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Green Manufacturing and Sustainable Performance of Firms in North-Central Nigeria

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Abstract: This study focused on green manufacturing and sustainable performance of firms in North-Central Nigeria. The study examined the extent to which green design affects environmental performance and determined the effect of green efficient processes on product quality. The study utilized a survey research design. A sample size 341 was established. A multi-stage sampling technique was utilized to ensure thorough representation. The study utilized construct validity and applied factor analysis. The study utilized both descriptive and inferential statistics for analyzing the data. Regression analyses were employed to test the established hypotheses. Findings showed that green design has a significant positive effect on environmental performance, and that green efficient processes have a significant positive effect on product quality. The study affirmed that green manufacturing significantly enhances the sustainable performance of firms. The study recommended that manufacturing firms should prioritize the integration of green design into their product development processes to enhance environmental performance, and that manufacturing firms should integrate green efficient processes into their operations to enhance product quality and competitiveness.

Keywords: Green Design; Green Efficient Processes; Green Purchasing; Environmental Performance; Product Quality

JEL Classification: D83; M00; M10

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1. Introduction

Emerging as a fresh perspective across the globe, the notion of green manufacturing has become a panacea for environmental concerns brought about by firms. Green manufacturing took shape in Germany towards the end of the 1980s and into the early 1990s (Beaman et al., 2020; Karuppiah et al., 2020). The introduction of ISO 14001 in 1996 marked a significant milestone, prompting numerous firms to adopt principles of sustainable manufacturing (Govindan, 2015). This internationally recognized standard established a framework for businesses seeking to thrive on the global stage, compelling them to align their products with the stringent green regulations of European markets. The standard extended the waste reduction philosophy inherent in lean manufacturing, emphasizing not just the minimization of waste and pollution, but also the efficient use of raw materials and energy. This holistic approach aims to mitigate environmental and health risks, thereby fulfilling the increasing demand for greener practices (Okunuga et al., 2022). The Sustainable Development Goals (SDGs) also promote green manufacturing practices which prioritize equitable social conditions, economic growth, and environmental protection (Khoshnava et al., 2019; Ye et al., 2023).

In Africa, there is a growing commitment to green manufacturing practices as countries strive to align their industrial activities with the SDGs. African nations are recognizing that environmentally sustainable methods can address ecological challenges while promoting economic growth (Tiba & Belaid, 2021; Wachira & Mathuva, 2022). Manufacturing activities, historically concentrated in stable regions, are primarily driven by key countries such as Morocco, Nigeria, and Egypt, with South Africa traditionally leading the sector (Ukanwa, n.d.). However, the overall size of the manufacturing industry in sub-Saharan Africa remains relatively modest (Mijiyawa, 2017). Green manufacturing gained momentum from the late 1990s onward as a response to climate change and the environmental damage caused by traditional industrial practices. As industrialization accelerated, it became clear that old handcrafting methods were insufficient for modern demands. The high energy consumption of industrial activities, contributing significantly to global greenhouse gas emissions, prompted a rethinking of manufacturing processes (Lamb et al., 2021). Today, African countries are exploring a range of strategies to promote green production, including the adoption of cleaner technologies and resource efficiency measures, supported by policies aimed at expanding renewable energy sources (Mungai et al., 2022). In addition to minimizing the ecological impact of production, these green initiatives are also designed to create jobs and spur economic growth across the continent. By prioritizing sustainable industrial practices, African nations are positioning themselves to address both environmental and economic challenges in tandem, fostering a more resilient and sustainable future.

