EFFICACY OF DIGITAL GREEN SUPPLY CHAIN MANAGEMENT TECHNOLOGIES ON TRIPLE BOTTOM LINE PERFORMANCE: MODERATING ROLE OF MANDATORY EXTERNAL REGULATORY PRESSURE

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Abstract
This study examined the efficacy of digital green supply chain management technologies on triple bottom line performance: Moderating role of mandatory external regulatory pressure in Dangote Group of companies. Survey design was used for the study as data were collected using questionnaires administered on a sample of two hundred and eighty-four (284) respondents using Taro Yamane sample size determination model from 979 population of supply chain Managers, operations Directors, and sustainability Officers of all major subsidiaries (Cement, Sugar, Salt, Oil/Gas, and Logistics). The data analysis for the study was undertaken through PLM-SEM. Consequently, the findings of the study revealed that digital green supply chain management dimensions positively influence the TBL performance of Dangote Group of companies with beta ($\beta = 0.230$), t-statistic ($t = 2.468$) and p value ($p = 0.014$), ($\beta = 0.656$), t statistics ($t = 11.280$) and p value ($p = 0.000$) and ($\beta = -0.182$), t statistics ($t = 1.788$) and p value ($p = 0.074$) respectively. The study highlights the critical role of digital green supply chain management technologies as a strategic driver for sustainability and improved TBL performance in the manufacturing company as the results conclusively establish that green supply chain management technologies have positive and significant relationship with TBL performance. The study further recommends that digital green supply chain management technologies should be Integrated into business operations as these would enhance sustainability credentials and improve overall firm performance, contributing to both social, economic and environmental goals of firms.

Introduction
The integration of environmental efforts and global value chains has been defined as green supply chain management (GSCM), a term which refers to a managerial approach adopted within supply chains to improve the environmental performance of processes and products while ensuring profit, market share and operational performance (Gorane & Kant 2017). This shift of supply chains toward more conscious, sustainable and environmentally friendly managerial approaches is a consequence of growing concerns regarding the environmental issues that are threatening our world and our society (Cammarano et al., 2022). Green supply

chains include activities which mirror those adopted within firms (De Giovanni & Cariola, 2021), namely reducing emissions, minimizing waste, lowering energy use, using renewable materials, incorporating resource conservation measures to ensure that a product/service can be delivered in an environmentally sustainable manner, decreasing the consumption of hazardous and toxic materials, and undertaking reverse logistics actions.

The contemporary business landscape is also defined by the twin imperatives of digital transformation and sustainability (Senyo & Osabutey, 2023). As global supply chains become increasingly complex and environmentally impactful, organizations are under immense pressure to move beyond traditional operational metrics and adopt practices that ensure the longevity of their business, the welfare of society, and the health of the planet (Kusi-Sarpong et al., 2019; Jabbour et al., 2020).

Moreover, the concept of sustainability has become central to the operational strategies of supply chains worldwide. Digital Green Supply Chain Management Technologies (DGSCMT) have emerged as a transformative approach to achieving sustainability goals while maintaining economic viability, environmental accountability, and social responsibility, collectively referred to as the Triple Bottom Line (TBL) performance. The integration of digital technologies, such as artificial intelligence, blockchain and IoT, into green supply chain practices has been shown to enhance resource efficiency, reduce carbon footprints, and improve environmental performance (Hariyani et al., 2024). Current developments in digital technology, such as blockchain, artificial intelligence (AI), and the Internet of Things (IoT), have made circular supply chains feasible. Blockchain technology provides transparent material monitoring and ensures ethical sourcing, while artificial intelligence minimizes overproduction through inventory optimization and demand forecasting (Bressanelli et al., 2018; Saberi et al. 2019). Supply chain resource allocation is improved by real-time asset tracking made feasible by IoT (Zhong et al. 2017). However, the efficacy of these technologies is strongly influenced by external regulatory pressures, which play a critical role in shaping organizational behavior and compliance with sustainable practices.

