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INNOVATIVE FINANCIAL PLANNING TOOLS AND ENVIRONMENTAL SUSTAINABILITY OF MANUFACTURING FIRMS IN NIGERIA

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ABSTRACT

The study examined the effect of innovative financial planning on environmental sustainability of manufacturing firms in Nigeria. The study employed the ex-post facto research design with a population of 53 firms comprising listed manufacturing firms on the Nigerian Exchange Group (NGX) as at 31st Dec. 2024. OLS regression was used to validate the hypotheses. The model was fine-tuned and improved using Generalized Least Square (GLS) regression technique with robust panel. The study found that there is a significant positive effect of ICT & technology risk disclosure on carbon emission disclosure of manufacturing firms in Nigeria (coef = 0.961; p < 0.0);there is a positive but insignificant effect of research and development (R&D) on carbon emission disclosure of manufacturing firms in Nigeria (coef = 0.005; p > 0.673); Software use or development disclosure has a positive but insignificant effect on carbon emission disclosure of manufacturing firms in Nigeria (coef = 0.263; p > 0.319). The study recommended amongst others that manufacturing firms should be encouraged to adopt and disclose ICT and technology risk management systems, as these have been shown to significantly enhance both carbon emission disclosure. Industry associations and regulators can support this through capacity-building programs and incentives for digital adoption.

Key words: Innovative financial planning, Environmental sustainability, ICT technology risk disclosure, Research and development disclosure, Carbon emission disclosure

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1. INTRODUCTION

The global economic landscape has changed dramatically over the past few decades. Improvements in technology and finance have changed how businesses work. Nigerian businesses are adopting digital tools like mobile banking, scenario forecasting, and ESG-integrated financial dashboards to make themselves more flexible, open, and strong (Wasiu, 2025). One of the most important changes has been the rise of new financial planning tools, which are now a key part of strategic business management. Fintech and data-driven financial planning products are becoming more popular, which is exciting. Some of these tools are advanced forecasting models, financial analytics, scenario planning, and integrated enterprise resource planning (ERP) systems. They help businesses make better choices, be more open about their finances, and work toward long-term goals (Brynjolfsson & McElheran, 2016). Using them means moving away from old, reactive ways of managing money and toward more proactive, data-driven methods that leverage AI, big data, and machine learning (Bughin, et al, 2018).At the same time, people all across the world are paying more and more attention to environmental sustainability. Companies have had to reconsider how they do business because of worries about climate change, resource depletion, and damage to the environment. The Global Reporting Initiative (GRI) and other frameworks have made it apparent what responsible environmental management means. The GRI (2021) says that sustainability means lowering the negative effects on air, water, and land, managing natural resources wisely, and lowering carbon emissions. These guidelines require businesses to be open about their environmental impact, which promotes responsibility and encourages people to take action to safeguard resources for the future.

The connection between financial innovation and sustainability has gotten stronger in the last several years. Historically, financial planning has focused on how to allocate money to help people or businesses reach their short- and long-term goals, like saving for retirement, managing risk, and growing their investments. But as people around the world become more aware of sustainability, social justice, and ethical governance, more and more people are realizing that financial performance are affected by both financial and non-financial factors. As a result, ESG (Environmental, Social, Governance) frameworks have been created to include this larger range of factors (Zairis et al., 2024). Studies indicate that firms integrating ESG aspects into financial models enhance risk management, exhibit greater resilience to environmental disruptions, and cultivate more robust reputations (Clark, Feiner & Viehs, 2015). Because of this, financial planning tools are being changed to take environmental concerns into account. This lets companies model sustainability scenarios, figure out how much carbon emissions would cost, and add green assets to their portfolios (Boffo & Patalano, 2020).The increase of industry has helped the manufacturing sector, which has led to economic growth but also more damage to the environment (National Bureau of Statistics, 2021). According to the Federal Ministry of Environment (2019), manufacturing is a major source of carbon emissions, waste, and resource consumption. However, this sector is still in the early stages of integrating sustainability into financial planning. There are programs like the Nigerian Sustainable Banking Principles (2012) and environmental laws, but they aren't always followed or adopted (Adebayo & Olayemi, 2020; Okere, Olayemi & Omodero, 2022). The manufacturing sector has a dual role as a driver of economic growth and a major contributor to environmental damage. As a result, there is growing pressure on businesses to cut their carbon emissions and use more environmentally friendly methods (UNIDO, 2020).

