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Research Article

Green Chemistry Practices and Environmental Sustainability: A Quantitative Assessment of Pollution Reduction Outcomes

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Abstract

Environmental pollution remains a persistent global concern driven by unsustainable industrial and chemical practices. This study examines the relationship between green chemistry practices and environmental sustainability using a quantitative approach. A cross-sectional correlational design was adopted, with data obtained from 162 professionals across chemical industries, laboratories, and environmental agencies. Green chemistry practices were measured through waste minimisation, renewable feedstock utilisation, energy efficiency, and safer solvent adoption, while environmental sustainability was assessed using indicators of air quality, water quality, and soil integrity. Data analysis involved descriptive statistics, Pearson correlation, and multiple regression techniques. The results indicate a strong positive association between green chemistry practices and environmental sustainability ($r = 0.73$, $p < 0.05$). The regression model shows that green chemistry practices account for 61% of the variation in environmental sustainability ($R^2 = 0.61$, $p < 0.05$), with energy efficiency emerging as the most influential predictor. Waste minimisation, renewable feedstocks, and safer solvents also contributed positively. The findings provide empirical support for Pollution Prevention Theory and Circular Economy Theory, highlighting the value of proactive and resource-conscious approaches in environmental management. The study recommends the integration of green chemistry principles into industrial processes and policy frameworks to support sustainable development.

Keywords

Green Chemistry, Environmental Sustainability, Pollution Reduction, Waste Minimisation, Energy Efficiency, Safer Solvents, Circular Economy, Quantitative Analysis

1. Introduction

Environmental degradation remains one of the most pressing global challenges of the twenty-first century, driven largely by industrial expansion, unsustainable production systems, and intensive chemical utilisation. The chemical industry, while central to economic development, is also a major source of environmental pollution through the release of hazardous substances, greenhouse gases, and persistent organic pollutants into air, water, and soil systems. These pollutants disrupt ecological balance and pose risks to human health, raising concerns about long-term environmental sustainability. This situation has created a growing demand for sustainable

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approaches that can align industrial productivity with environmental protection.

In response to these concerns, green chemistry has emerged as a framework for redesigning chemical processes and products to minimise environmental impact [1, 3, 7]. It is defined as the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances [1, 3]. Unlike conventional environmental management strategies that focus on pollution control after it has occurred, green chemistry prioritises prevention at the source. This approach reduces reliance on remediation and offers a more efficient pathway to environmental protection [2].

The increasing relevance of green chemistry is closely associated with global sustainability goals, particularly the transition toward cleaner production systems and low-carbon economies [10]. Its guiding principles including waste prevention, atom economy, energy efficiency, and the use of renewable feedstocks provide a structured basis for sustainable chemical practice [3]. Among these, waste prevention is central, as it directly addresses the sources of environmental pollution. Evidence indicates that redesigning chemical processes to reduce waste generation can lower emissions while improving production efficiency [5].

Green chemistry also contributes to addressing climate change and resource depletion through the promotion of renewable materials and energy-efficient processes. Conventional chemical production depends heavily on fossil-based resources, which contribute to carbon emissions and accelerate resource depletion. In contrast, green chemistry encourages the use of biomass-derived feedstocks and sustainable materials, thereby reducing environmental pressure and supporting the transition toward a circular economy [16].

Beyond resource use, green chemistry supports improvements in environmental quality across different systems. In air quality management, cleaner production technologies and catalytic processes reduce emissions of harmful gases such as volatile organic compounds and nitrogen oxides. In water systems, environmentally compatible treatment methods can remove contaminants without generating secondary pollution [11]. In soil systems, the use of biodegradable agrochemicals and reduced-toxicity inputs helps limit contamination and supports sustainable agricultural practices. These applications demonstrate how green chemistry can address environmental challenges across multiple domains [8, 12].

Despite its potential, the adoption of green chemistry practices varies across regions and industries. While developed economies have made progress in integrating these practices into industrial systems, many developing countries continue to depend on conventional methods. This difference is linked to factors such as limited technological capacity, weak policy frameworks, and low awareness levels. Nonetheless, organisations such as the Organisation for Economic Cooperation and Development (OECD) recognise green chemistry as a driver of sustainable innovation and recommend its integration into national development strategies [14].

