From Sustainability to Product Quality: Analyzing Green Manufacturing Practices in Southwest, Nigeria

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ABSTRACT

This study focused on green manufacturing practices and product quality in Southwest Nigeria. The study employed a survey research design. The sample size of 379 was determined. A multi-stage sampling technique was used to ensure comprehensive representation. Cronbach's coefficient alpha to assess its reliability. The study employed both descriptive and inferential statistics for data analysis, using regression analyses to test hypotheses. Findings revealed that green design has significant positive effect on product serviceability (given $\beta = 0.792$; p-value <0.01); green efficient processes has significant positive effect on product perceive quality (given $\beta = 0.847$; p-value <0.01); and that green purchasing has significant positive influence on product reliability (given $\beta = 0.795$; p-value <0.01). The study strongly supports the notion that green manufacturing practices play a crucial role in improving product quality within the beverage industry in Southwest Nigeria. The study recommended that firms should focus on implementing user-friendly product designs that facilitate easy repairs and upgrades, thereby enhancing product serviceability.

Keywords: Green Manufacturing, Product Quality, Green Design, Product Serviceability, Green Efficient Processes

Introduction

The global manufacturing industry has seen a transformation due to the growing concern for environmental sustainability, especially in light of industrial practices that have historically been linked to pollution and resource depletion. This movement's historical background dates back to the industrial revolution, when the consequences of unchecked industrial activity became more apparent. Green manufacturing practices were made possible by the 1960s publication of Rachel Carson's "Silent Spring," which served as a catalyst for international efforts to mitigate environmental damage (Bhatt et al., 2020; Gandhi et al., 2018). Since ISO 14001, a global standard that promotes environmentally friendly manufacturing practices, was introduced in 1996, this change has been especially noticeable (Govindan, 2015).

Green practices may greatly reduce environmental impacts and improve product quality in the beverage business, which is a crucial area in the manufacturing sector. According to the United Nations Environmental Programme [UNEP] (2024), manufacturing is mostly responsible for the significant use of water and power, and it accounts for almost 30% of world carbon dioxide emissions. Since the Sustainable Development Goals (SDGs) place a high priority on social justice, economic growth, and environmental preservation, manufacturing firms are under increasing pressure to adopt sustainable practices that support these goals (Khoshnava et al., 2019; Ye et al., 2023).

A growing number of African nations, especially Nigeria, are realizing the value of green manufacturing as they attempt to match their industrial operations with frameworks for sustainable development. Although progress has been slow compared to other regions, many African countries, including Nigeria, are starting to realize that environmentally sustainable practices can boost economic growth in addition to addressing urgent ecological challenges (Gu et al., 2018; Tiba & Belaid, 2021; Wachira & Mathuva, 2022). As public awareness of environmental issues and the health risks associated with conventional manufacturing processes grows, regulatory bodies and consumers alike are putting increasing pressure on Nigeria's manufacturing sector to adopt greener practices (Abanyam & Uwameiye, 2019; Madu, 2022).

A shift is taking place in the beverage sector in particular as producers aim to lessen their environmental impact without sacrificing their ability to compete. The total quality of products has been demonstrated to be improved by the incorporation of green manufacturing procedures, such as sustainable supply chain practices, efficient production practices, and environmentally friendly design. Efficient manufacturing techniques have been shown to improve product uniformity and dependability, which are important components of customer satisfaction, in addition to lowering waste and pollution (Hermawan et al., 2024; Ramos et al., 2018). Additionally, there is evidence that buying materials from eco-friendly sources improves product performance and longevity, which can increase customer loyalty and trust (Ghosh, 2019; Yook et al., 2017).

Nevertheless, many companies in Southwest Nigeria's beverage industry encounter considerable challenges in successfully putting green production into practice, even with its acknowledged advantages. Problems such as poor infrastructure, restricted access to sustainable resources, and a lack of investment in green technologies may threaten the sector's long-term survival. We desperately need thorough research to examine the complex effects of green manufacturing on product quality as the industry grapples with these issues. The results will provide manufacturers with crucial information they need to successfully negotiate the complexities of sustainability in a cutthroat market. This study attempts to close this knowledge gap by exploring how adopting green practices can improve product quality and encourage environmental responsibility in the beverage sector. Thus, the study specifically:

i. Ascertained the extent to which green design affects product serviceability.
ii. Examined the effect of green efficient processes on product perceive quality.
iii. Assessed the extent to which green purchasing influences product reliability.

LITERATURE REVIEW

The existing literature offers various viewpoints regarding the conceptualizations of green manufacturing and product quality. Thus, the purpose of this study is to investigate these variables in detail and pinpoint their particular indicators. By doing this, the study hopes to shed light on the relationship between environmentally conscious manufacturing practices and the end product's quality. Gaining an understanding of these indicators can help one see how sustainable manufacturing practices can improve the quality of products. The purpose of this study is to offer a more precise framework for assessing how product quality and green manufacturing interact.