In Nigeria, the manufacturing sector is increasingly prioritizing green manufacturing practices. A combination of environmental ethics, public pressure, and economic and technological factors has driven industries towards greater environmental awareness. Manufacturers are adopting green processes to conserve energy and resources, minimize hazardous waste through reuse and recycling, and prevent contamination at the source (Abanyam & Uwameiye, 2019; Madu, 2022; Mbang et al., 2020). Embracing green manufacturing helps companies comply with environmental laws and regulations set by government authorities and regulatory bodies and enhance their reputation as environmentally responsible organizations (Adekunle & Omoregbe, 2022; Akpan & Nkanta, 2023). The benefits of these practices motivate manufacturing firms to integrate green initiatives, enabling them to achieve a sustainable competitive advantage. Research supports the notion that green manufacturing practices can significantly contribute to this competitive edge (Al-Hakimi et al., 2022; Chukwuka & Eboh, 2018; Rasheed, 2022). In North-Central Nigeria, studies have explored green manufacturing and green supply chain management practices (Akpoghol et al., 2024; Enyi, Adebanjo & Adudu, 2024; Okunuga et al., 2022). The region faces significant environmental challenges, including climate change, deforestation, land degradation, waste disposal (including e-waste), threats to wildlife, coastal erosion, air pollution, and water contamination. These issues have increased the need for sustainable development policies, particularly within the manufacturing sector, which is a major contributor to environmental pollution. In response, the government has begun to prioritize green manufacturing, recognizing its role in improving sustainability among manufacturing firms (Enyi et al., 2024).

Numerous studies have examined green manufacturing (Chukwuka & Eboh, 2018; Enyi & Adebanjo, 2024; Okunuga et al., 2022). Previous research has explored various components of green manufacturing, such as green design (Gao et al., 2022; Sharma et al., 2017), green purchasing (Ghosh, 2019; Yook et al., 2017), green technology (Miranda et al., 2021; Nehra et al., 2023), and efficient processes, including recycling methods (Alzlzly, 2023; Sandin & Peters, 2018). Rehman et al. (2016) argued that most prior research has been conceptual, with limited empirical studies. Existing research often lacks coverage of the entire spectrum of green manufacturing, leaving certain gaps unaddressed. More researchers have contributed to the understanding of green manufacturing (Govindan et al., 2018; Enyi et al., 2024). However, these studies have not specifically explored the relationship between green manufacturing practices and sustainable performance, particularly in North-Central Nigeria. This gap highlights the need for further research to investigate how green manufacturing proxies' impact sustainable performance in this region, enhancing our understanding of sustainable practices and their implications for local industries.

1.1. Objectives of the Study

The broad objective of this study is to investigate the effect of green manufacturing on sustainable performance of manufacturing companies in the North-Central - Nigeria. The specific objectives are to:

- Examine the extent to which green design affects environmental performance.
- Determine the effect of green efficient processes on product quality.
- Assess the extent to which green purchasing influences economic performance.

1.2. Research Hypotheses

The following hypotheses will be formulated to guide the study:

- Green design has a significant effect on environmental performance.
- Green efficient processes have a significant effect on product quality.
- Green purchasing has a significant effect on economic performance.

2. Literature Review

2.1. Green Manufacturing

At its core, green manufacturing represents the "greening" of production processes for goods and services, focusing on minimizing negative environmental impacts while maximising resource efficiency (Bui, Nguyen, Wu, Lim & Tseng, 2024). This approach is holistic, addressing every aspect of production to ensure that environmental sustainability becomes an integral part of a company's core operations. It not only supports environmental preservation but also drives economic efficiency by reducing pollution, eliminating waste, and minimising the inefficient consumption of natural resources (Elemure et al., 2023).

The concept of green manufacturing revolves around the adoption of state-of-the-art production techniques that focus on waste reduction, recycling, and improved resource utilisation to mitigate environmental damage (Haleem et al., 2023). This holistic approach emphasises the integration of eco-friendly practices at every stage of the production cycle, ensuring that environmental considerations are central to all manufacturing activities. As such, green manufacturing is seen as a multifaceted approach that seeks to embed environmental and social considerations within the core operations of organisations (Al-Hakimi et al., 2022; Rashid et al., 2024). The important variables of green manufacturing include green design, green efficient processes, green purchasing, green technology, and green recycling.

2.2. Sustainable Performance

Sustainable performance encompasses a multidimensional framework that integrates economic viability, environmental stewardship, and social equity, thereby promoting an enduring balance among these critical facets of organizational operation (Aragón-Correa et al., 2020). As businesses increasingly recognize the importance of sustainability, the concept has evolved to reflect a comprehensive approach to performance measurement that transcends traditional profit-centric metrics. This holistic perspective is essential in addressing the pressing challenges of contemporary society, including climate change, resource depletion, and social inequality.