Most studies like Akinleye and Ogundipe, (2024); Emenyi and Okpokpo, (2024); Adegbite and Olayemi, (2023) largely focus on the effect of environmental disclosures on firm value and financial performance. While these provide valuable insights into market reactions, they

overlook the operational mechanisms such as ICT adoption, software integration, and R&D investments that drive disclosure practices in the first place. Although some research such as Ene and Moses, (2024); Bassey and Nwachukwu, (2023) examined the role of software and digital tools, these studies are either industry-specific in scope or limited in coverage. There is insufficient empirical evidence on how digital financial planning systems, beyond environmental management software, shape the breadth and quality of disclosures across the wider Nigerian manufacturing sector. As a result, it is important to use new financial planning techniques that take environmental factors into account. This shows that there needs to be more research on how these technologies affect environmental sustainability in Nigeria's manufacturing industry.

Objectives of the Study

The broad objective of this study is to investigate the effect of innovative financial planning tools on environmental sustainability of manufacturing firms in Nigeria. Specifically, the study intends to:

i. Evaluate the effect of ICT & technology risk disclosure on carbon emission disclosure of manufacturing firms in Nigeria.
ii. Ascertain the effect of research and development (R&D) on carbon emission disclosure of manufacturing firms in Nigeria.
iii. Investigate the effect of software use or development on carbon emission disclosure of manufacturing firms in Nigeria.

Research Hypotheses

Based on the research objectives, the following null hypotheses have been formulated to be tested in the study:

$HO_{1:}$ There is no significant effect of ICT & technology risk disclosure on carbon emission disclosure of manufacturing firms in Nigeria.

$HO_{2:}$ There is no significant effect of research and development (R&D) on carbon emission disclosure of manufacturing firms in Nigeria.

$HO_{3:}$ Software use or development disclosure has no significant effect on carbon emission disclosure of manufacturing firms in Nigeria.

2. REVIEW OF RELATED LITERATURE

Financial Planning Tools

Innovative financial planning tools are sophisticated digital systems, analytical approaches, and technology that improve traditional financial planning, budgeting, and forecasting processes (Workday, 2024). These tools integrate real-time data, predictive analytics, and scenario modelling to support more accurate, agile, and strategic financial decision-making. Unlike conventional spreadsheet-based approaches, innovative tools leverage automation, artificial intelligence (AI), cloud computing, and data visualization to improve efficiency, transparency, and alignment with organizational goals including sustainability and long-term value creation(Workday, 2024).

ICT and Technology Risk Disclosure

ICT and Technology Risk Disclosure encompass the methods through which organizations convey details regarding their vulnerabilities stemming from ICT and digital systems. This includes risks associated with cybersecurity, data protection, system failures, digital transformation, and technological obsolescence (European Union, 2022). ICT frameworks enable firms to assess potential threats to sustainability, such as energy inefficiencies or emissions from production technologies.

Research and Development

Research and Development (R&D) serves as a critical financial planning tool. It means strategically leveraging R&D activities to enhance long-term financial planning, inform investment decisions, and foster value creation. In the realm of financial planning, R&D transcends its role as a mere cost center; it functions as a proactive investment strategy that enables organizations to allocate financial resources effectively toward innovation, productivity enhancements, and sustainable growth(OECD, 2021).

Software Use or Development

Software use or development pertains to the application or creation of digital systems and analytical software designed to facilitate budgeting, forecasting, investment analysis, and strategic financial decision-making. These tools serve to automate intricate calculations, integrate data from various business units, and improve the accuracy, efficiency, and transparency of financial planning processes (Oracle, 2023).

Environmental Sustainability

Environmental sustainability consists of making life decisions that ensure the stability and health of natural resources and ecosystems, supporting human well-being and economic development (UNEP, 2021). Environmental sustainability encompasses the continuous effort to manage human interactions with the environment in order to preserve natural systems, reduce resource depletion, and uphold ecological balance for future generations. This concept integrates ecological integrity with the social and economic aspects of sustainable development (World Bank, 2022).

Carbon Emission Disclosure

Carbon emission disclosure refers to the process by which firms report their greenhouse gas (GHG) emissions, often through sustainability, environmental, or integrated reports. It serves as a mechanism for transparency, helping stakeholders understand the environmental impact of a company's operations (Li et al., 2023).