As environmental concerns and the need for sustainable production grow, green manufacturing has emerged as a significant trend. This method incorporates cutting-edge techniques to improve resource efficiency, cut waste, and lessen the negative effects of industrial activities on the environment. Green manufacturing gives firms a competitive edge in a market that is becoming more environmentally sensitive while also promoting environmental sustainability (Bui et al., 2024). At its core, green manufacturing is the "greening" of production processes with an emphasis on minimizing adverse environmental impacts and maximizing resource use (Elemure et al., 2023). By integrating sustainability into fundamental business processes, this all-encompassing strategy enhances both economic and environmental performance.

Life cycle evaluation, reverse supply chain management, and sustainable value stream mapping are important strategies that improve productivity and lessen environmental damage (Haleem et al., 2023; Leong et al., 2019; Pang & Zhang, 2019). For example, to reduce waste and promote a circular economy, reverse supply chain management entails reclaiming and reusing commodities (Kinobe et al., 2012). Similar to this, life cycle assessment guides sustainability improvements by analyzing environmental impacts during a product's lifetime (Rosenbaum et al., 2018). By encouraging techniques like recycling, reducing, and reusing resources, green manufacturing also tackles important problems like pollution and waste management (Cooper & Gutowski, 2017; Peng et al., 2018). These techniques improve long-term economic viability, regulatory compliance, and operational cost reduction in addition to environmental benefits (Luan et al., 2022). Enterprises must transition from non-renewable to renewable resources, such as bioplastics and recycled metals, to reduce their carbon footprint and transition from a linear economy to a circular one (Armstrong et al., 2023; Saxena & Srivastava, 2022). A cultural shift and the integration of sustainability into business models through industry collaboration and employee participation are necessary for the successful implementation of green manufacturing (Ali et al., 2021). Green manufacturing offers enterprises a sustainable route that combines corporate expansion with environmental stewardship. It encompasses green purchasing, green design, and green efficient operations.

Product quality is a complex idea that includes a range of characteristics that affect a product's capacity to satisfy both industry norms and consumer expectations. Reliability, perceived quality, and product serviceability are three important indicators of product quality. The term "product serviceability" describes how simple it is to upgrade, maintain, and repair a product across its whole lifecycle. It entails ease of maintenance, accessibility, and spare component availability (Das Guru & Paulssen, 2020). Puspitaweni et al. (2021) posits that well-designed serviceable products improve user experience, lower life-cycle costs, and foster brand loyalty. A consumer's subjective evaluation of a product based on expectations, brand reputation, and experience is known as perceived quality (Stylidis et al., 2020). It affects consumer loyalty and purchase decisions (Samudro et al., 2020). Product reliability quantifies a product's capacity to function reliably under predetermined circumstances. Reliability increases customer trust and lowers failure rates (Donchenko et al., 2021). Together, these proxies impact market competitiveness and product quality.

Theoretical and Hypothetical Development

The Brundtland Commission (1987) developed the Sustainable Development Theory, which combines economic, social, and environmental sustainability (Fenech-Caruana, 2023). By promoting long-term sustainability and resource efficiency, this theory backs green manufacturing (Mensah, 2019). Green design uses environmentally friendly materials that increase durability, which helps make products more serviceable. Reducing environmental impact while preserving performance is one way that green efficient processes enhance perceived quality (Aithal & Aithal, 2022). Green purchasing increases dependability by guaranteeing that materials are of superior quality and sourced ethically (Hu et al., 2022). According to research, sustainable practices encourage innovation and longer product lifespans (Yıldız et al., 2023).

Green design promotes environmentally friendly practices in product creation, which greatly improves product serviceability (Tariq et al., 2017; Wijesooriya & Brambilla, 2021). The practice makes maintenance and repair simpler by emphasizing modularity and durability (Syahrial et al., 2019). Durable goods lower maintenance requirements and failure rates, while interchangeable parts allow for updates without total replacement (De Fazio et al., 2021). Using recyclable materials also makes disassembly easier, which promotes repairs rather than disposal (He et al., 2020). Green design gives companies a competitive edge and helps them comply with regulations while also improving serviceability in response to consumer demands for sustainable products (Chuang & Huang, 2018). This knowledge informs the hypothesis that:

H1: Green design has a significant effect on product serviceability.

Green efficient processes are becoming a key strategy for improving the perceived quality of products and advancing sustainability (Le, 2022; Liu, Zhu, & Seuring, 2017). Through the use of sustainable materials, waste minimization, and resource conservation, these processes lessen their negative effects on the environment (Jahanger et al., 2023; Razzaq et al., 2021; Shrivastava & Shrivastava, 2017). Cleaner technologies, recycling programs, and energy-efficient operations all help to increase the longevity and dependability and decrease the faults of products (Razzaq et al., 2021; Siegel et al., 2019). Sustainability is becoming more and more linked by consumers to better quality, moral standards, and durable goods (Gelderman et al., 2021; Wong et al., 2020). According to studies, green practices improve emotional ties and brand perception (Szabo & Webster, 2021). Consequently, the following hypothesis emerges:

H2: Green efficient processes have a significant effect on product perceived quality.