Sustainable performance is often assessed through the lens of the Triple Bottom Line (TBL), which emphasizes three core pillars: people, planet, and profit. This framework encourages organizations to evaluate their performance not only based on financial outcomes but also in terms of their social and environmental impacts. By adopting the TBL approach, companies can better align their strategic objectives with broader societal goals, fostering a culture of accountability and responsibility. Research indicates that firms embracing sustainable practices often experience enhanced reputation, increased customer loyalty, and improved operational efficiencies (Afum et al., 2020).

2.3. Green Design and Environmental Performance

Green design refers to the integration of sustainability principles into the product design process with the aim of reducing negative environmental impacts across the product lifecycle (Tariq et al., 2017; Wijesooriya & Brambilla, 2021). This approach not only focuses on minimizing the environmental footprint of products but also significantly affects environmental performance by optimizing resource use, reducing waste, and improving energy efficiency (Syahrial et al., 2019).

Green design promotes the use of renewable and recyclable materials, which are critical for improving environmental performance. By selecting sustainable materials that can be reused or recycled, manufacturers reduce the environmental burden associated with raw material extraction and disposal (Batwara et al., 2022). This material efficiency not only conserves natural resources but also minimizes the environmental impact of the manufacturing process by reducing waste and pollution. For instance, designing products with materials that can be easily recycled at the end of their life reduces the amount of waste that ends up in landfills, contributing to a circular economy (De Fazio et al., 2021; Shahbazi et al., 2021).

2.4. Green Efficient Processes and Product Quality

In an age where environmental awareness is becoming increasingly significant, the adoption of green efficient processes in manufacturing firms has emerged as a critical strategy (Le, 2022; Liu et al., 2017) not only for promoting sustainability but also for enhancing the perceived quality of products. Green efficient processes refer to manufacturing practices aimed at reducing environmental impact through resource conservation, waste minimization, and the use of sustainable materials (Jahanger et al., 2023; Razzaq et al., 2021; Shrivastava & Shrivastava, 2017). These practices include energy-efficient operations, recycling programs, and the implementation of cleaner technologies (Razzaq et al., 2021; Siegel et al., 2019). The application of these processes can have both direct and indirect effects on how consumers perceive product quality.

2.5. Green Purchasing and Economic Performance

Green purchasing is the practice of acquiring products and services that minimize environmental impact throughout their lifecycle, and it plays a crucial role in shaping the economic performance of organizations. As businesses increasingly recognize the benefits of sustainable practices, green purchasing has become a critical driver for improving economic outcomes. This practice influences economic performance in several keyways, including cost savings, enhanced reputation, customer loyalty, and operational efficiency (Shao & Ünal, 2019). One of the most direct ways green purchasing impacts economic performances is through cost savings. Organizations that implement green purchasing policies often choose suppliers that prioritize sustainability, which can lead to reductions in material and energy costs. By selecting high-quality, durable, and energy-efficient products, businesses can lower long-term operational expenses. For instance, the use of energy-efficient machinery or eco-friendly packaging reduces energy consumption and waste management costs. Furthermore, green purchasing can help businesses avoid fines and penalties related to environmental regulations, as many governments are increasingly enforcing stricter environmental laws (Huang et al., 2021).

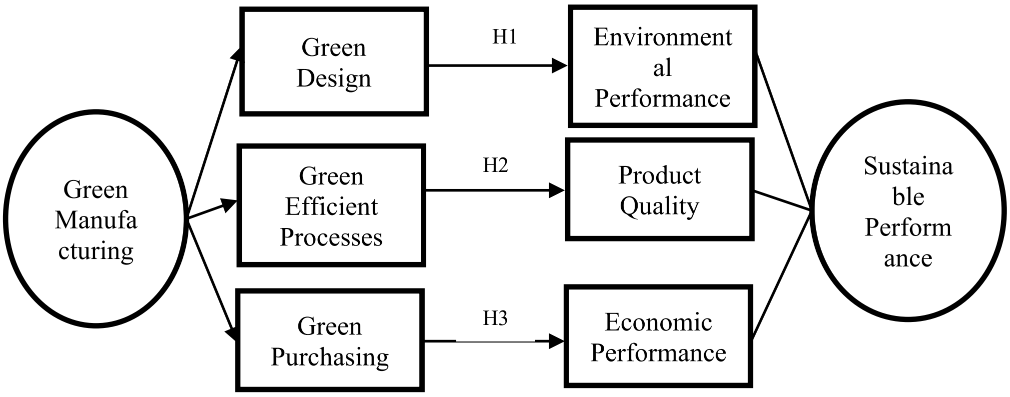

Figure 1. Conceptual Framework of Green Manufacturing and Sustainable Performance