Mandatory external regulatory pressures, such as government policies, international agreements, and environmental standards, act as moderating variables that influence organizational adoption of DGSCMT. Despite the clear benefits, the adoption of DGSCM practices often faces internal barriers such as high initial investment and organizational inertia (Benmebarek et al., 2025). Consequently, external institutional pressures, particularly mandatory regulatory pressure (also known as coercive pressure), play a pivotal role in compelling firms to implement sustainable supply chain practices (Yadav et al., 2023). Regulatory bodies, by issuing environmental standards and enforcing compliance, often serve as the most critical external driver for GSCM functions (Latif et al., 2021).

In addition, study shows that institutional pressures can drive organizations to align their operations more effectively with sustainability objectives, particularly in emerging and developed economies (Agyapong, 2023). Nevertheless, the extent to which these pressures impact the TBL performance remains underexplored, especially in contexts where regulatory compliance is mandatory rather than voluntary (Kumari, 2025). This study aims to examine the efficacy of DGSCMT in achieving TBL performance and to evaluate the moderating effect of mandatory external regulatory pressures. By analyzing the interplay of digital transformation, supply chain sustainability, and institutional pressures, this research seeks to provide a comprehensive understanding of how organizations can leverage technology to meet sustainability goals in a regulatory-driven environment.

Statement of the Problem

The increasing emphasis on sustainability across industries has brought the Triple Bottom Line (TBL) economic, environmental, and social performance into sharp focus. Traditional supply chain management practices are no longer sufficient to meet the growing demands for sustainable operations, especially in light of global environmental challenges and societal expectations (Kumari, 2025). Digital Green Supply Chain Management Technologies (DGSCMT), such as blockchain, IoT, big data analytics, and artificial intelligence, have been identified as critical enablers of sustainable practices in supply chains. These technologies are not only instrumental in reducing environmental footprints but also in improving operational efficiency and social inclusivity (Ning, 2025). However, despite their potential, the widespread adoption and efficacy of these technologies in achieving TBL performance remain inconsistent due to varying levels of external regulatory pressures.

In addition, mandatory external regulatory pressures, such as governmental policies, international environmental agreements, and compliance standards, significantly influence the adoption and implementation of DGSCMT (Agyapong, 2023). While stringent regulations may compel organizations to align their operations with sustainability goals, they can also create challenges, such as increased compliance costs and operational disruptions (Hebaz, 2024). In regions with weak regulatory enforcement, organizations often deprioritize sustainability, leading to suboptimal adoption of DGSCMT and limited improvements in TBL performance (Hariyani, 2024).

Moreover, prior studies have largely focused on the benefits of DGSCMT in isolation, with limited attention to the moderating role of mandatory external regulatory pressures. This gap in the literature calls for an in-depth investigation into how external regulatory environments influence the relationship between DGSCMT and TBL performance, particularly in both developed and developing economies. Addressing this gap is essential to provide insights into the conditions under which DGSCMT can maximize its impact on economic, environmental, and social sustainability. Without a comprehensive understanding of these dynamics, organizations may struggle to implement effective sustainability strategies, and policymakers may fail to design regulations that support the adoption of green technologies.

This study seeks to bridge this gap by exploring the efficacy of DGSCMT in achieving TBL performance and examining the extent to which mandatory external regulatory pressures moderate this relationship. The general objective of the study is to explore the effect of Digital Green Supply Chain Management Technologies on Triple Bottom Line Performance of Dangote Group of Companies in Nigeria with the moderating role of mandatory external regulatory pressure while the specific objectives of the study are to; examines the effect of Artificial Intelligence (AI) on the Triple Bottom line performance; investigate the relationship between Internet of Things (IoT) and the Triple Bottom line performance and determine the relationship between Blockchain Technology and the Triple Bottom line performance of Dangote Group of Companies in Nigeria.

Literature Review

Digital Green Supply Chain Management (DGSCM)

The literature on Digital Green Supply Chain Management (DGSCM) Technologies is a rapidly evolving field that examines how the adoption of digital tools can enhance the environmental and economic sustainability of supply chains. Recent systematic reviews and empirical studies emphasize that the synergy between digital transformation and green practices is crucial for achieving modern sustainability goals (Wang et al., 2023; Keroo, 2023).