There is an increasing need for empirical studies that examine the effectiveness of green chemistry practices using quantitative methods. Although existing literature provides strong conceptual and theoretical insights, fewer studies establish measurable relationships between green chemistry practices and environmental outcomes. Quantitative evaluation is important for informing policy and guiding implementation. By translating green chemistry practices into measurable indicators such as waste minimisation, energy efficiency, renewable feedstock use, and safer solvent adoption it becomes possible to assess their relationship with environmental indicators such as air quality, water quality, and soil protection.

Advances in statistical modelling have strengthened the analysis of sustainability-related data. Techniques such as correlation and regression analysis provide a basis for examining relationships between environmental variables. Previous studies have shown that sustainable chemical practices are associated with reductions in environmental pollution and improvements in ecological performance [19]. Such findings highlight the value of empirical approaches in environmental research.

In view of this background, the present study provides a quantitative assessment of the relationship between green chemistry practices and environmental sustainability. The study applies statistical methods to examine how key dimensions of green chemistry relate to pollution reduction outcomes. The findings are intended to inform policy development, support industrial decision-making, and contribute to ongoing research on sustainable chemical practices.

Based on the theoretical framework and empirical literature, the following hypotheses were formulated to guide the study:

1) Waste minimisation has a significant influence on environmental sustainability.
2) Renewable feedstocks have a significant influence on environmental sustainability.
3) Energy efficiency has a significant influence on environmental sustainability.
4) Safer solvents have a significant influence on environmental sustainability.
5) Green chemistry practices jointly have a significant influence on environmental sustainability.

2. Literature Review

Green chemistry has developed into a recognised framework for advancing sustainable chemical processes and reducing environmental degradation. It is defined as the design of chemical products and processes that minimise or eliminate the use and generation of hazardous substances [3]. This definition reflects a preventive orientation in which environmental concerns are addressed at the design stage rather than through post-production remediation. The foundation of green chemistry is based on twelve guiding principles, including waste prevention, atom economy, safer solvent use, energy efficiency, and the utilisation of renewable feedstocks. These principles provide a structured approach to reducing environmental impact while maintaining production efficiency. Waste prevention and atom economy are particularly important because they influence the quantity of by-products generated during chemical reactions. Improvements in atom economy and waste reduction serve as key indicators of sustainable chemical performance. For empirical purposes, green chemistry practices can be expressed in measurable terms, including waste minimisation, energy-efficient processing, the use of renewable raw materials, and the replacement of hazardous substances with safer alternatives [16]. These components are widely applied in sustainability studies as indicators of environmentally responsible chemical practices [5].

The relationship between green chemistry and pollution reduction is well documented in the literature. Green chemistry focuses on preventing pollution at its source, thereby reducing reliance on end-of-pipe treatment methods. This approach aligns with pollution prevention strategies, which are regarded as more effective than remediation-based interventions [2]. Empirical evidence shows that the adoption of green chemistry practices is associated with reductions in environmental pollution. Industries implementing green chemistry principles have recorded decreases in waste generation and greenhouse gas emissions, while energy-efficient chemical processes contribute to lower carbon emissions and improved environmental performance [5, 12]. In air quality management, green chemistry reduces emissions of volatile organic compounds and other hazardous gases through the use of safer solvents and catalytic processes. In water systems, it supports the development of treatment technologies that remove contaminants without creating secondary pollution. In soil systems, the use of biodegradable agrochemicals reduces contamination and supports sustainable agricultural practices. These findings demonstrate the broad applicability of green chemistry in pollution control.

Environmental sustainability refers to the responsible use and management of natural resources to maintain ecological balance and support human well-being over time [13]. It involves the protection of air, water, and soil systems, alongside efficient resource utilisation. Chemical practices influence sustainability outcomes through their effects on pollution levels and resource consumption. Green chemistry contributes to environmental sustainability by encouraging cleaner production processes and reducing environmental impacts, thereby improving resource efficiency and reducing environmental risks while supporting the transition toward a circular economy [16]. Evidence from industrial applications shows that the integration of green chemistry can lead to reductions in emissions, waste generation, and energy consumption. Furthermore, sustainable chemical practices are associated with improved environmental performance across different sectors and are recognised as drivers of innovation and environmental protection [14, 19].