Source: Author (2025)

3. Methodology

The study utilized a survey research design. This design was chosen for its ability to systematically gather quantitative data from a diverse range of participants, enabling a comprehensive understanding of the variables involved. The study's population consists of 3,188 potential participants from medium-sized manufacturing firms located in North-Central Nigeria. The primary focus of this research centers on the key managers of these manufacturing companies. This group encompasses individuals from four states: Kogi, Benue, Nasarawa, and Kwara. Sample size refers to the count of individuals, items, or data points selected from a larger population for research, surveys, experiments, or data analysis (Johnson, 2018). In this study, a sample size of 341 was established using the Krejcie and Morgan (1970) sample size table (see Fig. 2).

Table for Determining Sample Size of a Known Population

N	S	N	S	N	S	N	S	N	S
10	10	100	80	280	162	800	260	2800	338
15	14	110	86	290	165	850	265	3000	341
20	19	120	92	300	169	900	269	3500	346
25	24	130	97	320	175	950	274	4000	351
30	28	140	103	340	181	1000	278	4500	354
35	32	150	108	360	186	1100	285	5000	357
40	36	160	113	380	191	1200	291	6000	361
45	40	170	118	400	196	1300	297	7000	364
50	44	180	123	420	201	1400	302	8000	367
55	48	190	127	440	205	1500	306	9000	368
60	52	200	132	460	210	1600	310	10000	370
65	56	210	136	480	214	1700	313	15000	375
70	59	220	140	500	217	1800	317	20000	377
75	63	230	144	550	226	1900	320	30000	379
80	66	240	148	600	234	2000	322	40000	380
85	70	250	152	650	242	2200	327	50000	381
90	73	260	155	700	248	2400	331	75000	382
95	76	270	159	750	254	2600	335	1000000	384

Note: N is Population Size; S is Sample Size *Source: Krejcie & Morgan, 1970*

Figure 2. Sample Size

Source: Krejcie and Morgan (1970)

In the process of selecting a sample, a multi-stage sampling technique was utilized to ensure thorough representation. This study utilized primary data gathered directly from the field to ensure that the information is pertinent and aligned with the research goals. The study utilized construct validity and applied factor analysis as the primary analytical method. Factor analysis is chosen for its capability to investigate relationships among multiple items and to uncover common underlying dimensions. The factor loadings derived from this analysis indicate the strength of these relationships, with values above 0.30 deemed significant, values over 0.40 considered more significant, and loadings greater than 0.70 classified as highly significant (Creswell, 2003). A comprehensive presentation of the factor loadings for each construct is included in Table 1 for detailed analysis and interpretation.

Table 1. Validation of Instrument

Indicator Variable	**Loading**	**Square of Loading**	**Sum of the square loading**	**AVE**	**CR**
Green Design					
GRD1	0.72	0.5184	2.711102	0.5422204	0.736356164
GRD2	0.711	0.505521			
GRD3	0.792	0.627264			
GRD4	0.701	0.491401			
GRD5	0.754	0.568516			

Green Efficient Processes					
GEP1	0.735	0.540225	3.084066	0.6168132	0.78537456
GEP2	0.767	0.588289			
GEP3	0.812	0.659344			
GEP4	0.732	0.535824			
GEP5	0.872	0.760384			
Green Purchasing					
GPG1	0.788	0.620944	3.021199	0.6042398	0.777328631
GPG2	0.741	0.549081			
GPG3	0.802	0.643204			
GPG4	0.761	0.579121			
GPG5	0.793	0.628849			
Environmental performance					
EPE1	0.768	0.589824	2.805643	0.5611286	0.749085175
EPE2	0.745	0.555025			
EPE3	0.755	0.570025			
EPE4	0.737	0.543169			
EPE5	0.74	0.5476			
Product Quality					
PQY1	0.742	0.550564	2.989818	0.5979636	0.773281061
PQY2	0.819	0.670761			
PQY3	0.83	0.6889			
PQY4	0.752	0.565504			
PQY5	0.717	0.514089			
Economic Performance					
EPF1	0.728	0.529984	3.079747	0.6159494	0.784824439
EPF2	0.736	0.541696			
EPF3	0.739	0.546121			