Theoretical Review

Resource-Base View (RBV) Theory

The Resource-Based View (RBV), initially formulated by Wernerfelt (1984) and subsequently elaborated by Barney (1991), posits that organizations attain enduring competitive advantage through the acquisition and utilization of resources that are valuable, rare, inimitable, and non-substitutable (VRIN). RBV emphasizes the importance of internal resources in achieving better performance, in contrast to theories that concentrate on the external environment. This study considers new financial planning tools, including ICT-enabled risk disclosure, research and development (R&D), and sustainability software, as strategic resources that enhance both financial resilience and environmental sustainability.

RBV helps us understand why sustainability outcomes are different in the same industry. Companies that put money on IT infrastructure, competent workers, and flexible finance systems frequently do better than their competitors because they have better internal capabilities. RBV also fits with the trend toward creating long-term value, as companies use sustainability criteria in their financial planning to get ready for changes in the law, lower risks, and take advantage of green market opportunities.

Empirical Review

Akinleye and Ogundipe (2024) examined the impact of environmental sustainability disclosure on the market performance of publicly traded consumer products companies in Nigeria. The research involved a population of 21 publicly traded consumer products manufacturing companies, utilizing a census sample method during a twelve-year span from 2012 to 2023. The study employed descriptive and inferential statistics, such as panel regression and correlational analysis, to ascertain that the disclosure of environmental protection costs and environmental R&D costs exerted favorable and significant impacts on market performance. On the other hand, disclosing the costs of environmental pollution had a negative but significant effect, whereas disclosing the costs of controlling environmental waste management had a positive but not significant effect.

Tanko, Kpazo, and Oluwapelumi (2024) conducted a study on environmental sustainability practices in Nigerian manufacturing companies using a life cycle assessment (LCA) method. The study sought to assess environmental impacts at different phases of production and pinpoint opportunities for enhancement. The study emphasized the necessity of implementing complete Life Cycle Assessment (LCA) approaches to alleviate detrimental environmental impacts and foster sustainable industrial advancement. The authors suggested that manufacturing companies include LCA into their production processes to improve sustainability performance.

Emenyi and Okpokpo (2024) investigated the influence of environmental disclosures on the valuation of publicly traded industrial companies in Nigeria. The study utilized an ex-post facto design, examining data from 20 manufacturing enterprises over a seven-year timeframe (2013–2019). Annual reports were used to get the data, which focused on environmental disclosure indices and business value indicators including market capitalization. The study indicated that companies with more environmental disclosures have higher values, which shows how important it is to be open about environmental reporting. It was suggested that companies improve how they disclose environmental information to get more investors and raise their market value.

Ene and Moses (2024) examined the impact of the adoption and advancement of sustainability-related software on environmental reporting procedures among industrial enterprises in Nigeria. The research concentrated on the role of tailored data management systems in assisting companies with monitoring carbon emissions and wastewater discharges. The study employed a mixed-methods approach, integrating quantitative surveys and qualitative interviews. There were 50 significant manufacturing businesses in Lagos, Kano, and Rivers States that made up the population. The data gathered from 2020 to 2023 were subjected to thematic analysis and ANOVA. The research indicated that companies utilizing internally designed or third-party sustainability software exhibited a 40% increased rate of carbon and waste disclosure in contrast to those employing conventional reporting systems. The authors determined that software innovation is essential for enhancing environmental transparency and adherence to international disclosure norms.

Adebayo and Dogo (2022) examined how ICT adoption influences the environmental performance of industrial firms in Nigeria, with a particular focus on green accounting and emission disclosure. The research adopted a longitudinal design using panel data from 30 firms listed on the NGX from 2012 to 2021. Data were obtained from the sustainability and the published financial statement. The study found that ICT tools, especially enterprise resource planning (ERP) systems and integrated reporting software, improved the capacity of firms to document and disclose carbon emissions and waste management data accurately. The

study concluded that ICT serves as a strategic enabler of financial and environmental planning, supporting firms to meet global sustainability standards

Shaaban-Nejad and Shirazi (2022) looked into how international conventions, national unrest and fierceness, and ICT affect carbon emissions worldwide. They looked at how ICT, teaching, GDP, national unrest, among others, relate to CO_2releasesmeasuredinloadsper head internationally. Finding shows ICT significantly has lowering effects on CO_2 releases worldwide, though the effects are much more pronounced for nations that belong to OECD.