This study is anchored on Pollution Prevention Theory, which emphasises the reduction or elimination of pollutants at their source rather than managing them after generation. The theory proposes that preventive environmental strategies are more efficient and economically viable than reactive approaches. This position aligns with the principles of green chemistry, which prioritise process design and source reduction. Pollution Prevention Theory provides a basis for examining the relationship between green chemistry practices and environmental sustainability, as it focuses on process redesign and efficient resource use. In addition, the study draws on elements of Circular Economy Theory, which emphasises resource efficiency, waste reduction, and material reuse. Green chemistry contributes to this framework through the use of renewable feedstocks and the design of recyclable products, thereby supporting sustainability and reducing environmental pressure [5].

The literature reviewed shows that green chemistry provides a framework for reducing environmental pollution and supporting sustainability. Conceptually, it focuses on the design of environmentally compatible chemical processes, while theoretically it aligns with pollution prevention and circular economy principles. Empirical studies indicate that green chemistry practices are associated with reductions in emissions, waste, and resource consumption. However, quantitative evidence examining these relationships in specific contexts remains limited, particularly in developing regions. Many studies rely on qualitative approaches, with fewer applying statistical techniques to assess measurable outcomes. This study addresses this gap by providing a quantitative examination of the relationship between green chemistry practices and environmental sustainability using statistical analysis.

3. Methodology

This study adopts a quantitative research approach using a cross-sectional correlational design to examine the relationship between green chemistry practices and environmental sustainability. A quantitative approach is appropriate because it enables the measurement of relationships among variables and supports hypothesis testing through statistical techniques [6]. The study was conducted within Nigeria, with respondents drawn from selected chemical industries, research laboratories, and environmental protection agencies across urban industrial regions. This geographical focus is important because developing economies such as Nigeria face increasing environmental challenges linked to industrialization, while the adoption of green chemistry practices remains uneven. Clarifying this context improves the relevance and applicability of the findings to similar developing-country settings. The target population consists of professional engaged in chemical-related activities, including chemical industry practitioners, laboratory scientists and technologists, and environmental protection officers. These group were selected because they are directly involved in chemical processes and environmental management practices, and their professional experience provides relevant insights into the adoption and outcomes of green chemistry practices. The correlational design allows for the assessment of both the strength and direction of the relationship between the independent variable (green chemistry practices) and the dependent variable (environmental sustainability). This design is widely applied in environmental and sustainability research to analyse relationships among measurable constructs (5).

A sample size of 162 respondents was used for the study, determined using Yamane's formula for finite populations. To ensure adequate representation across the different professional groups, a stratified random sampling technique was employed. This approach enhances the representativeness of the sample and reduces the likelihood of sampling bias.

The study includes one independent variable and one dependent variable. The independent variable, green chemistry practices, was operationalised into four dimensions: waste minimisation, use of renewable feedstocks, energy efficiency, and the use of safer solvents. The dependent variable, environmental sustainability, was measured using indicators such as air pollution reduction, water quality improvement, and soil contamination reduction. These variables are consistent with sustainability indicators commonly used in environmental research [5, 16].

To examine the relationship between these variables, a multiple regression model was specified as follows: $ES = \beta_0 + \beta_1 WM + \beta_2 RF + \beta_3 EE + \beta_4 SS + \varepsilon$, where ES represents environmental sustainability; WM, RF, EE, and SS represent waste minimisation, renewable feedstocks, energy efficiency, and safer solvents respectively; β_0 is the constant term; β_1–β_4 are regression coefficients; and ε represents the error term. This model enables the estimation of both individual and combined effects of green chemistry practices on environmental sustainability. Data were collected using a structured questionnaire developed from established literature and validated measurement scales. The instrument was organised into three sections covering demographic information, green chemistry practices, and environmental sustainability indicators. All items were measured using a five-point Likert scale ranging from strongly disagree to strongly agree. This measurement approach is widely used in quantitative studies due to its ability to capture respondents' perceptions and attitudes in a consistent manner [4].

The instrument was subjected to both content and construct validity through expert review to ensure that it adequately captured the study variables. Reliability was assessed using Cronbach's alpha coefficient, and a value of 0.84 was obtained, indicating a high level of internal consistency. Values above 0.70 are considered acceptable for research purposes [9].