Green purchasing is the practice of obtaining goods and services that have the least possible negative effects on the environment throughout the course of their lifecycle. In light of growing environmental consciousness, this approach has become more popular (Shao & Ünal, 2019). Product dependability is essential for customer happiness, brand loyalty, and cost savings. It is described as a product's capacity to operate correctly under given conditions for an extended period of time (Khan et al., 2023). Because green purchasing improves quality control, it can greatly increase product reliability. Organizations that put sustainability first when making purchases frequently choose suppliers who uphold strict criteria (Govindan et al., 2018). Usually, these suppliers make investments in high-quality materials that increase the longevity of the product. Companies that practice green purchasing also have a tendency to establish enduring partnerships with suppliers who prioritize quality, which guarantees more dependable products (Kumar & Barua, 2022). Furthermore, by taking a lifecycle approach, companies can spot possible reliability problems early on in the design and production process (De Giacomo et al., 2019). Sustainable and innovative materials can improve product performance, resulting in longer lifespans and fewer faults (Porter & van der Linde, 1995; Abu-Seman et al., 2019). Therefore, investigating the long-term impacts of green purchasing on product reliability is crucial to creating sustainable procurement best practices. Hence the hypothesis that:

H3: Green purchasing has a significant effect on product reliability.

In this study, we developed a framework (see fig.1) that connects green design, efficient processes, and green purchasing to product reliability, serviceability, and quality.

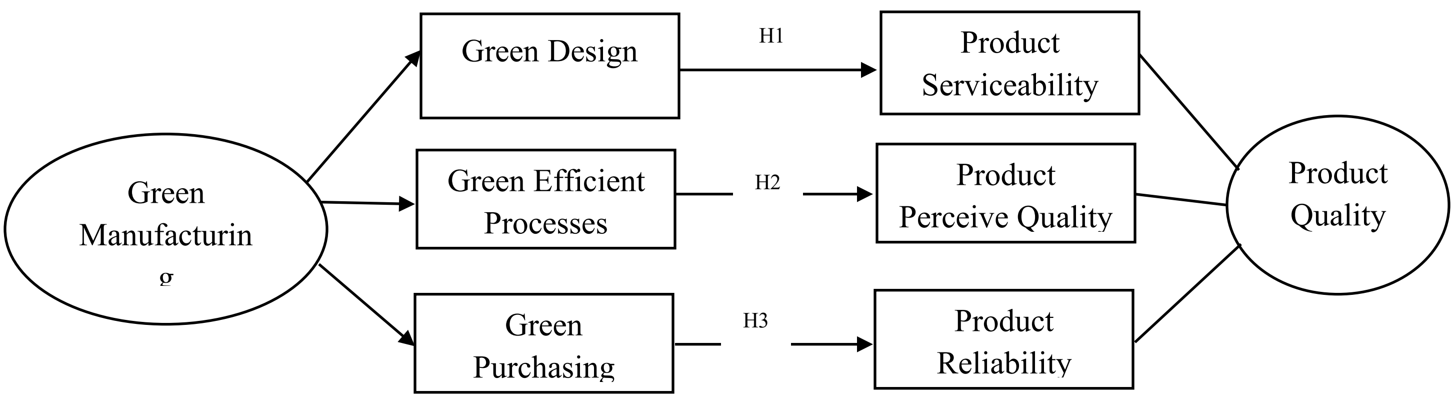

Figure 1 Conceptual Framework of Green Manufacturing and Product Quality
Source: Authors (2024)

METHODOLOGY

Research Design

In order to systematically collect data and information, the study used a survey research design that made use of a standardized research instrument. A comprehensive grasp of the variables and relationships involved was guaranteed by the survey research design. Utilizing a uniform research tool ensures consistency and dependability while streamlining data gathering (Panigrahi et al., 2023).

Data Instrument

To ensure the information is relevant and aligns with the study's goals, we used primary data gathered directly from the field. The original, carefully chosen sources used for this study provided the primary data. We carefully crafted questionnaires for a specified sample population as part of the data collection procedure. When designing the measure, the study used a 5-point Likert scale.

Population and Sampling

The study's population consisted of 30,398 prospective participants from certain industrial firms. To draw conclusions or make inferences about the complete population, a subset of the population represents the sample size. Using Krejcie and Morgan's (1970) sample size, 379 was the number of participants chosen for this investigation. The sample selection procedure employed a multi-stage sampling technique to ensure thorough representation. The first step involved classifying the participants from the chosen manufacturing firms in Southwest Nigeria according to their respective activities. The classification was further refined based on shared traits relevant to the research. The third stage involved conducting the survey in the selected states, using samples chosen according to the size of the manufacturing firms and their degree of expertise in the field. This method improved the study's inclusivity and allowed for a more in-depth analysis. We distributed 379 questionnaires in total, which is 100% of the target sample. With 350 of these successfully returned, the response rate was high at 96.58%. This suggests that the data gathered are probably representative of the target group and show high involvement.