Chukwuemeka and Hassan (2020) investigated how R&D investments affect emission reduction strategies in Nigerian manufacturing firms. The objective was to determine whether increased financial commitment to research leads to meaningful environmental innovations. The study adopted an ex-post facto design and focused on 33 manufacturing firms with a consistent R&D history from 2010 to 2019. Data were obtained from company annual reports and environmental audit statements. Analysis was conducted using panel data regression models. The results revealed that firms with higher R&D spending developed advanced emission control technologies and more efficient energy systems.

3. METHODOLOGY

The ex-post facto research design was used. The population consists of manufacturing companies listed on the NGX at the conclusion of the 2024 financial year. The study focused on forty (40) listed manufacturing companies chosen through purposive sampling; this selection was based on their classification as non-financial entities. The omission of additional sectors aligned with previous research (Abid, Shaique, & Anwar-ul-Haq, 2018). We removed any company from the sample during the data analysis if its needed data were incomplete or not available. The final sample percentage in relation to the population is around 75.47% of all the manufacturing enterprises listed on the Nigerian exchange group.

The data used in this study came from the appropriate stock exchange, fact books and the annual financial reports of the corporations for the periods in question. The research utilized both descriptive and inferential statistical methodologies to examine the dataset in question. We calculated the following descriptive statistics: the mean, median, standard deviation, minimum and maximum values, and the Skewness-Kurtosis statistics. The correlation matrix was made to find the relationship between the independent and dependent variables. Finally, the hypotheses were confirmed using OLS regression. Using the Generalized Least Square regression technique with robust panel, the model was fine-tuned and made better. Other first diagnostic tests were conducted, including the VIF for multicollinearity assessment, the Shapiro-Wilk normality test, the serial correlation test, the Ramsey RESET test for model fitness, and the heteroskedasticity test. These testing helped figure out which model would work best. We used the R-squared in measuring how well the model fit, and we used STATA statistical software version 14.2 to complete the analysis.

4. DATA PRESENTATION AND ANALYSIS

Data Presentation

Table 4.1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
carbonemi~10	440	.1659091	.3724225	0	1
icttechnol~e	440	.1	.3003415	0	1
researchan~i	439	.3621868	.4811808	0	1
softwareus~s	440	.1704545	.3764597	0	1
firmsize	440	7.182545	.8867023	5.239405	9.327067
leverage	440	-.0521112	1.499551	-31.2306	2.029

Source: STATA 14.2(2025)

The study analyzed 440 observations drawn from manufacturing firms in Nigeria, focusing on variables that capture elements of innovative financial planning tools and environmental sustainability. The descriptive statistics provide insight into the extent of firm engagement in various sustainability-related disclosures and practices.

The results indicate that only about 16.6% of the firms disclose information related to carbon emissions, as reflected in a mean value of 0.165. This low figure suggests limited transparency in reporting carbon-related environmental impacts. The standard deviation of 0.372 shows minimal variation across the sample, which aligns with the generally low level of disclosure.

The variable representing ICT technology risk disclosure has a mean of 0.100, suggesting that only 10% of the firms disclose how they manage risks related to ICT. The low standard deviation of 0.300 further confirms limited adoption or disclosure in this area, reflecting a significant gap in digital environmental risk transparency.

In terms of research and development, the mean is 0.362, which shows that about 36.2% of firms engage in or disclose sustainability-oriented research and innovation efforts. This figure is the highest among the sustainability-related binary variables, indicating a relatively greater recognition of the importance of innovation in promoting environmental sustainability within the manufacturing sector.

For software use or development for environmental financial planning, the mean value is 0.170. This suggests that only 17% of the firms either use or have developed specialized software tools to support their environmental sustainability initiatives. The low mean and a standard deviation of 0.376 again point to limited technological integration in environmental management.

Turning to firm characteristics, the average firm size (measured on a logarithmic scale) is 7.18, with a standard deviation of 0.89. This indicates a fairly consistent distribution of firm sizes across the sample, with values ranging from 5.24 to 9.33, reflecting a mix of medium to large-scale manufacturing firms.

Finally, the leverage ratio has a mean of -0.052, suggesting that on average, firms have a slightly negative financial leverage position. The standard deviation of 1.50, along with a minimum value as low as -31.23, points to considerable variation in financial structure, possibly due to some firms having high levels of debt or experiencing financial distress.