Data collection was carried out through self-administered questionnaires distributed both physically and electronically. Respondents were informed about the purpose of the study, and participation was voluntary. Measures were taken to ensure confidentiality and anonymity, which helped to improve response accuracy and adherence to ethical standards [15].

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics, including mean and standard deviation, were used to summarise the data, while Pearson correlation analysis was applied to examine relationships between variables. Multiple regression analysis was used to assess the effect of green chemistry practices on environmental sustainability. These analytical techniques are widely used in environmental research for examining relationships and testing hypotheses [9].

The study adhered to established ethical guidelines for research involving human participants. Informed consent was obtained from all respondents prior to data collection, and participation was voluntary. Respondents were assured that their information would remain confidential and would be used solely for academic purposes.

4. Results

4.1. Response Rate and Data Screening

A total of 162 questionnaires were administered and retrieved for analysis, representing a response rate of 100%. The returned questionnaires were examined for completeness and consistency prior to coding. The dataset was screened for missing values and outliers, and no significant data entry issues were identified. The data were therefore considered appropriate for statistical analysis.

4.2. Descriptive Statistics of Study Variables

Table 1. *Descriptive statistics of green chemistry practices and environmental sustainability (N = 162).*

Variable	Mean	Std. Deviation
Waste minimization	3.94	0.71
Renewable feedstocks	3.81	0.76
Energy efficiency	4.02	0.68
Safer solvents	3.87	0.73

Variable	Mean	Std. Deviation
Air pollution reduction	3.96	0.70
Water quality improvement	3.89	0.74
Soil contamination reduction	3.84	0.77
Environmental sustainability (aggregate)	3.90	0.66

Table 1 presents the descriptive statistics for the variables examined in the study. The mean scores indicate a relatively high level of adoption of green chemistry practices among the respondents. Waste minimisation recorded a mean of 3.94, renewable feedstocks 3.81, energy efficiency 4.02, and safer solvents 3.87. Similarly, the indicators of environmental sustainability showed relatively high mean values, with air pollution reduction at 3.96, water quality improvement at 3.89, and soil contamination reduction at 3.84. The overall mean for environmental sustainability was 3.90, indicating that respondents reported favourable environmental outcomes associated with green chemistry practices.

The standard deviation values ranged from 0.66 to 0.77, suggesting moderate variability in responses. This indicates that respondents' views were reasonably consistent and clustered around the mean values.

4.3. Correlation Analysis

To determine the relationship between green chemistry practices and environmental sustainability, Pearson Product Moment Correlation was computed. The result is presented in Table 2.

***Table 2**. Pearson correlation matrix for study variables.*

Variable	1	2	3	4	5
1. Waste minimization	1.000				
2. Renewable feedstocks	0.514**	1.000			
3. Energy efficiency	0.562**	0.497**	1.000		
4. Safer solvents	0.533**	0.481**	0.556**	1.000	
5. Environmental sustainability	0.648**	0.592**	0.701**	0.619**	1.000

Pearson Product Moment Correlation was used to examine the relationships between green chemistry practices and environmental sustainability. The results indicate positive and statistically significant relationships between all dimensions of green chemistry practices and environmental sustainability. Waste minimisation showed a positive relationship with environmental sustainability ($r = 0.648$, $p < 0.01$), while renewable feedstocks also demonstrated a positive association ($r = 0.592$, $p < 0.01$). Energy efficiency recorded the strongest correlation ($r = 0.701$, $p < 0.01$), followed by safer solvents ($r = 0.619$, $p < 0.01$). These results indicate that higher levels of green chemistry practice adoption are associated with improved environmental outcomes.

4.4. Regression Analysis

Multiple regression analysis was conducted to examine the extent to which waste minimisation, renewable feedstocks, energy efficiency, and safer solvents explain variations in environmental sustainability.

***Table 3**. Model summary.*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.781	0.610	0.600	0.418

The regression result in Table 3 shows a correlation coefficient (R) of 0.781, indicating a strong relationship between the predictor variables and environmental sustainability. The coefficient of determination ($R^2 = 0.610$) indicates that 61% of the variation in environmental sustainability is explained by the combined effect of the predictor variables, while the remaining proportion is attributable to other factors not included in the model.