EPF4	0.911	0.829921
EPF5	0.795	0.632025

Source: AMOS SPSS, 2024

The research employed Cronbach's coefficient alpha to assess the internal consistency reliability of the constructs. This method was chosen because it effectively demonstrates the extent to which various items measure the same variable. Items with Cronbach alpha coefficients was above 0.70 (see Table 2).

Table 2. Reliability Statistics of Variables

S/N	Variables	N of Items	Cronbach's Alpha
1	Green Product Design	5	0.839
2	Green Efficient Processes	5	0.787
3	Green Purchasing	5	0.717
4	Environmental Performance	5	0.766
5	Product Quality	5	0.827
6	Economic Performance	5	0.811

Source: SPSS, 2024

The study utilized both descriptive and inferential statistics for analyzing the data. Regression analyses was employed to test the established hypotheses. The models are outlined according to the study's objectives as follows:

$PQ = \beta 0 + \beta_1 GM + \varepsilon$………………………………………………………………… 1

$EPE = \beta_0 + \beta_1 GRD + \varepsilon$ …………………………………………………………… 2

$PQY = \beta_0 + \beta_1 GEP + \varepsilon$ ……………………………………………………………… 3

$EPF = \beta_0 + \beta_1 GPG + \varepsilon$ …………………………………………………………… 4

Where:

GRD = Green design

GEP = Green efficient processes

GPG = Green purchasing

EPE = Environmental performance

PQY = Product quality

EPF = Economic performance

4. Data Analyses and Results

Of the total number (341) of questionnaires distributed, 332 were successfully returned, representing a high response rate of 97.36%. Analyses were based on the 332 questionnaires returned.

Table 3. Gender of Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	172	51.8	51.8	51.8
	Female	160	48.2	48.2	100.0
	Total	**332**	**100.0**	**100.0**	

Source: Field survey, 2025

Table 3 shows the gender distribution of the respondents. Out of the 332 valid responses, 172 respondents were male, representing 51.8% of the total, while 160 were female, accounting for 48.2%. This indicates a relatively balanced gender representation among the respondents, with males slightly outnumbering females by a margin of 3.6%. The cumulative percentage confirms that all responses were accounted for, reaching 100%.

Table 4. Age Distribution of Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-24 Years	30	9.0	9.0	9.0
	25-31 years	130	39.2	39.2	48.2
	32- 48 years	125	37.7	37.7	85.8
	49-55 years	43	13.0	13.0	98.8
	56 & above	4	1.2	1.2	100.0
	Total	**332**	**100.0**	**100.0**	

Source: Field survey, 2025

Table 4 presents the age distribution of the respondents. The majority fall within the 25–31 years age group, accounting for 39.2% of the total respondents, followed closely by those aged 32–48 years at 37.7%. Respondents aged 49–55 years make up 13.0%, while the youngest group (18–24 years) constitutes 9.0%. Only 1.2% of respondents are aged 56 and above. This distribution indicates that the survey primarily engaged a youthful to middle-aged population, with over 76% of respondents falling between the ages of 25 and 48.

Table 5. Educational Qualification of Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	OND/NCE	122	36.7	36.7	36.7
	HND	138	41.6	41.6	78.3

	B.Sc	48	14.5	14.5	92.8
	MBA/M.Sc	24	7.2	7.2	100.0
	Total	**332**	**100.0**	**100.0**	

Source: Field survey, 2025

Table 5 displays the educational qualifications of the respondents. The majority hold HND qualifications, representing 41.6% of the total, followed by OND/NCE holders at 36.7%. Respondents with a B.Sc degree make up 14.5%, while those with postgraduate qualifications (MBA/M.Sc) account for 7.2%. This suggests that a significant portion of the respondents possess mid-level tertiary education, with fewer individuals having attained higher academic degrees. The data indicates a well-educated respondent pool, predominantly with technical or professional qualifications.