Green Supply Chain Management (GSCM) involves integrating environmental concerns into inter-organizational supply chain processes, from raw material sourcing to end-of-life management (Zhu & Sarkis, 2004). Digital technologies, often categorized as Industry 4.0 enablers, are increasingly recognized as the key mechanism to overcome the informational and operational barriers that have traditionally limited GSCM effectiveness (Ageron et al., 2020). The integration of digital capabilities, such as real-time data collection and advanced analytics, is shown to significantly and favorably impact green innovation performance (He et al., 2021). This convergence gives rise to the concept of Smart Green Supply Chain Management, where digital intelligence enhances green outcomes (Keroo, 2023). Recent research focuses on several core digital technologies and their applications across various GSCM phases:

i. Artificial Intelligence (AI) and Big Data Analytics (BDA)

AI and BDA are viewed as central to optimizing green performance. AI-powered GSCM practices, including machine learning for predictive analytics, significantly influence both technology innovation and sustainable performance (Taseen et al., 2024). This includes Green Logistics Optimization where AI algorithms are used to optimize transportation routes and networks, directly reducing fuel consumption and carbon emissions (Sun et al., 2021) and Green Production and Consumption**;** BDA also analyze consumer demand patterns to enable more accurate, on-demand production, thereby minimizing waste and overstocking, which is a key practice in green consumption (Wang et al., 2023).

ii. Internet of Things (IoT) and Cloud Computing

IoT devices, sensors, and Radio-Frequency Identification (RFID) tags play a critical role in providing real-time data for environmental monitoring (Li et al., 2022). This technology enables firms to monitor parameters such as energy consumption, emissions, and waste generation in real-time throughout the entire supply chain (Sun et al., 2021). This comprises Green Procurement where IoT sensors can monitor the quantity and quality of raw materials and energy usage, helping companies avoid resource waste and achieve environmental performance in procurement (Wang et al., 2023) and Data Sharing where Cloud computing facilitates seamless, secure data sharing and collaboration among supply chain partners, which is essential for coordinated green practices and supply chain flexibility (Gammelgaard & Nowicka, 2023).

iii. Blockchain Technology

Blockchain is highly valued for enhancing transparency and traceability within the green supply chain (Zheng et al., 2022). Its immutable ledger system is particularly useful for verifying the authenticity of green claims, such as the ethical sourcing of materials or the proper disposal of waste. It establishes an auditable record of environmental compliance, which is vital for increasing accountability, enhance supply chain transparency by providing traceability of raw materials, verify the ethical sourcing of materials (e.g., conflict-free minerals), reduce fraud and ensuring compliance with environmental and social standards and products and trust among stakeholders regarding sustainability performance (Di Vaio et al., 2024).

The collective literature demonstrates that DGSCM technologies lead to significant benefits. Studies confirm that digital capability, often mediated by green supply chain collaboration, positively and significantly impacts green innovation performance and overall sustainable performance (Taseen et al., 2024). The outcomes are multifaceted as it assists in reducing waste, lower energy consumption, and minimized carbon footprint (Wang et al., 2023), saves cost from improved efficiency, optimized inventory, and reduced risks (Taseen et al., 2024) and enhanced corporate image, stronger societal relationships, and increased market share due to an environmentally friendly image (Stroumpoulis et al., 2024).

Triple Bottom Line (TBL) Performance

The Triple Bottom Line (TBL) framework, conceptualized by Elkington (1997), has become a fundamental model for evaluating corporate performance beyond traditional financial metrics. It asserts that a company's success should be measured by its simultaneous performance across three interconnected dimensions; Profit (Economic), People (Social), and Planet (Environmental) (Luque-Vílchez et al., 2023). Recent literature reviews and empirical studies affirm the TBL's enduring relevance while highlighting its evolution from a theoretical concept into a strategic, actionable framework for achieving long-term corporate sustainability and value creation (Nogueira et al., 2025). TBL performance is characterized by an increasing focus on its practical application, integration with global sustainability goals, and critical assessment of its measurement (Naharuddin et al., 2024; Parhi & Subudhi, 2024).