Table 4.2: Saphirowilk W normality test

Variable	Obs	W	V	z	Prob>z
carbonemi~10	440	0.98041	5.874	4.231	0.00001
icttechnol~e	440	0.96148	11.551	5.848	0.00000
researchan~i	439	0.99711	0.864	-0.349	0.63636
softwareus~s	440	0.98122	5.632	4.131	0.00002
firmsize	440	0.98822	3.532	3.016	0.00128
leverage	440	0.03730	288.673	13.540	0.00000

Source: STATA 14.2 (2025)

Table 4.2 presents the results of the Shapiro-Wilk test for normality applied to each of the study variables. For carbon emission disclosure, the Shapiro-Wilk test yields a W statistic of 0.9804 and a p-value of 0.00001. This indicates a statistically significant deviation from normality. Hence, carbon emission disclosure is not normally distributed across the sampled firms.

For ICT technology risk disclosure, the W statistic is 0.9615 with a very small p-value (< 0.00001), confirming that this variable is also significantly non-normally distributed. In contrast, the research and development variable yields a W of 0.9971 and a p-value of 0.63636, which is well above 0.05. This suggests that the research and development data follows a normal distribution and does not significantly deviate from normality.

Regarding software use or development, the W statistic is 0.9812 and the p-value is 0.00002. This confirms that the distribution of this variable is significantly non-normal. For firm size, the test returns a W of 0.9882 and a p-value of 0.00128, indicating a statistically significant departure from normality, although the deviation appears moderate.

Lastly, leverage has a very low W statistic of 0.0373 and a z-score of 13.54, with a corresponding p-value of 0.00000. This clearly indicates a strong and highly significant deviation from normality, likely due to the presence of extreme outliers or skewness.

Summarily, with the exception of research and development, all other variables show statistically significant deviations from normality. The implication of these findings is that statistical techniques that assume normality, such as ordinary least squares regression, may not be suitable for variables which deviates from normal distribution. Instead, alternative methods such as transformations, non-parametric tests, or generalized least square regression which estimates and corrects heteroskedasticity and autocorrelation issues in regression models.

Table 4.3: Correlation Analysis

	carbo~10	efflue~1	icttec~e	resear~i	softwa~s	firmsize	leverage
carbonemi~10	1.0000						
icttechnol~e	0.6658	0.4912	1.0000				
researchan~i	0.3763	0.3379	0.4271	1.0000			
softwareus~s	0.4800	0.4591	0.6547	0.2624	1.0000		
firmsize	0.3318	0.3576	0.0672	0.2650	0.1333	1.0000	
leverage	0.0205	0.0273	0.0154	0.0358	0.0221	0.1005	1.0000

--**Source:** STATA 14.2 (2025)

From Table 4.3, the correlation analysis explores the relationships among variables related to environmental sustainability practices, the use of innovative financial planning tools, and firm characteristics in Nigerian manufacturing firms. Correlation coefficients range from -1 to +1, where values closer to 1 indicate strong positive associations.

Carbon emission disclosure shows a high positive correlation (0.6658) with ICT technology risk disclosure, indicating that firms more active in reporting technological risks are also likely to engage in carbon-related disclosures.

Furthermore, software use or development has a strong correlation with ICT technology disclosure (0.6547), highlighting that firms utilizing software tools are often those more engaged with ICT-related environmental risks.

The relationship between carbon emission disclosure and research and development is moderately positive at 0.3763. This suggests that firms investing in sustainability-oriented R&D are also more inclined to disclose their carbon emissions. Similarly, software use or development correlates positively with research and development (0.2624), reflecting a shared emphasis on innovation and environmental planning.

In terms of firm characteristics, firm size is positively correlated with all the sustainability variables, although the strength of the relationship is relatively modest. The highest is with carbon emission disclosure (0.3318). This implies that larger firms are more likely to disclose environmental practices, possibly due to greater regulatory scrutiny or more resources to support such initiatives.

Conversely, leverage exhibits very weak correlations with all variables, with coefficients close to zero. The highest, at just 0.1005, is with firm size. This suggests that a firm's financial leverage is largely unrelated to its sustainability disclosures or adoption of financial planning tools, within the context of this sample.