Research instrument's validity

Factor loading served as the main analytical technique in this study, which made use of construct validity. Its capacity to investigate connections between multiple items and uncover shared underlying features made it a suitable choice for this study. Factor loadings above 0.30 are significant, loadings above 0.40 are more significant, and loadings above 0.70 are extremely significant (Creswell, 2003). These loadings show how strong these correlations are. Table 1 provides a comprehensive analysis and interpretation of the factor loading data for each construct.

Table 1 Validation of Instrument

Variable Items	Loading	Square of Loading	Sum of the square loading	AVE	CR
Green Product Design					
GPD1	0.825	0.681	3.178	0.636	0.797
GPD2	0.865	0.748			
GPD3	0.702	0.493			
GPD4	0.811	0.658			
GPD5	0.774	0.599			
Green Efficient Processes					
GPI1	0.792	0.627	3.226	0.645	0.803
GPI2	0.807	0.651			

GPI3	0.732	0.536			
GPI4	0.787	0.619			
GPI5	0.89	0.792			
Green Purchasing					
GRP1	0.8	0.64	2.937	0.587	0.766
GRP2	0.721	0.520			
GRP3	0.817	0.667			
GRP4	0.767	0.588			
GRP5	0.722	0.521			
Green Technology					
GTI1	0.735	0.540	2.924	0.585	0.765
GTI2	0.713	0.508			
GTI3	0.834	0.696			
GTI4	0.752	0.566			
GTI5	0.784	0.615			
Green Recycling					
GRR1	0.746	0.557	2.975	0.595	0.771
GRR2	0.772	0.596			
GRR3	0.756	0.572			
GRR4	0.755	0.570			
GRR5	0.825	0.681			
Product Serviceability					
PRS1	0.763	0.582	3.073	0.615	0.784
PRS2	0.732	0.536			
PRS3	0.88	0.7744			
PRS4	0.744	0.554			
PRS5	0.792	0.627			
Product Perceive Quality					
PPQ1	0.828	0.686	3.182	0.636	0.798
PPQ2	0.765	0.585			
PPQ3	0.738	0.545			
PPQ4	0.757	0.573			
PPQ5	0.891	0.794			
Product Reliability					
PRR1	0.748	0.560	2.948	0.590	0.768
PRR2	0.823	0.677			
PRR3	0.741	0.549			
PRR4	0.779	0.607			
PRR5	0.745	0.555			
Product Performance					
PRP1	0.768	0.590	3.116	0.623	0.789
PRP2	0.722	0.521			

PRP3	0.873	0.762			
PRP4	0.754	0.569			
PRP5	0.821	0.674			
Product Durability					
PRD1	0.766	0.587	3.024	0.605	0.778
PRD2	0.778	0.605			
PRD3	0.725	0.526			
PRD4	0.791	0.626			
PRD5	0.825	0.681			

Source: AMOS SPSS, 2024

Reliability of the Research Instrument

The study assessed the components' internal consistency reliability using Cronbach's coefficient alpha. We chose this method because it clearly demonstrated how well the many items measure the same variable. We calculated Cronbach's coefficient alpha, a statistic that assesses the reliability of a collection of items that together form a single scale, to evaluate internal consistency. Reliability coefficients of 0.70 or greater are generally considered satisfactory (Creswell, 2003). Therefore, items having Cronbach alpha coefficients of 0.70 or higher were considered suitable for scale inclusion in this study. Table 2 shows the reliability coefficients are higher than the generally recognized cutoff point of 0.70.

Table 2 Reliability Statistics

S/N	Variables	N of Items	Cronbach's Alpha
1	Green Product Design	5	0.754
2	Green Efficient Processes	5	0.702
3	Green Purchasing	5	0.745
4	Product Serviceability	5	0.784
5	Product Perceive Quality	5	0.715
6	Product Reliability	5	0.759

Source: SPSS, 2024

Data Analyses Techniques

For data analysis, the study employed both descriptive and inferential statistics. We displayed the data in tables using the percentage approach to provide a clear and succinct summary of the respondents' demographics. The survey results were analyzed using descriptive statistics, such as the mean and standard deviation, which reveal the data's central tendency and variability. We used the Satorra-Bentler test to assess the credibility of the data by examining covariance between proxies of the independent and dependent variables. We also used regression analyses to test the developed hypotheses.

DATA ANALYSES AND RESULTS

Table 3 Biodata of Respondents

	Responses	Frequency	Percent
Gender of participants	Male	196	56.0
	Female	154	44.0
Age of participants	< 25 years	64	18.3
	25-34 years	136	38.9
	35-44 years	86	24.6
	45-54 years	31	8.9
	55-64 years	18	5.1
	> 65 years	15	4.3
Academic Qualification of participants	SSCE	18	5.1
	OND/NCE	81	23.1
	HND/Bachelor's Degree	126	36.0
	Master's Degree	96	27.4
	Doctorate	22	6.3
	Other	7	2.0
Job role of participants	Production Man.	38	10.9
	Quality Control Off.	69	19.7
	Process Eng.	81	23.1
	Environmental Compliance Off.	115	32.9
	Operations Man.	47	13.4
Years of experience of participants	< 1 year	66	18.9
	1-3 years	79	22.6
	4-6 years	93	26.6
	7-10 years	74	21.1
	> 10 years	38	10.9

Source: Field survey (2024)

Table 3 displays the participant's gender. It reveals that there were 196 men (56%) and 154 women (44%) among the participants. Owing to the implication, men constituted the majority of those who participated in the study area.