In addition, current study indicates a shift in TBL from a broad management concept to an actionable sustainability framework (Nica et al., 2024). Studies now emphasize its practical utility in specialized areas, such as the circular economy, life cycle assessment, and climate impact, aligning it with global targets like the Sustainable Development Goals (SDGs) (Nica et al., 2024). The TBL approach is viewed as crucial for driving a paradigm shift from solely profit-driven measurement toward a more holistic view of organizational success (Nogueira et al., 2023).

There is a growing body of work linking the TBL framework with Environmental, Social, and Governance (ESG) criteria, which are often used to operationalize the TBL's principles into corporate practices (Luque-Vílchez et al., 2023). The TBL forms the foundational worldview for corporate sustainability strategies, helping organizations balance economic growth with ecological integrity and social well-being. However, research also notes that TBL implementation is often still lopsided, with a need for more concerted effort on the "People" and "Planet" dimensions (Luque-Vílchez et al., 2023).

A significant theme in recent reviews is the inherent difficulty and inconsistency in measuring and reporting TBL performance (Parhi & Subudhi, 2024). Scholars continue to point out gaps, including a lack of consistent measuring instruments, issues with integration, and challenges in quantifying the value created by non-financial dimensions (Hashim et al., 2023). This complexity has prompted calls for the strategic renewal of the TBL framework to address its underlying criticisms and enhance its capacity to deliver maximum value benefit to all stakeholders (Bhatti et al., 2022).

Mandatory External Regulatory Pressure

Mandatory external regulatory pressure, often conceptualized under coercive isomorphic pressure in Institutional Theory, compels firms to conform to legislative requirements or face penalties (Ding et al., 2024). This pressure acts as a crucial corrective mechanism, forcing corporations to internalize externalities like pollution and resource depletion that are often ignored in purely profit-driven models (Abreu & Abreu, 2025).

Environmental regulations represent one of the most direct forms of mandatory external pressure. Recent research highlights a dual effect of these regulations, particularly in emerging economies (Papafloratos & Pantazi, 2025). Appropriate, strict environmental regulation is increasingly shown to stimulate technological innovation within firms, often leading to the adoption of green technologies to improve environmental quality and enhance enterprise resilience (Chen et al., 2024; Wang et al., 2025). This aligns with the "Porter Hypothesis," suggesting that regulation can spur innovation that ultimately offsets compliance costs (Wu & Tham, 2023).

Theoretical Review

The most robust theoretical framework for analyzing the impact of mandatory external regulatory pressure on corporate sustainability (or Triple Bottom Line - TBL) performance is an integrated approach combining Institutional Theory and Stakeholder Theory.

Institutional Theory: The Mechanism of Conformity

Institutional Theory explains why firms comply with mandatory external regulations. The key mechanism is coercive isomorphism, where organizations conform to legal requirements and societal expectations to gain legitimacy and secure resources. This pressure comes from powerful external actors, primarily government and regulatory bodies, through laws, directives and the threat of sanctions. Compliance is not voluntary; it is mandated. Recent literature confirms

that this coercive pressure is a significant factor driving firms to fulfill their ESG and social responsibility obligations (Ding et al., 2024).
The theory explains the shift from voluntary Corporate Social Responsibility to mandatory reporting, as regulations force organizations to standardize practices which is a form of institutional alignment. Studies highlight that mandatory regulation has a strong and positive influence on firms' environmental performance by compelling the adoption of green practices (Chen et al., 2024).

Stakeholder Theory: The Rationale for Sustainability
Stakeholder Theory provides the normative and strategic basis for focusing on sustainability, aligning perfectly with the People and Planet dimensions of the TBL (economic, social, and environmental performance). Firms must manage relationships with all relevant stakeholders (investors, employees, communities, regulators) whose demands and expectations can significantly affect the firm's survival and performance. Regulatory pressure often strengthens the voice and power of stakeholders (Latip et al., 2022).