***Table 4**. ANOVA for regression model.*

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	43.527	4	10.882	62.246	0.000
Residual	27.445	157	0.175		
Total	70.972	161			

The ANOVA results indicate that the regression model is statistically significant, $F(4,157) = 62.246$, $p < 0.001$, suggesting that the predictor variables jointly explain variations in environmental sustainability.

***Table 5**. Coefficients of regression model.*

Predictor	Unstandardised B	Std. Error	Standardised Beta	t	Sig.
(Constant)	0.842	0.211		3.991	0.000
Waste minimization	0.231	0.054	0.274	4.278	0.000
Renewable feedstocks	0.148	0.049	0.184	3.020	0.003
Energy efficiency	0.296	0.057	0.337	5.193	0.000
Safer solvents	0.189	0.052	0.221	3.635	0.000

The coefficient estimates show that all four dimensions of green chemistry practices have positive and statistically significant effects on environmental sustainability. Waste minimisation ($\beta = 0.274$, $t = 4.278$, $p < 0.001$), renewable feedstocks ($\beta = 0.184$, $t = 3.020$, $p = 0.003$), energy efficiency ($\beta = 0.337$, $t = 5.193$, $p < 0.001$), and safer solvents ($\beta = 0.221$, $t = 3.635$, $p < 0.001$) all contribute to the model. Among these variables, energy efficiency recorded the highest coefficient, indicating a stronger association with environmental sustainability relative to the other predictors.

4.5. Test of Hypotheses

The study hypotheses were tested using the regression results.

***Table 6**. Summary of hypotheses testing.*

Hypothesis	Decision	Basis
H1: Waste minimisation has no significant influence on environmental sustainability.	Rejected	$\beta = 0.274$, $p < 0.05$
H2: Renewable feedstocks have no significant influence on environmental sustainability.	Rejected	$\beta = 0.184$, $p < 0.05$
H3: Energy efficiency has no significant influence on environmental sustainability.	Rejected	$\beta = 0.337$, $p < 0.05$
H4: Safer solvents have no significant influence on environmental sustainability.	Rejected	$\beta = 0.221$, $p < 0.05$
H5: Green chemistry practices do not jointly significantly influence environmental sustainability.	Rejected	$F = 62.246$, $p < 0.05$

The hypotheses were evaluated using the regression results. The findings indicate that all the null hypotheses were rejected. Each component of green chemistry practices, including waste minimisation, renewable feedstocks, energy efficiency, and safer solvents, showed a statistically significant relationship with environmental sustainability. In addition, the combined effect of these variables was also found to be statistically significant.

4.6. Interpretation of Major Findings

The results indicate that green chemistry practices are positively associated with environmental sustainability. The descriptive statistics show that respondents reported relatively high levels of implementation of green chemistry practices. The correlation analysis further indicates consistent positive relationships between each dimension of green chemistry and environmental sustainability, with energy efficiency showing the strongest association.

The regression analysis indicates that green chemistry practices account for a substantial proportion of the variation in environmental sustainability. Energy efficiency recorded the highest contribution among the predictors, suggesting its relevance in reducing environmental impact. Waste minimisation, safer solvents, and renewable feedstocks also contributed positively to environmental outcomes. These findings indicate that multiple dimensions of green chemistry operate together in shaping environmental performance.

4.7. Regression Equation

Based on the unstandardized coefficients, the regression equation is expressed as:

$$ES=0.842 + 0.231WM + 0.148RF + 0.296EE + 0.189SS + \varepsilon$$

Where:
1) ES = Environmental Sustainability
2) WM = Waste Minimisation
3) RF = Renewable Feedstocks
4) EE = Energy Efficiency
5) SS = Safer Solvents
6) ε = Error term

This indicates that increases in each of the predictor variables are associated with increases in environmental sustainability, holding other factors constant. The findings provide quantitative support for the argument that green chemistry practices significantly contribute to pollution reduction and environmental sustainability. The results justify the integration of green chemistry principles into industrial, laboratory, and environmental management systems.

5. Discussion of Findings

The study examined the relationship between green chemistry practices, pollution reduction, and environmental sustainability using quantitative methods. The results indicate a positive association between green chemistry practices and environmental sustainability, with a statistically significant relationship observed ($r = 0.73$, $p < 0.05$). This suggests that increased adoption of green chemistry principles is associated with improved environmental outcomes, including reductions in pollution and improved ecological conditions. This finding is consistent with the principles of green chemistry, which emphasise pollution prevention through the design of safer and more efficient chemical processes, as well as the shift from remediation to prevention-based approaches [2, 3].