Table 3 shows the participant's age distribution. 64 (18.3%) of participants were under 25 years old, 136 (30.8%) were between 25 and 34 years old, 86 (24.6%) were between 35 and 44 years old, 31 (8.9%) were between 45 and 54 years old, 18 (5.1%) were between 55 and 64 years old, and 15 (4.3%) were 65 years of age or older. In the research locations, most of the participants were between the ages of 25 and 34.

Table 3 displays the participant's educational backgrounds. It shows that 18 participants (5.1%) have completed secondary school; 81 participants (23.1%) have completed an ordinary national diploma; 126 participants (36.0%) have completed a bachelor's degree or higher national diploma;

96 participants (27.4%) have completed a master's certificate; 22 participants (6.3%) have completed a doctorate; and 7 participants (2.0%) have completed other certificates. Results demonstrate that a sizable percentage of the participants possess the educational background necessary to comprehend the topic.

Table 3 lists each participant's roles or job titles. It indicates that the 81 participants (23.1%) were process engineers, 115 participants (32.9%) were environmental compliance officers, 47 participants (13.4%) were operations managers, 38 participants (10.9%) were production managers, and 69 of the participants (19.7%) were quality control officers. The results demonstrate that a sizable percentage of respondents work in engineering, production, quality assurance, and environmental compliance-related activities, suggesting that the sample is representative of a wide range of occupations pertinent to the study's emphasis.

Table 3 displays each participant's years of experience. 66 participants (18.9%) had less than a year's experience, 79 participants (22.6%) had one to three years' experience, 93 participants (26.6%) had four to six years' experience, 74 participants (21.1%) had seven to ten years' experience, and 38 participants (10.9%) had more than ten years' experience. According to the results, the majority of the participants (69.2%) have one to ten years of experience, with 26.6% of participants having four to six years of experience. The result indicates that the majority of responders have moderate to substantial experience in the industry in question. Nonetheless, the distribution shows a wide variety of experience levels, which makes the analysis more thorough.

Table 4 Satorra-Bentler Covariance Test on the Constructs of Green Manufacturing

	Coef	Std. Err.	Z	P>z	[95% Conf. Interval]	
mean(GPD)	3.743	0.064	58.33	0.000	3.617	3.869
mean(GPI)	2.849	0.071	39.95	0.000	2.709	2.988
mean(GRP)	3.117	0.073	42.72	0.000	2.974	3.260
var(GPD)	1.437	0.107	-	-	1.241	1.663
var(GPI)	1.774	0.088	-	-	1.610	1.955
var(GRP)	1.858	0.084	-	-	1.701	2.029
cov(GPD,GPI)	.066	0.089	0.75	0.453	-0.107	.241
cov(GPD,GRP)	.076	0.092	0.82	0.410	0.104	.256
cov(GPI,GRP)	0.223	0.096	2.33	0.020	0.036	0.411

Source: Field Survey, 2024

Table 4 displays the results of the Satorra-Bentler Covariance Test for the green manufacturing constructs. The average score for green design is 3.743, and the Z-value is 58.33, which is very significant (p-value < 0.001). According to the confidence interval, the true mean is between 3.617 and 3.869, suggesting that participants place a high value on green design. With a significant Z-value of 39.95 (p-value < 0.001) and a confidence interval ranging from 2.709 to 2.988, the mean score for green efficient processes is 2.849. This result highlights the significance of implementing effective green procedures. With a mean score of 3.117, a Z-value of 42.72 (p-value < 0.001), and a confidence range between 2.974 and 3.260, green purchasing is well regarded.

With a variance of 1.437 and a standard error of 0.107, green design exhibits a considerable degree of perceptional variability, with a confidence range ranging from 1.241 to 1.663. With a variance of 1.774 (standard error of 0.088) and a confidence range ranging from 1.610 to 1.955, green efficient processes exhibit moderate response variability. With a confidence range ranging from 1.701 to 2.029 and a variance of 1.858 (standard error = 0.084), green purchasing exhibits some degree of perception variability.

With a Z-value of 0.75 (p-value = 0.453) and a covariance of 0.067 (standard error of 0.089), there is no discernible correlation between green design and green efficient processes within the 95% CI range of -0.107 to 0.241. With a Z-value of 0.82 (p-value = 0.410), a covariance of 0.076 (standard error of 0.092), and a confidence interval ranging from -0.104 to 0.256, the association between green design and green purchasing is not statistically significant. The significant correlation between green purchasing and green efficient processes is 0.223 (standard error of 0.096), with a Z-value of 2.33 (p-value = 0.020) and a confidence interval of 0.036 to 0.411. This result implies a favourable correlation.

