

The study found that access to electricity from renewables significantly and positively affects environmental responsibility. This implies that access to renewable electricity increases SMEs' ability to enhance environmental stewardship and comply with sustainability policies. The finding confirms the significant role of accessible renewable electricity in shaping environmentally ethical business practices. The findings are consistent with the studies of Awamleh et al. (2025) and Guo et al. (2022), which concluded that the availability of renewable electricity encourages SMEs to make their practices green and incorporate sustainability into their operational frameworks. Similarly, Balogun et al. (2023) observed that access to renewable electricity increases the environmental responsibility and green compliance of companies.

6. CONCLUSION

This study concludes that utilization of renewable energy can improve environmental sustainability among SMEs. The adoption of renewable energy sources such as solar, wind, and biomass is a strategic option for reducing dependence on fossil fuels, mitigating greenhouse gas emissions, and encouraging environmentally friendly industrial practices. SMEs can improve their environmental performance, enhance their sustainability profile, and attract environmentally conscious customers, investors, and development partners who increasingly prefer green business models through the adoption of renewable energy.

7. RECOMMENDATIONS

The following recommendations are made.

i. SMEs need to prioritize the adoption and utilization of renewable energy sources such as solar, wind, and biomass to improve their environmental sustainability.
ii. SMEs should increase their investment in renewable energy infrastructure and capacity development to strengthen their ability to control pollution and manage waste efficiently.
iii. Renewable electricity access needs to be enhanced and made more reliable through a concerted effort by private sector financiers, the government, and energy suppliers.

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Institutional Review Board Statement: The Ethical Committee of the Department of Business Administration, Prince Abubakar Audu University, Nigeria has granted approval for this study on 16 June 2025.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Data Availability Statement: Upon a reasonable request, the supporting data of this study can be provided by the corresponding author.
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