Table 6. Work Experience of Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	below 1 year	28	8.4	8.4	8.4
	1-3 years	98	29.5	29.5	38.0
	4-6 years	97	29.2	29.2	67.2
	7-10 years	44	13.3	13.3	80.4
	above 10 years	65	19.6	19.6	100.0
	Total	**332**	**100.0**	**100.0**	

Source: Field survey, 2025

Table 6 presents the work experience of the respondents. The largest proportions of respondents have 1–3 years (29.5%) and 4–6 years (29.2%) of work experience, indicating that a significant number are in the early to mid-stages of their careers. Additionally, 19.6% of respondents have over 10 years of experience, suggesting a notable presence of seasoned professionals. Those with 7–10 years of experience constitute 13.3%, while the least experienced group—those with less than 1 year—accounts for 8.4%. The data reflects a diverse range of professional experience among respondents, with a strong representation from both emerging and experienced workers.

Table 7a. Regression on Green Design and Environmental Performance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C (Constant)	0.333994	0.065274	5.116771	0.0000
GRD	0.918446	0.017160	53.52333	0.0000

Source: Author's Computation Using E-views 12

Model Line: $EPE = \beta_0 + \beta_1 GRD + \varepsilon$

Regression Line: $EPE = 0.333994 + 0.918446GRD$

Table 7b. Model Summary Statistics on Green Design and Environmental Performance

Statistic	Value	Statistic	Value
R-squared	0.896705	Mean dependent variable	3.620482
Adjusted R-squared	0.896392	Standard deviation (dependent var)	1.253612
S.E. of regression	0.403514	Akaike Information Criterion (AIC)	1.028796
Sum squared residuals	53.73185	Schwarz Criterion	1.051719
Log likelihood	-168.7802	Hannan-Quinn Criterion	1.037938
F-statistic	2864.746	Durbin-Watson statistic	1.973165
Prob(F-statistic)	0.000000		

Source: Author's Computation Using E-views 12

The regression analysis presented in Tables 7a and 7b explores the relationship between Green Design (GRD) and Environmental Performance (EPE). The result shows a strong and statistically significant positive relationship between the two variables. Specifically, the coefficient of Green Design is 0.918446, indicating that a one-unit increase in green design practices leads to an approximate 0.92 unit increase in environmental performance, holding other factors constant. The associated t-statistic (53.52333) is highly significant, with a p-value of 0.0000, confirming that this relationship is not due to random chance. The constant term (intercept) of 0.333994 is also statistically significant, suggesting a baseline level of environmental performance even in the absence of green design input.

The model's overall fit is excellent. The R-squared value of 0.896705 implies that about 89.67% of the variability in environmental performance is explained by green design. This is a very high proportion, reflecting a strong explanatory power of the model. The Adjusted R-squared (0.896392), which adjusts for the number of predictors, remains nearly identical, reinforcing the model's robustness.

Additional model diagnostics also support the model's validity. The F-statistic of 2864.746 and its p-value of 0.000000 indicate that the regression model is highly significant overall. The Durbin-Watson statistics of 1.973165 is very close to 2, suggesting that there is no significant autocorrelation in the residuals. Furthermore, the model has a relatively low standard error of regression (0.403514), indicating good precision in prediction. Model selection criteria like the Akaike Information Criterion (AIC = 1.028796), Schwarz Criterion (1.051719), and Hannan-Quinn Criterion (1.037938) are also relatively low, implying a good model fit with minimal information loss.

Table 8a. Regression on Green Efficient Processes on Product Quality

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C (Constant)	0.574359	0.094256	6.093635	0.0000
GEP	0.863915	0.026118	33.07791	0.0000

Source: Author's Computation Using E-views 12

Model Line: PQY = $\beta_0 + \beta_1$GEP + ε

Regression Line: PQY = 0.574359 + 0.863915GEP

Table 8b. Model Summary Statistics on Green Efficient Processes on Product Quality