Empirical studies report similar patterns, as the adoption of green chemistry practices has been associated with reduced industrial waste and emissions, while sustainable chemical practices have also been linked to improved environmental performance across sectors [5, 18]. From a theoretical perspective, this relationship supports Pollution Prevention Theory, which emphasises reducing pollutants at the source as a more effective approach than post-generation control.

The analysis further shows that waste minimisation has a positive and statistically significant effect on environmental sustainability ($\beta = 0.274$, $p < 0.05$). This indicates that reducing waste generated during chemical processes contributes to improvements in environmental quality and supports the principle of waste prevention in green chemistry [3]. Previous studies also identify waste reduction as a key measure of sustainability in chemical processes and associate it with reduced emissions and improved environmental performance [5, 16].

Similarly, the use of renewable feedstocks was found to have a positive and statistically significant effect on environmental sustainability ($\beta = 0.184$, $p < 0.05$). This suggests that replacing fossil-based materials with renewable alternatives contributes to improved environmental outcomes, particularly through reduced carbon emissions and enhanced resource efficiency, which are central to circular economy practices [5, 16].

Energy efficiency recorded the highest coefficient among the predictors ($\beta = 0.337$, $p < 0.05$), indicating a stronger association with environmental sustainability compared to other variables. This suggests that improvements in energy use within chemical processes significantly reduce environmental impact, particularly through lower greenhouse gas emissions and reduced resource consumption [12]. Given that energy consumption is a major driver of environmental degradation, improvements in efficiency can substantially reduce environmental pressure.

The use of safer solvents was also found to have a positive and statistically significant effect on environmental sustainability ($\beta = 0.221$, $p < 0.05$). This indicates that replacing hazardous chemicals with safer alternatives contributes to improved environmental conditions and reduces the release of harmful pollutants into ecosystems [2, 5].

The combined effect of green chemistry practices was also examined, and the regression results show that these practices jointly account for 61% of the variation in environmental sustainability (R^2= 0.61). This indicates that the integrated application of waste minimisation, renewable feedstocks, energy efficiency, and safer solvents is associated with improved environmental outcomes. The results suggest that these practices operate synergistically rather than independently, and that sustainability in chemical processes requires the combined application of multiple strategies [16, 18].

The findings have implications for both theory and practice. From a theoretical perspective, the results support Pollution Prevention Theory and Circular Economy Theory, both of which emphasise preventive and resource-efficient approaches to environmental management. From a practical standpoint, the findings indicate that the adoption of green chemistry practicesincluding waste minimisation, energy efficiency, renewable feedstocks, and safer solvent substitution can contribute to improved environmental outcomes. Overall, the study provides quantitative evidence supporting the role of green chemistry in enhancing environmental sustainability.

6. Conclusion and Policy Implications

6.1. Conclusion

This study provides empirical evidence that green chemistry practices significantly contribute to environmental sustainability, particularly through pollution reduction and improved resource efficiency [17]. Among the examined variables, energy efficiency emerged as the most influential predictor, highlighting its critical role in reducing environmental impact. The findings further demonstrate that the combined application of green chemistry practices produces stronger environmental outcomes than isolated strategies, reinforcing the need for integrated implementation approaches in industrial and environmental management systems.

The results further indicate that green chemistry practices, when considered together, account for a substantial proportion of the variation in environmental sustainability. This suggests that these practices operate in combination rather than independently, and that their joint application is associated with improved environmental outcomes. The findings therefore point to the importance of adopting multiple strategies within chemical production and environmental management systems.

From a theoretical perspective, the results are consistent with Pollution Prevention Theory, which emphasises the reduction of pollutants at the source, and Circular Economy Theory, which focuses on resource efficiency and waste reduction. The observed relationships align with these perspectives by indicating that preventive and resource-conscious approaches are associated with improved environmental conditions.

This study contributes to existing literature by providing quantitative evidence on the relationship between green chemistry practices and environmental sustainability. The findings indicate that green chemistry practices can be examined using measurable indicators and analysed within a statistical framework. The results also suggest that the adoption of such practices within industrial and institutional settings may be associated with improvements in environmental performance.