The findings, however, indicate that covariances between the green manufacturing constructs are not an issue. Given that the covariance results are less than 0.5, the finding suggests that each of the constructs has real data independence, which denotes a high degree of data credibility.

Table 5 Satorra-Bentler Covariance Test on the Constructs of Products Quality

	Coef	Std. Err.	Z	P>z	[95% Conf. Interval]	
mean(PRS)	3.694	0.066	55.75	0.000	3.564	3.824
mean(PPQ)	2.923	0.073	40.29	0.000	2.781	3.065
mean(PRR)	3.177	0.074	42.99	0.000	3.032	3.322
var(PRS)	1.532	0.106	-	-	1.337	1.756
var(PPQ)	1.837	0.089	-	-	1.671	2.019
var(PRR)	1.906	0.087	-	-	1.742	2.085
cov(PRS,PPQ)	0.159	0.092	1.72	0.085	-0.022	0.340
cov(PRS,PRR)	0.263	0.097	2.71	0.007	0.073	0.453
cov(PPQ,PRR)	0.191	0.103	1.86	0.063	-0.011	0.392

Source: Field Survey, 2024

Table 5 presents the findings of the Satorra-Bentler Covariance Test concerning the product quality constructs. Product serviceability has a mean score of 3.694 and a highly significant Z-value of 55.75 (p-value < 0.001). The 95% CI (3.564 to 3.824) shows that the true mean is within this range, indicating that participants place a high value on product serviceability.

With a significant Z-value of 40.29 (p-value < 0.001) and a confidence range ranging from 2.781 to 3.065, the mean for product perceived quality is 2.923. This number implies a high opinion of the evaluated products' quality. A mean score of 3.177, a Z-value of 42.99 (p-value < 0.001), and a confidence range ranging from 3.032 to 3.322 indicate that participants place a high priority on product reliability.

With a variance of 1.532 (standard error of 0.106) and a confidence interval ranging from 1.337 to 1.756, product serviceability indicates a moderate range of opinions. Product perceived quality has a variance of 1.837 (standard error of 0.089) and a confidence interval of 1.671 to 2.019, which shows significant variability. With a confidence interval ranging from 1.742 to 2.085 and a variance of 1.906 (standard error of 0.087), product reliability reflects a wider range of responses.

There are noteworthy connections between the constructs, according to the covariance analysis. The covariance between product reliability and serviceability, for example, is 0.263 (standard error of 0.097) with a Z-value of 2.71 (p-value = 0.007), suggesting a strong positive correlation. With a Z-value of 1.72 (p-value = 0.085) and a covariance of 0.159 (standard error of 0.092), the association between product serviceability and perceived quality appears to be weaker or less certain. The relationship is not statistically significant at the 5% level. With a Z-value of 1.86 (p-value = 0.063) and a covariance of 0.191 (standard error of 0.103), product perceived quality and product reliability are close to significant but fall short of the traditional 5% threshold.

Table 6: Regression on Green design and Product serviceability

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.728	0.140	5.220	<0.001
GPD	0.792	0.035	22.324	<0.001
R-squared	0.589	Mean dependent var		3.694
Adjusted R-squared	0.588	S.D. dependent var		1.240
S.E. of regression	0.796	Akaike info criterion		2.387
Sum squared resid	220.511	Schwarz criterion		2.409
Log likelihood	-415.781	Hannan-Quinn criter.		2.396
F-statistic	498.344	Durbin-Watson stat		1.842
Prob(F-statistic)	<0.001			

Source: *Author's Computation Using E-views*

Model Line: $PRS = \beta_0 + \beta_1 GPD + \varepsilon$

Regression Line: $PRS = 0.728 + 0.792GPD$

Where; *PRS* = Product serviceability, *GPD* = Green design and ε = Stochastic error term.

Table 6 examines how green design (GPD) affects the serviceability of products. With an R-squared value of 0.589, green design accounts for about 58.9% of the variation in product serviceability. Given that other factors account for 41.1% of the variation, the result indicates a modest link. The corrected R-squared value is 0.588 once the number of predictors in the model has been considered. The small difference between adjusted R-squared and R-squared suggests that the model is well-fitted and not unduly impacted by extraneous factors. The regression's standard error, which shows how much observed values typically deviate from the regression line, is 0.796. The total divergence of the response values from the fitted response values is 220.511, which is the sum of the squared residuals. The Hannan-Quinn Criterion (2.396), the Schwarz Criterion (2.409), and the Akaike Information Criterion (2.387) are among the criteria used to pick the model. A model with lower values of these criteria fits data better. With a p-value of <0.001 and an F-statistic of 498.344, the regression model as a whole appears to be statistically significant. This evidence suggests that the independent variable (green design) largely explains the variability in the dependent variable (product serviceability). With a Durbin-Watson statistic of 1.842, which is near to 2, the residuals show no discernible autocorrelation.