The theory explains that mandatory disclosure helps mitigate information asymmetry between the firm and its stakeholders, thereby increasing accountability (Al-Bassam et al., 2025). Furthermore, it is linked with TBL concepts to argue that long-term value creation depends on meeting the needs of this broader group, especially when institutional forces (like new regulations) empower them (Linder et al., 2025; Wang et al., 2025).

Methodology
This study adopts cross-sectional survey method to assess the efficacy of digital green supply chain management technologies on triple bottom line performance with the moderating role of mandatory external regulatory pressure. Survey method was considered through a structured self-administered questionnaire. The 284 questionnaires derived from the population of 979 staff of Dangote Group, ranging from supply chain Managers, operations Directors, and sustainability Officers of all major subsidiaries (Cement, Sugar, Salt, Oil/Gas, and Logistics) of the company in Nigeria through Taro Yamane sample size determination model as the convenience sampling technique was also adopted.

To ascertain the validity of the instrument, content validity was adopted. The instruments were validated by the researcher's superior researcher who have more wealth of knowledge on the subject matter to scrutinize the questionnaire to ensure that the questions therein are not at variance with the subject matter under study. They ensured that the instruments represent the entire range of possible items to be tested in the study.

Finally, the collected data were analyzed using inferential statistical tools. In addition, multiple regression analysis was conducted using SmartPLS, a Partial Least Squares Structural Equation Modeling tool, to test the hypotheses and measure the efficacy of digital green supply chain management on TBL performance of Dangote Group of Companies in Nigeria. The analysis approach allowed for the testing of complex relationships among constructs and provided robust validation for the model used in the study. Ethical considerations were adhered to throughout the research, including voluntary participation, informed consent, and the assurance of confidentiality and data protection.

Analysis and Results

Descriptive Analysis of Constructs

The results of these statistical values as shown in Table 1 were used to determine the respondents' views on the level of low (M = 1.00 – 2.25), medium (M = 2.26 – 3.75) and high (M = 3.76 and above) (Healey, 2005). Therefore, the descriptive test was conducted to provide answer to research question one.

Table 1: Descriptive Analysis of Constructs

LATENT CONSRUCTS	N	Mean	Std. Deviation	Level
AI	247	17.88	4.18	High
IoT	247	18.83	3.43	High
BCT	247	18.34	3.62	High

Observably, from table 1, the mean and standard deviation of the independent variables are green Artificial Intelligence (M = 17.88, Stdev = 4.18), Internet of Things (M = 18.83, Stdev = 3.43), and Blockchain Technology (M = 18.34, Stdev = 3.62). These results signified that high Artificial Intelligence practice could lead to Triple Bottom line performance being exhibited by Dangote Group of companies.

Evaluation of PLS-SEM Results

This section presents the results of the PLS-SEM in two stages as recommended in literature (Hair, et al., 2014; Hair et al., 2011). The two stages are regarded as measurement model assessment and structural model assessment (Hair et al., 2011). Particularly, the measurement model assessment presents the results of reliability of individual items, construct internal consistency reliability and construct validity (convergent and discriminant). While the structural measurement assessment presents the results of collinearity, path coefficients, variance explained (R^2), effect size (f^2), predictive validity (Q^2) and its effect size (q^2). Also assessed in this section is the interaction effects (moderating) of the relationship between exogenous and endogenous variables.

Reliability of Individual Measurement Items

Item loadings have been established as the measure used to determine the reliability of an item (Byrne, 2010). This represents the correlation coefficients between the individual indicators and the latent construct they measured. Items with loadings of less than 0.4 were deleted while those items with loading of less than 0.7 that increased the AVE were retained. The results of item loading in Table 1 revealed that all items loaded above 0.4, signifying the reliability of the items.