Overall, the correlation analysis reveals that firms demonstrating one form of sustainability disclosure or innovation are likely to engage in others, particularly in areas involving ICT, software, and environmental transparency. However, financial structure, as measured by leverage, appears to have little to no association with these practices.

Table 4.4: OLS Regression – Model 1

```
      Source |       SS           df       MS      Number of obs   =       439
-------------+----------------------------------   F(5, 433)       =     96.82
       Model |  32.1257134         5  6.42514269   Prob > F        =    0.0000
    Residual |  28.7353344       433  .066363359   R-squared       =    0.5279
-------------+----------------------------------   Adj R-squared   =    0.5224
       Total |  60.8610478       438  .138952164   Root MSE        =    .25761

------------------------------------------------------------------------------
carbonemis~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
icttechnolo~e |   .7567514   .0582555    12.99   0.000     .6422527    .8712501
researchand~i |   .0256457   .0293659     0.87   0.383    -.0320717    .0833631
softwareuse~s |    .034563   .0435965     0.79   0.428     -.051124     .12025
firmsize |    .117249   .0145867     8.04   0.000     .0885796    .1459185
     leverage |  -.0047086   .0082415    -0.57   0.568     -.020907    .0114897
        _cons |  -.7670982   .1029781    -7.45   0.000    -.9694974   -.5646991
------------------------------------------------------------------------------
```

Source: STATA 14.2 (2025)

From table 4.4, the OLS regression results examine the effect of selected innovative financial planning tools on carbon emission disclosure, while controlling for firm size and leverage.

The model is statistically significant overall, as shown by the F-statistic of 96.82 and a p-value of 0.000, indicating that the predictors collectively explain a significant portion of the variation in carbon emission disclosure. The R-squared value of 0.528 implies that about 52.8% of the variation in carbon emission disclosure is accounted for by the model.

Among the variables of interest, ICT technology risk disclosure shows a strong positive and statistically significant effect on carbon emission disclosure (coefficient = 0.757, $p < 0.001$), suggesting that firms disclosing ICT-related risks are more likely to also report on carbon emissions.

However, both research and development and software use or development have positive but statistically insignificant effects, with p-values of 0.383 and 0.428 respectively. This implies that, in this model, these tools do not significantly influence carbon emission disclosure.

Regarding the control variables, firm size has a significant positive effect ($p < 0.001$), indicating that larger firms are more likely to disclose carbon emissions. On the other hand, leverage shows a negative but statistically insignificant relationship ($p = 0.568$), suggesting that the firm's financial leverage does not play a meaningful role in disclosure behavior.

Summarily, ICT technology risk disclosure emerges as the most influential variable among the planning tools considered, while firm size also plays a notable role as a control factor.

Table 4.5: Variance inflation Factor (VIF)

Variable	VIF	1/VIF
icttechnol~e	2.02	0.493935
softwareus~s	1.78	0.561471
researchan~i	1.32	0.758842
firmsize	1.11	0.903727
leverage	1.01	0.989759
Mean VIF	**1.45**	

Source: STATA 14.2 (2025)

The results from Table 4.5 shows that VIF values are well below the common threshold of 10, with the highest being 2.02 for ICT technology risk disclosure. The mean VIF is 1.45, which further confirms that multicollinearity is not a concern in this study. This indicates that the independent variables are not excessively correlated with one another and that the regression estimates are likely to be stable and reliable.

Table 4.6: Ramsey RESET test

Ramsey RESET test using powers of the fitted values

Ho: model has no omitted Variable	F(3, 430)	Prob > F
Carbon emission disclosure	19.45	0.0000

Source: STATA 14.2 (2025)

From table 4.6, Ramsey RESET test evaluates whether the regression models suffer from omitted variable bias by testing for model specification errors. For the carbon emission disclosure model, the test yields an F-value of 19.45 with a p-value of 0.0000, indicating that

the model is mis-specified and likely omits relevant variables. This suggests that additional factors influencing carbon emission disclosure may not have been included in the model.
The results therefore highlight the need for caution in interpreting the models.
To improve the model, further analysis was conducted. The study employed generalized least square regression models as this can help to control for unobserved heterogeneity that may be causing the omitted variable bias.