The constant term (C) has a coefficient of 0.728, and its standard error is 0.140. With a t-statistic of 5.220 and a corresponding p-value of <0.001, the constant term is statistically significant. Green design has a coefficient of 0.792 and a standard error of 0.035. The p-value of <0.001 and the high t-statistic of 22.324 show a strong and statistically significant positive connection. Keeping all variables equal, the evidence suggests that product serviceability rises by roughly 0.79 units for every unit increase in green design. This result suggests that green design significantly improves the serviceability of products.

Table 7 Regression on Green efficient processes and Product Perceive Quality

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.510	0.095069	5.368	<0.001
GPI	0.847	0.030233	28.013	<0.001
R-squared	0.693	Mean dependent var		2.923
Adjusted R-squared	0.692	S.D. dependent var		1.357
S.E. of regression	0.753	Akaike info criterion		2.277
Sum squared resid	197.516	Schwarz criterion		2.299
Log likelihood	-396.508	Hannan-Quinn criter.		2.286
F-statistic	784.746	Durbin-Watson stat		1.741
Prob(F-statistic)	<0.001			

Source: *Author's Computation Using E-views*

Model Line: $PPQ = \beta_0 + \beta_1 GPI + \varepsilon$

Regression Line: $PPQ = 0.510 + 0.847GPI$

Where; *PPQ* = Product perceive quality, *GPI* = Green efficient processes and ε = Stochastic error term.

Table 7 examines the effect of green efficient processes (GPI) on the perceived quality of products. Green efficient processes account for about 69.3% of the variation in product perceived quality, according to the R-squared value of 0.693. This number indicates that the two variables have a significant relationship, whereas other factors not included in the model account for the remaining 30.7% of the variation. With an adjusted R-squared value of 0.692, which is quite near to the R-squared, the model is well-fitted and has little inflation from extra variables. The average separation between observed values and the regression line is indicated by the regression's standard error, which is 0.753. A better model fit is indicated by a lower standard error. The overall divergence of response values from the predicted values is measured by the sum squared residuals, which is 197.516. This information helps us further understand the accuracy of the model. The model selection criteria display the Hannan-Quinn Criterion at 2.286, the Schwarz Criterion at 2.299, and the Akaike Information Criterion (AIC) at 2.277. Lower values for these criteria indicate a better match, facilitating model comparison. The model as a whole is statistically significant, as indicated by the F-statistic of 784.746 and the corresponding p-value of <0.001. As an independent variable, the result suggests that green, efficient processes account for a considerable portion of the variation in perceived product quality. The residuals exhibit no discernible autocorrelation, with a Durbin-Watson statistic of 1.741, close to 2, indicating that the regression's assumptions hold true.

The standard error for the constant term (C) is 0.095069, and its coefficient is 0.510. The constant term is statistically significant, as indicated by the t-statistic of 5.368 and the corresponding p-value of less than 0.001. Green efficient processes have a coefficient of 0.847 and a standard error of 0.030233. A strong and statistically significant positive correlation is shown by this coefficient's high t-statistic of 28.013 and p-value of less than 0.001. Keeping all variables equal, this conclusion suggests that product perceived quality rises by roughly 0.85 units for every unit increase in green, efficient operations. The findings show that the perceived quality of products is positively and significantly impacted by green efficient processes.

Table 8 Regression on Green Purchasing and Product Reliability

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.700	0.115	6.111	<0.001
GRP	0.795	0.034	23.612	<0.001
R-squared	0.616	Mean dependent var		3.177
Adjusted R-squared	0.615	S.D. dependent var		1.382
S.E. of regression	0.858	Akaike info criterion		2.538
Sum squared resid	256.346	Schwarz criterion		2.560
Log likelihood	-442.133	Hannan-Quinn criter.		2.547
F-statistic	557.503	Durbin-Watson stat		1.942
Prob(F-statistic)	<0.001			

Source: *Author's Computation Using E-views*

Model Line: $PRR = \beta_0 + \beta_1 GRP + \varepsilon$

Regression Line: $PRR = 0.700 + 0.795GRP$

Where; *PRR* = Product reliability, *GRP* = Green purchasing and ε = Stochastic error term.

Table 8 looks at how product reliability is affected by green purchasing (GRP). The R-squared score is 0.616, meaning that green purchasing accounts for about 61.6% of the variation in product reliability. The result indicates a moderate to strong relationship between the two variables, with other factors not included in the model accounting for the remaining 38.4% of the variation. Very near to the R-squared, the adjusted R-squared value of 0.615 shows that the model is well-fitted with little inflation from extra variables. The average separation between the regression line and the observed values is indicated by the regression's standard error, which is 0.858. A reduced standard error indicates a better-fitting model. The sum of squared residuals, which equals 256.346 and shows the overall difference between the response values and the expected values, helps us understand how accurate the model is. The model selection criteria display the Hannan-Quinn Criterion (2.547), the Schwarz Criterion (2.560), and the Akaike Information Criterion (AIC) at

2.538. Model comparison is aided by these criteria, where a better fit is indicated by lower numbers. The overall statistical significance of the model is confirmed by the F-statistic of 557.503 and the corresponding p-value of <0.001. This suggests that green purchasing, as an independent variable, can substantially explain the heterogeneity in product reliability. The residuals show no discernible autocorrelation, suggesting that the regression's assumptions are upheld, as indicated by the Durbin-Watson value of 1.942, which is quite near to 2.