Internal Consistency Reliability

Internal consistent reliability represents the extent of correlation among items that measure a construct with higher correlation indicating higher reliability and vice versa (Kline, 2013). Composite reliability (CR) estimates were used to measure internal consistency reliability in this study. However, it was suggested that the coefficient of CR should not be less than 0.7 (Chin, 1998; Hair et al., 2014). The coefficients of CR for the constructs of this study are all greater than 0.7 as suggested, indicating that all the constructs have adequate internal consistency reliability and this is shown in Table 1.

Convergent validity

Convergent validity is described as a type of construct's validity that evaluates how a particular measure truly measures what its intended to measure and correlates positively with other alternative measures of the same construct (Hair et al., 2006). the value of AVE of 0.50 and above signifies that the variable has a convergent validity (Chin, 1998; Hair et al., 2011). The rationale behind this is that an AVE with 0.50 means that the latent construct explains a half of the variance of its items (Hair et al., 2014).

Therefore, achieving adequate convergent validity entails that AVE of each latent variable must not be less than 0.50 as suggested by Chin (1998). With this argument, all the AVE values in this study exceeded the recommended value of 0.50 on their respective variables which indicates adequate convergent validity. Table 1 shows the convergent validity of every variable in this study.

Table 2: Summary of Items Loading, Composite Reliability and Average Variance Extracted (AVE)

Constructs	Items	Loading	Composite Reliability	Average Variance Extracted (AVE)
Internet of Things			0.803	0.630
	IoT_01	0.835		
	IoT _03	0.826		
	IoT _04	0.830		
	IoT _05	0.672		
Artificial Intelligence			0.881	0.659
	AI_01	0.747		
	AI _02	0.730		
	AI _03	0.833		
	AI _04	0.874		
	AI _05	0.865		
Blockchain Technology			0.914	0.764
	BCT_01	0.892		
	BCT _02	0.883		
	BCT _03	0.856		
	BCT _04	0.864		
Triple Bottom line Performance			0.902	0.718
	PO_01	0.821		
	PO_02	0.848		
	PO_03	0.877		
	PO_04	0.862		
	PO_05	0.825		

Discriminant validity

Discriminant validity ensures that a construct is truly distinct from other constructs in a model. It confirms that measurement items relate more strongly to their own construct than to others. In PLS-SEM, discriminant validity is assessed using three main methods: the Fornell-Larcker criterion, cross-loadings, and the Heterotrait-Monotrait (HTMT) ratio. The Fornell-Larcker method compares the square root of AVE with correlations between constructs, while HTMT addresses its limitations by providing a more sensitive estimate of inter-construct correlations. In this study, all constructs met the acceptable thresholds for both Fornell-Larcker and HTMT (below 0.85), confirming adequate discriminant validity.

Table 3: Discriminant Validity (Fornell-Larcker Criterion)

Variables	IoT	AI	BCT	TBL	CR
Internet of Things	0.794				
Artificial Intelligence	0.762	0.812			
Blockchain Technology	0.772	0.609	0.874		
TBL Performance	0.708	0.816	0.517	0.848	O.885

Source: Authors Computation (2025)

Table 4: Heterotrait-Monotrait Ratio (HTMT)

Variables	IoT	BCT	AI	TBL	CR
Internet of Things					
Blockchain Technology	0.922				
Artificial Intelligence	0.901	0.688			
TBL Performance	0.832	0.915	0.563		

Source: Authors Computation (2025)

Assessment of Structural Model

The second step in PLS analysis is assessing the structural model, also known as the inner model, which evaluates the hypothesized relationships among latent constructs (Hair et al., 2016). This involves testing how exogenous variables—such as environmental consciousness, green product innovation, green process innovation, and renewable energy—affect the endogenous variable, organizational performance. In this study, the structural model was assessed using key indicators: path coefficient significance, coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), and the predictive relevance effect size (q^2).

Direct Path Coefficients Assessment

Assessing both direct and indirect path coefficients typically involve the bootstrapping method, as recommended by Chin (1998) and Hair et al. (2013). Bootstrapping involves repeatedly resampling from the original dataset to estimate model parameters and test their statistical significance (Henseler, Hubona & Ray, 2016). In this study, bootstrapping was used to evaluate the significance of direct and indirect relationships among variables, with 5,000 bootstrap samples employed, following the recommendation of Hair et al. (2017).