Table 4.7: Heteroskedasticity test

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance **Variable fitted values**	**Chi2(1)**	**Prob >chi2**
Carbon emission disclosure	59.00	0.0000

Source: STATA 14.2 (2025)

From table 4.7, Heteroskedasticity test presents the results of the Breusch-Pagan/Cook-Weisberg test, used to determine whether the assumption of constant variance in the regression models holds. For the carbon emission disclosure model, the test yields a Chi-squared value of 59.00 with a p-value of 0.0000, indicating a strong presence of heteroskedasticity. This suggests that the variance of the error terms is not constant, which may affect the efficiency of the regression estimates.

The results imply that both models violate the homoskedasticity assumption, and as such, robust standard errors should be considered to ensure valid inference.

To correct this problem, given that the presence of heteroskedasticity may indicate potential model misspecification, the generalized least squares (GLS) with robust panel was therefore explored to obtain more efficient estimates and to correct autocorrelation in the model.

4.2.3 Fine-tuning the models – Robustness check

After conducting the initial OLS regression analysis, diagnostic tests revealed the presence of heteroskedasticity and potential model misspecification in the models. To ensure the reliability and accuracy of the estimates, the model required fine-tuning through appropriate corrective measures. These refinements aim to improve the model's validity, ensuring that the estimated relationships between innovative financial planning tools and environmental sustainability are both statistically sound and economically meaningful.

Table 4.8: Generalized Least Square(GLS) – Model 1

Cross-sectional time-series FGLS regression

```
Coefficients:  generalized least squares
Panels:        heteroskedastic
Correlation:   no autocorrelation
Estimated covariances      =        40          Number of obs     =         439
Estimated autocorrelations =         0          Number of groups  =          40
Estimated coefficients     =         6          Obs per group:
                                                              min =          10
                                                              avg =      10.975
                                                              max =          11
                                                Wald chi2(5)      =     4371.51
                                                Prob > chi2       =      0.0000
```

carbonemis~10	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
icttechnolo~e	.9607729	.0319019	30.12	0.000	.8982463	1.0233
researchand~i	.0054486	.0128967	0.42	0.673	-.0198286	.0307257
softwareuse~s	.0263485	.0264559	1.00	0.319	-.0255041	.0782012
firmsize	.0101854	.0090839	1.12	0.262	-.0076187	.0279896
leverage	-.0004222	.0046755	-0.09	0.928	-.0095859	.0087415
_cons	-.0679069	.061215	-1.11	0.267	-.1878861	.0520723

Source: STATA 14.2 (2025)

From table 4.8 which shows the Generalized Least Squares (GLS) formodel 1, the result presents the results of a cross-sectional time-series FGLS regression to account for heteroskedasticity and improve estimation efficiency in the model explaining carbon emission disclosure.

The model is statistically significant overall, with a Wald chi-squared value of 4371.51 and a p-value of 0.0000, indicating that the independent variables collectively have a meaningful influence on the dependent variable.

Among the variables of interest, ICT technology risk disclosure remains a strong, positive, and highly significant predictor of carbon emission disclosure (coefficient = 0.961, $p < 0.001$). This reinforces the earlier findings that firms disclosing ICT-related risks are more likely to be transparent about their carbon emissions.

However, research and development and software use or development both show positive but statistically insignificant effects ($p = 0.673$ and 0.319, respectively), suggesting they do not have a substantial impact on carbon emission disclosure in this model.

The control variables, firm size and leverage, also show insignificant effects ($p = 0.262$ and 0.928, respectively), indicating no strong influence on carbon disclosure after adjusting for heteroskedasticity.

Conclusively, the GLS model confirms ICT risk disclosure as a key driver of carbon emission reporting, while other variables, including the controls, do not show statistically significant effects in this specification.

4.3 Hypotheses testing

Table 4.8 was used in the hypotheses testing.

$H0_1$: There is no significant effect of ICT & technology risk disclosure on carbon emission disclosure of manufacturing firms in Nigeria.

Based on the Generalized Least Squares (GLS) analysis in Model 1 (Table 4.8), the coefficient for ICT and technology risk disclosure is 0.961, with a z-value of 30.12 and a p-value of 0.000. This indicates a highly significant and positive effect of ICT risk disclosure on carbon emission disclosure.

There is therefore insufficient statistical evidence to support the null hypothesis. Thus, we reject the null hypothesis (H_{01}) and conclude that ICT and technology risk disclosure has a significant positive impact on the carbon emission disclosure practices of manufacturing firms in Nigeria.