Statistic	Value	Statistic	Value
R-squared	0.768283	Mean dependent variable	3.493976
Adjusted R-squared	0.767580	Standard deviation of dependent variable	1.249759
S.E. of regression	0.602508	Akaike Information Criterion (AIC)	1.830573
Sum squared residuals	119.7951	Schwarz Criterion	1.853496
Log likelihood	-301.8752	Hannan-Quinn Criterion	1.839715
F-statistic	1094.148	Durbin-Watson statistic	1.435371
Prob(F-statistic)	0.000000		

Source: Author's Computation Using E-views 12

The regression analysis presented in Tables 8a and 8b examines the effect of Green Efficient Processes (GEP) on Product Quality. The result reveals a strong, positive, and statistically significant relationship between GEP and product quality. The coefficient of 0.863915 indicates that for every one-unit increase in the implementation of green efficient processes, product quality increases by approximately 0.86 units, holding other factors constant. This high coefficient reflects a substantial effect. The t-statistic of 33.07791 and the p-value of 0.0000 confirm that this result is statistically significant and not due to random chance. Additionally, the constant value (intercept) of 0.574359 is also significant ($p < 0.05$), indicating the base level of product quality when GEP is absent.

The R-squared value of 0.768283 implies that approximately 76.83% of the variability in product quality is explained by the green efficient processes. This shows a strong explanatory power, which is further confirmed by the Adjusted R-squared value of 0.767580, demonstrating that the model remains robust even after accounting for degrees of freedom.

The regression also has a standard error of 0.602508, which indicates a relatively low average deviation of the observed values from the regression line, thus reflecting good model precision. The F-statistic of 1094.148 with a p-value of 0.000000 demonstrates that the overall model is statistically significant. The Durbin-Watson statistic of 1.435371, although slightly below the ideal value of 2, suggests a mild positive autocorrelation, which may warrant further examination but is not immediately alarming. Model selection statistics, including the Akaike Information Criterion (1.830573), Schwarz Criterion (1.853496), and Hannan-Quinn Criterion

(1.839715), are relatively low, indicating an efficient model with minimal information loss.

The analysis strongly supports the assertion that green efficient processes significantly have positive effect on product quality. The model demonstrates high statistical significance and strong explanatory power, making a compelling case for organizations to adopt environmentally efficient production methods to improve their output quality.

Table 9a. Regression on Green Purchasing and Economic Performance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C (Constant)	0.217123	0.114664	1.893558	0.0592
GPG (Green Purchasing)	0.896567	0.030818	29.09225	0.0000

Source: Author's Computation Using E-views 12

Model Line: $EPF = \beta_0 + \beta_1 GPG + \varepsilon$

Regression Line: EPF = 0.217123 + 0.896567GPG

Table 9b. Model Summary Statistics on Green Purchasing and Economic Performance

Statistic	Value	Statistic	Value
R-squared	0.719473	Mean dependent variable	3.430723
Adjusted R-squared	0.718623	Std. deviation of dependent variable	1.056424
Standard Error of Regression	0.560380	Akaike Information Criterion (AIC)	1.685602
Sum Squared Residuals	103.6284	Schwarz Criterion	1.708524
Log Likelihood	-277.8099	Hannan-Quinn Criterion	1.694743
F-statistic	846.3589	Durbin-Watson Statistic	1.923243
Prob(F-statistic)	0.000000		

Source: Author's Computation Using E-views 12

The regression results in Tables 9a and 9b assess the effect of Green Purchasing (GPG) on Economic Performance (EPF). The results reveal a strong and statistically significant positive relationship between green purchasing and economic performance. Specifically, the coefficient of 0.896567 implies that a one-unit increase in green purchasing activities leads to a 0.8965-unit increase in economic performance, assuming other factors remain constant. This relationship is statistically significant, as indicated by the t-statistic of 29.09225 and a p-value of 0.0000, which is far below the 0.05 threshold.

The constant term (intercept) of 0.217123 represents the estimated baseline economic performance when green purchasing is zero. However, this coefficient has a p-value of 0.0592, which slightly exceeds the 0.05 threshold, suggesting it is not statistically significant at the conventional 5% level. This implies that while the intercept is positive, it may not meaningfully contribute to the model's prediction in isolation.

The R-squared value of 0.719473 shows that approximately 71.95% of the variation in economic performance can be explained by green purchasing practices. The Adjusted R-squared value of 0.718623 confirms the model's goodness of fit while adjusting for degrees of freedom, indicating a strong explanatory power.