The result of the structural model for the direct relationships between independent and dependent variables of this study is presented in the Table 2.

Table 2 shows the results of the hypothesis testing for the direct relationship as proposed in this study. The discussion for the results on this table is as follows:

Table 5: Direct Path Coefficients

HYPOTHESES	Paths	Beta	STDEV	T Statistics	P Values	Remark
H1	**IoT -> PO**	0.230	0.093	2.468	0.014	Accepted
H2	**AI -> PO**	0.656	0.058	11.280	0.000	Accepted
H3	**BCT -> PO**	-0.182	0.102	1.788	0.074	Accepted

Hypothesis 1: Internet of Things positively influences the Triple Bottom Line performance of Dangote Group of companies is represented by path linking IoT to PO on table 2. The result from the table shows the path estimates for the linkage between IoT and PO with beta (β = 0.230), t-statistic (t = 2.468) and p value (p = 0.014). This signifies that the relationship between IoT and PO is positive and significant, hence hypothesis H1 was accepted based on this outcome.

Hypothesis 2: Artificial Intelligence positively influences the performance of Dangote Group of companies is represented by path linking AI to PO on table 2. The path estimates for this relationship reveals beta (β = 0.656), t statistics (t = 11.280) and p value (p = 0.000). The hypothesized relationship between AI and PO is accepted based on these values, indicating a positive and significant relationship at 5% level of significance.

Hypothesis 3: Blockchain Technology positively influences the performance of Dangote Group of companies is represented by path linking BCT to PO with path estimates of beta (β = -0.182), t statistics (t = 1.788) and p value (p = 0.074) as shown in table 4.10. The result signifies a positive and significant relationship between BCT and PO at 1% significance level, thus the proposed hypothesis H3 is accepted. This result indicates that green process innovation significantly influences the performance of Peace and Tuyil pharmaceutical company.

Coefficient of Determination (R-squared)

From the model of this study, R^2 value of 0.698 (69.8%) was found and indicating that the independent variables (IoT, AI, BCT) treated initially as exogenous variable in the model jointly accounted for 69.8% of variance in the dependent variable (OP). This revealed that a substantial variance explained was obtained (Chin, 1998).

Effect Size Assessment

Table 3 shows the f^2 of all the exogenous constructs from the result of PLS-SEM conducted using the survey data. As observed from this table, the independent variables that recorded significant positive effects on dependent variable have between small to medium effect on the dependent variable.

Table 6: Constructs Effect Size

Constructs	SMEP	Effect Size
IoT	0.043	Small
AI	0.596	Substantial
BCT	0.036	Small

Discussion of the findings

The findings of this study reveal a statistically significant and positive relationship between Artificial Intelligence (AI) and TBL performance (OP) Dangote Group of companies. As presented in Table 1, the direct path coefficient from AI to OP is strong ($\beta = 0.656$, $t = 11.280$, $p = 0.000$), indicating that firms actively developing environmentally friendly products experience superior performance outcomes. This significance suggests AI is a critical driver for sustainable and superior business outcomes, aligning with the strategic view that technology enhances corporate social and environmental responsibility. The study aligns with empirical evidence that supports those technologies like AI can improve resource efficiency and optimize green operations, consistent with studies linking digital transformation to TBL goals (Khan et al., 2024; Dubey et al., 2023). Specifically, AI's role in developing environmentally friendly products as the prompt highlights is a key mechanism for this superior TBL performance, echoing research that links eco-innovation and sustainability practices to competitive advantage (Rejeb et al., 2023; Gholami et al., 2021).