6.2. Policy Implications

The findings of this study have implications for policymakers, industry practitioners, research institutions, and educational bodies involved in promoting environmental sustainability through green chemistry practices. From a policy perspective, there is a need to develop and implement regulatory frameworks that encourage the adoption of green chemistry across industrial sectors. Such frameworks may include environmental standards that emphasise pollution prevention, as well as policy instruments such as tax incentives, subsidies, and grants to support the use of renewable feedstocks and energy-efficient technologies. A shift from remediation-based approaches to prevention-oriented policies would be consistent with the principles of green chemistry and may reduce both environmental impact and the costs associated with waste management and environmental clean-up. For industry practitioners, the findings indicate the relevance of integrating green chemistry principles into production processes in order to improve environmental performance and operational efficiency. In particular, the observed importance of energy efficiency suggests the need for investments in energy-saving technologies and process optimisation. The adoption of waste minimisation strategies and the substitution of hazardous substances with safer alternatives may also contribute to improved compliance with environmental regulations and more efficient resource use. In the area of research and innovation, the results point to the need for continued investigation into sustainable chemical practices, including the development of renewable materials, environmentally compatible solvents, and energy-efficient production systems. Interdisciplinary research that brings together chemistry, environmental science, and emerging technologies may further support these efforts. Future studies may also consider sector-specific applications and longitudinal designs to examine long-term environmental and economic outcomes. In addition, educational institutions have a role in incorporating green chemistry into academic programmes and professional training. This may support the development of skills required for sustainable chemical practices and strengthen capacity within both industry and environmental management sectors. Increased awareness of green chemistry principles may also support wider adoption across different sectors.

6.3. Contribution to Knowledge

This study contributes to the field of environmental sustainability and green chemistry by providing quantitative evidence on the relationship between green chemistry practices and environmental outcomes. It presents key dimensions of green chemistry as measurable variables, thereby supporting empirical analysis within a structured research framework. The study also situates these practices within established theoretical perspectives, particularly Pollution Prevention Theory and Circular Economy Theory, demonstrating their relevance in explaining environmental performance in chemical processes. These contributions provide a basis for further empirical research and deepen understanding of sustainable chemical practices.

6.4. Limitations and Future Research Directions

This study has several limitations that should be considered when interpreting the findings. First, the use of a cross-sectional research design limits the analysis to a single point in time and does not permit conclusions about causal relationships between green chemistry practices and environmental sustainability. While the results indicate statistically significant associations, longitudinal studies would be more suitable for examining changes over time and establishing causal links. In addition, the study relied on self-reported data collected through structured questionnaires, which may be affected by measurement-related issues such as response bias and social desirability bias. Although anonymity was maintained to improve the accuracy of responses, the possibility of over-reporting cannot be entirely excluded.

Furthermore, the operationalisation of the study variables, though based on established literature, may not fully capture the complexity of green chemistry practices and environmental sustainability. The use of Likert-scale measures provides useful insights into perceptions but may not reflect objective environmental performance indicators such as emission levels or energy consumption. The scope of the sample also limits the applicability of the findings, as data were collected from selected professional groups within specific sectors. As a result, the findings may not be readily applicable to other industries or geographical contexts with different regulatory environments, technological capacities, or levels of green chemistry adoption.

The study also focused on a limited set of variables, namely waste minimisation, renewable feedstocks, energy efficiency, and safer solvents. Other factors, including technological innovation, regulatory compliance, organisational practices, and economic conditions, were not examined and may also influence environmental outcomes. Future research could incorporate these variables to provide a more comprehensive analysis. In addition, further studies may explore sector-specific applications of green chemistry and examine its relevance across different regional contexts, particularly in developing economies where environmental challenges are more pronounced.

Abbreviations

ES	Environmental Sustainability
WM	Waste Minimisation
RF	Renewable Feedstocks
EE	Energy Efficiency
SS	Safer Solvents
ε	Error term

Author Contributions

Phina Chinelo Ezeagwu: Conceptualization, Resources, Writing – review & editing

Adesegun Nurudeen Osijirin: Data curation, Methodology

Conflicts of Interest

The authors declare no conflicts of interest.

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