The intercept of the regression line is statistically significant, as indicated by the coefficient for the constant term (C) of 0.700 and the standard error of 0.115. When green purchasing is not present, the constant term is considerably different from zero, as seen by the high t-statistic of 6.111 and p-value of <0.001. This evidence suggests a baseline level of product reliability of 0.70. The standard error for the green purchasing (GRP) coefficient is 0.034, and it is 0.795. This result suggests that product reliability and green purchasing are strongly positively correlated. The large t-statistic of 23.612 and the p-value of less than 0.001 confirm the statistical significance of this relationship. In real terms, if all other factors stay the same, product reliability should rise by roughly 0.79 units for every unit increase in green purchasing. This result demonstrates how crucial green purchasing is in affecting and enhancing product reliability.

Discussion of Findings

Green design significantly enhances the serviceability of products, according to research. The study suggests products that are developed with environmental factors in mind—for example, by utilizing long-lasting materials, modular components, and easily repairable parts—are likely to show better serviceability over the course of their lifetime. Growing research on eco-design principles supports the positive impact of green design on serviceability, highlighting the need for products to be not only environmentally benign but also useful and long-lasting in daily usage. Musau and Rucha's (2021) study, for instance, found that green design in manufacturing can improve performance. In a similar vein, Nag et al.'s (2022) research suggested that eco-designed products typically had reduced failure rates and were simpler to fix, which improved serviceability results. This study explicitly emphasizes the effect of green design on serviceability, a crucial but frequently overlooked component of sustainability, which makes it unique. The main focus of previous research has been on the environmental benefits of green design, like reducing waste or resource use (Al-Hakimi et al., 2022; Madah, 2023). This study looks at how green design strategies can improve the operational aspects of products, especially how easy they are to maintain and repair.

Finding indicates that the implementation of green, efficient processes significantly enhances the perceived quality of the product. This conclusion suggests that consumers are more likely to consider items as having higher quality when companies include green innovations into their manufacturing processes, such as implementing cleaner technology, optimizing energy usage, decreasing waste, or enhancing resource efficiency. Studies on sustainability in manufacturing are increasingly taking place in real-world settings. These studies focus on how environmentally friendly production methods can improve the quality of products beyond their basic functions. This work is in line with the idea that green, efficient processes make things seem better. This study improves on previous research that solely examined performance. Companies with corporate cultures that support their green product innovation and green efficient process practices, for example, have a major impact on their financial success and stakeholder performance, according to a study by Karabulut and Hatipoğlu (2020). As stakeholders, consumers were the focus of this study, which focused on how they view the product's quality. The study furthers the research of Cheng et al. (2023), which discovered that environmentally friendly, efficient processes significantly impact sustainability but did not address the perception of product quality. Green efficient processes, such as cleaner production methods and energy-efficient processes, frequently produce goods with fewer flaws, higher durability, and superior performance, which can improve consumer perceptions of product quality, according to research by Wang et al. (2021).

Findings demonstrated that green purchasing significantly improves product reliability. This result suggests that companies can improve the longevity and reliability of their products by giving priority to green purchasing, which involves finding high-quality, environmentally sustainable materials and components. Practically speaking, the incorporation of green purchasing can lead to notable increases in product reliability by ensuring that acquired materials are not only environmentally benign but also meet strict quality standards. This study supports earlier studies showing a positive relationship between product performance and sustainable supply chain practices. For instance, Famiyeh et al. (2018) discovered that by guaranteeing uniformity in material qualities and lowering the incidence of flaws, green sourcing practices improve product reliability. Additionally, the finding is consistent with those of González-Viralta et al. (2023), who emphasize the importance of environmentally friendly practices in promoting customer satisfaction and affecting a range of consumer behaviours. By adding sustainability as a quality factor, green purchasing strengthens quality.

Conclusion

There is strong evidence from this study that using green manufacturing practices improves the quality of products. The incorporation of green practices into product design and development is not merely a trend but a critical shift in business strategy. This study shows how responsible purchasing, efficient processes, and green design greatly improve the quality and reliability of products. Organizations that adopt these practices will fulfill their corporate social obligations and pave the way for a sustainable future.

Recommendations

The study made recommendations that:

i. Organizations should concentrate on putting into practice user-friendly product designs that make upgrades and repairs simple, improving the serviceability of their products. Such practices will boost customer loyalty and satisfaction while also promoting sustainability.
ii. Organizations ought to implement lean manufacturing strategies, which reduce waste and maximize production effectiveness, as this would enhance the perceived quality of their products. Consistent consumer input on quality perceptions can also help guide attempts to improve continuously.
iii. To guarantee product reliability, organizations should set criteria for choosing suppliers based on their green purchasing practices. Forming alliances with recognized environmentally friendly vendors can improve the general performance and quality of the

products. Routinely evaluating supplier procedures will facilitate the maintenance of high standards for product reliability and customer confidence.

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