Furthermore, the standard error of regression is 0.560380, which reflects a moderate level of dispersion around the predicted values. The overall significance of the model is affirmed by the F-statistic of 846.3589 and a Prob(F-statistic) of 0.000000, showing that the model as a whole is highly significant.

Model diagnostics including the Akaike Information Criterion (1.685602), Schwarz Criterion (1.708524), and Hannan-Quinn Criterion (1.694743) are low, suggesting a well-fitting model with minimal overfitting. The Durbin-Watson statistic of 1.923243 is very close to the ideal value of 2, indicating that there is no significant autocorrelation in the residuals, which supports the reliability of the estimates.

The analysis demonstrates that green purchasing is a strong and significant predictor of economic performance. The regression model shows high explanatory power and statistical validity, suggesting that organizations that adopt green purchasing strategies are likely to enhance their economic outcomes.

5. Discussion of Findings

Findings showed that green design has a significant positive effect on environmental performance. This implies that the adoption of green design practices—such as the use of environmentally friendly materials, energy-efficient product designs, and reduced emissions during product life cycles—substantially enhances a firm's environmental outcomes. When compared to existing literature, the findings corroborate previous studies (Alli et al., 2019; Musau & Rucha, 2021) that emphasize green design's role in operational performance and environmental sustainability. The findings confirm the assertion of Bungau et al. (2022) that green design is not merely a theoretical concept but a practical strategy with measurable environmental benefits. Zhang et al. (2020) and Wysocki (2021) reinforce the importance of integrating sustainable practices into core product design and manufacturing processes to achieve long-term ecological and operational gains. However, differences in findings across contexts might stem from variations in regulatory environments, organizational culture, or technological capacity, especially between developed and developing countries.

Findings showed that green efficient processes have a significant positive effect on product quality. This implies that when manufacturing firms adopt green efficient practices—such as energy-efficient production, waste reduction, and optimized resource usage, they are more likely to produce high-quality products. The findings are consistent with previous studies such as those by Moise et al. (2021), and Gelderman et al. (2021), which found that firms implementing environmentally friendly processes tend to experience improvements in product performance and customer satisfaction. In practical terms, this means that firms can use green efficiency not only to meet regulatory or environmental targets but also to enhance customer perception of their products, thus gaining a competitive edge. Compared to existing literature (Alli et al., 2019; Souri et al., 2018), this study reinforces the growing body of evidence linking sustainable practices to product excellence.

Findings showed that green purchasing has a significant positive effect on economic performance. This implies that environmentally conscious procurement practices can enhance financial outcomes for manufacturing firms. This finding is consistent with previous studies such as Balin and Sari (2023), which showed that green purchasing positively influences financial performance. It also aligns with the findings of Madah (2023), who emphasized that green manufacturing could lead to firms' competitive performance. Thus, the findings reinforce existing scholarly consensus on the economic viability of sustainable procurement. Compared to existing research (Al-Hakimi et al., 2022; Musau & Rucha, 2021; Omar et al., 2024), these findings confirm the growing body of evidence linking sustainability practices with improved business outcomes. However, they may differ in magnitude due to contextual variables such as the region of study, the specific industry (manufacturing), or firm size and capacity.

6. Conclusion and Recommendations

The study affirms that green manufacturing significantly enhances the sustainable performance of firms. Specifically, green design positively influences environmental performance, green efficient processes improve product quality, and green purchasing contributes to stronger economic performance. These highlight the strategic value of adopting green practices for achieving holistic and long-term business sustainability.

The study recommends that:

- Manufacturing firms should prioritize the integration of green design into their product development processes to enhance environmental performance. Policymakers and industry regulators should provide incentives and guidelines that support eco-friendly design innovations.

- Manufacturing firms should integrate green efficient processes into their operations to enhance product quality and competitiveness. Policymakers should incentivize green production practices through supportive regulations, tax reliefs, or grants.

- Manufacturing firms should adopt and institutionalize green purchasing policies as a strategic component of their procurement processes. Regulatory bodies and industry associations should offer incentives and guidelines to encourage the integration of sustainable procurement practices.

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