In contrast, the relationship between Blockchain Technology (BCT) and TBL performance, while positive, was weaker and only marginally significant ($\beta = -0.182$, $t = 1.788$, $p = 0.074$). Although the hypothesis was accepted, the lower path coefficient suggests that Blockchain Technology may not yield immediate or substantial performance improvements in the short term. This weak significance is notable, as it suggests the costs, complexity, and nascent adoption phase of BCT may currently outweigh the TBL benefits, especially concerning energy consumption and limited scale of sustainable applications. Empirical evidence highlights BCT's potential for supply chain transparency and traceability to improve TBL (Treiblmaier & Pan, 2022), but actual performance benefits are often constrained by implementation challenges and organizational readiness (Kshetri, 2021). Current literature suggests that the full positive impact of BCT on TBL is often moderated by other factors like AI integration or regulatory support, leading to non-significant direct effects in some contexts (Belhadi et al., 2024; Dubey et al., 2022).

Finally, Internet of Things (IoT) demonstrated a positive and statistically significant impact on TBL performance ($\beta = 0.230$, $t = 2.468$, $p = 0.014$). The finding signifies that the Internet of Things (IoT) is a statistically proven enabler of improved Triple Bottom Line (TBL) performance ($\beta=0.230$, $p=0.014$), making it a viable technology for sustainability strategies. The implication is that IoT's core function, that is, real-time data collection and system monitoring, directly translates to TBL gains across Profit, People, and Planet dimensions. The significance lies in IoT's capacity to drive operational efficiency and resource optimization, which is crucial for reducing environmental impact and boosting the economic bottom line simultaneously (Nižetić et al., 2020).

More so, empirical studies consistently show IoT usage enhances sustainable practices through better energy consumption and supply chain visibility, fostering a "win-win" scenario for both business and sustainability (Mattera & Gava, 2021; Tawfik et al., 2024). The TBL improvement stems from IoT-enabled predictive maintenance (reducing waste and downtime) and enhanced safety (People dimension), solidifying its strategic role in sustainable business models (Muridzi, 2023). This evidence confirms that investing in IoT is a strategic path toward achieving integrated economic, social, and environmental goals, aligning business outcomes with broader sustainable development objectives.

Conclusion

i. From the Hypothesis one, the results conclusively establish Artificial Intelligence (AI) as a critical and powerful catalyst ($\beta=0.656$, $p=0.000$) for driving superior Triple Bottom Line (TBL) performance at Dangote Group. This confirms the strategic value of AI in enhancing corporate environmental and social responsibility through eco-innovation and resource efficiency, thereby securing competitive advantage. Ultimately, the study reinforces the empirical consensus that digital transformation is vital for achieving integrated sustainability goals (Profit, People, Planet) in large enterprises.

ii. The hypothesis concludes that the marginally significant, negative path coefficient ($\beta=-0.182$, $p=0.074$) implies BCT is not yet a reliable, direct driver of TBL performance despite the accepted hypothesis. Its weak effect suggests that current costs and implementation complexities outweigh short-term benefits, especially related to energy and scalability limitations in sustainable applications. Therefore, BCT is categorized as an emergent technology requiring further maturity and integration before it can yield substantial, positive TBL improvements.

iii. The third hypothesis affirms that the positive and significant path coefficient (β=0.230, p=0.014) firmly establishes IoT as a statistically proven enabler of enhanced Triple Bottom Line (TBL) performance. This confirms that IoT's real-time data and monitoring capabilities translate directly into tangible improvements across economic, social, and environmental sustainability goals. Consequently, IoT is a viable and strategic technology for companies aiming to integrate and optimize sustainability within their core operations.

Recommendation

i. Dangote Group should significantly increase investment in AI to fully leverage its proven role in driving superior TBL outcomes, competitive advantage, and integrated sustainability. The focus should be on AI-enabled eco-innovation and operational efficiency to maximize gains across profit, people, and planet.

ii. Management should re-evaluate the BCT implementation strategy, focusing resources on pilot projects that directly address its complexity and energy demands to transition from a negative correlation to tangible TBL benefits. BCT investment should be approached cautiously and strategically, prioritizing use cases that maximize transparency and minimized operational drag.

iii. Actively scale IoT deployment across all major operations to leverage its proven and statistically significant positive impact on TBL performance (resource efficiency, operational monitoring, etc.). Prioritize integrating IoT data into TBL reporting and decision-making to maximize sustainability gains and strategic advantage.

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