This finding implies that greater transparency in ICT and technological risk management enhances the environmental accountability of firms, particularly in disclosing carbon emissions. It also suggests that firms that are more open about their technological risks may also be more proactive and structured in reporting their environmental performance.

4.3.2 Hypothesis two

$H0_2$: There is no significant effect of research and development (R&D) on carbon emission disclosure of manufacturing firms in Nigeria.

From the GLS analysis in Model 1 (Table 4.8), the coefficient for research and development (R&D) is 0.0054, with a z-value of 0.42 and a p-value of 0.673. This result indicates that R&D has a positive but statistically insignificant effect on carbon emission disclosure.

The study therefore fails to reject the null hypothesis (H_{02}) as there is insufficient evidence to conclude that research and development significantly influences carbon emission disclosure among manufacturing firms in Nigeria.

This suggests that while R&D activities may be present in these firms, they do not necessarily translate into improved carbon disclosure practices. It could indicate a gap between innovation efforts and environmental reporting, or that R&D is not sufficiently focused on sustainability-related outcomes. The result highlights the need for firms to better align their innovation strategies with environmental transparency goals and for regulators to provide clearer guidelines linking R&D reporting with sustainability disclosures.

4.3.3 Hypothesis three

$H0_3$: Software use or development disclosure has no significant effect on carbon emission disclosure of manufacturing firms in Nigeria.

According to the GLS results in Model 1 (Table 4.8), the coefficient for software use or development disclosure is 0.0263, with a z-value of 1.00 and a p-value of 0.319. This indicates a positive but statistically insignificant relationship between software-related disclosure and carbon emission disclosure.

The null hypothesis (H_{03}) is not rejected as there is no statistically significant evidence to show that software use or development disclosure influences carbon emission disclosure among manufacturing firms in Nigeria.

The result implies that while digital tools and software may support environmental management systems, their disclosure alone does not significantly impact carbon reporting practices. This may reflect either a low level of software integration in environmental performance or poor alignment between digital investments and sustainability reporting. It underscores the need for firms to not only adopt digital innovations but also integrate them meaningfully into their environmental strategies and disclosures.

Discussion of Findings

The result indicated that ICT and technology risk disclosure markedly enhance carbon emission disclosure. This aligns with the findings of Adebayo & Dogo (2022) which demonstrated that ICT solutions, including enterprise resource planning and risk dashboards, enhance organizations' capacity to disseminate environmental data.

The negligible impact of R&D on carbon disclosure contrasts with the findings of Chukwuemeka & Hassan (2020) and Oladimeji & Musa (2022), who identified that R&D expenditure facilitates technology that reduce emissions. The outcome may indicate a disparity between innovation and real disclosure, potentially attributable to inadequate regulation or a diminished emphasis on environmental considerations within Nigerian R&D methods. Also the diminished impact of R&D and software on carbon emission disclosure indicates deficiencies in the utilization of technology instruments for carbon-specific disclosures by enterprises. This indicates a necessity for additional investigation into the correlation between innovation and environmental transparency within the Nigerian manufacturing industry.

Similarly, the finding that software use does not strongly influence carbon emission reporting contrasts with Shaaban-Nejad & Shirazi, (2022) who found that the impact of ICT in minimizing the emission of CO_2 in the entire world is significant, though its' effect on nations that belong to OECD nations is more. This difference may stem from partial ICT adoption or the lag between implementation and effective reporting.

5. Conclusion and Recommendations

The results show that ICT and technology risk disclosure significantly improve carbon emission disclosures. This highlights the importance of digital transparency and clear communication of risks in driving environmental accountability. Software use or development was also found not to have a strong effect on carbon emissions, indicating that its benefits may be more operational and compliance-driven. Similarly, R&D has no significant effect on carbon emission disclosure, suggesting a gap between innovation efforts and strategic sustainability disclosure. In conclusion, new financial tools and disclosures about technology have a significant effect on environmental transparency, but the effect varies depending on the area of sustainability. The study recommends that manufacturing companies should be urged to implement and reveal ICT and technology risk management strategies. Companies should employ more environmental management and financial planning tools, especially ones that let them gather, track, and report on data in real time. Companies should shift their research and development spending to focus on ecologically friendly new ideas, like technologies that cut carbon emissions and renewable energy solutions. Lastly, regulatory organizations should think about making ICT-related disclosures a part of the sustainability reporting rules for industrial companies.

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