MRN Publishing

Vol. 14, No. 23, 2026, pp. 20–26.
ISSN 1596−5074

Management Network Journal

Industry 4.0 as a Moderator Between Sustainable Procurement and Firm Performance in Nigeria's Petroleum Downstream Sector

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Abstract

This study investigates the integration of Industry 4.0 applications with sustainable procurement practices to optimize firm performance within an eco-innovation framework. Within the context of Nigeria's petroleum downstream sector (PDS), the complexities of sourcing, volatile fuel pricing, and historically lax environmental compliance have often restricted the direct strategic benefits of sustainable procurement on overall performance. To address this challenge, this study examines the moderating role of Industry 4.0 applications (specifically Cyber-Physical Systems and the Internet of Things) on the relationship between sustainable procurement practices and firm performance. A quantitative research approach utilizing a cross-sectional survey design was adopted, gathering data from a stratified random sample of head staff across 365 business units and affiliates operating under NNPC Limited. Structural Equation Modeling (SEM) was conducted via SmartPLS to assess the hypothesized relationships. The empirical findings demonstrate that while sustainable procurement practices exert a strong and significant direct influence on firm performance (β = 0.914, p <0.001), Industry 4.0 applications do not currently exert a significant moderating effect on this relationship (β = -0.022, p = 0.153). These results suggest that the baseline performance returns of sustainable sourcing in Nigeria's downstream sector remain indifferent to the current level of Industry 4.0 integration. The study provides stakeholders with an empirical roadmap, emphasizing that while digital transformation is an emerging corporate asset, the primary driver for operational excellence remains the fundamental implementation of sustainable procurement practices.

Keywords: *Industry 4.0, Sustainable Procurement Practices, Firm Performance, Petroleum Downstream Sector, SmartPLS.*

Introduction

The industrialisation process began by the end of the 18th century with the advent of mechanical manufacturing machinery powered by water and steam. This initial shift marked the first industrial revolution, transforming societies from agricultural base to industrial economies (Gökalp *et al.*, 2017). This era was followed by the second industrial revolution around the turn of the 20th century, which introduced electrical power to enable mass production and automated mechanics within factories (Liao *et al.*, 2017). This second wave was predominantly driven by organizational changes, such as the implementation of the assembly line and scientific management procedures (Gökalp *et al.*, 2017). The evolution progressed into the third industrial revolution, starting around 1969, which was characterised by the rise of electronics and information technology to achieve advanced automation of manufacturing processes (Fettermann *et al.*, 2018). During this third phase, industry operations were improved by employing intelligent systems such as industrial robotics and automated processes, which allowed machines to take over a large proportion of manual labor (Pereira & Romero, 2017).

Finally, a new paradigm known as the fourth industrial revolution, or industry 4.0, has introduced a new era of industrialisation powered by cyber physical systems combined with the internet of things ecosystem (Ghadimi *et al.*, 2019; Xu, 2018). Through this technological leap, physical assets are supplemented by their virtual representations, which simultaneously increases operational automation, logistical flexibility, and the integration of vendor and customer demands (Bahrin *et al.*, 2016). Ultimately, industry 4.0 refers to the strategic application of cyber physical systems, the internet of things, big data analytics, and artificial intelligence to create fully interconnected ecosystems.

Scholarship indicates that the application of industry 4.0 has improved numerous business models by creating resource efficiencies, lowering energy consumption, and enhancing real-time data distribution across corporate networks (Lopes de Sousa Jabbour *et al.*, 2017). Inter-firm networks become more integrated because digital systems communicate seamlessly with one another, optimizing transaction speeds and compliance monitoring (Montavon *et al.*, 2018). Conversely, some operational perspectives note that companies are often more concerned with the foundational consistency of business operations than the mere sophistication of their technology; a robust business model supported by moderate technology frequently outperforms a flawed operational design paired with high technology (de Sousa Jabbour *et al.*, 2018). Within corporate purchasing functions, this tension emphasizes that digital tools must serve a specific strategic purpose, such as verifying the environmental and social compliance of vendors, rather than just automating existing inefficiencies.

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This study narrows the concept of industry 4.0 to focus specifically on two primary components: cyber physical systems and the internet of things. These two dimensions serve as critical enablers for operational integration and automated tracking within the petroleum downstream sector (Fatorachian & Kazemi, 2018). By embedding these technologies, firms operating within the petroleum downstream sector can establish real-time verification channels to evaluate supplier compliance, track fuel origin, and manage the volatile pricing complexities inherent in resource sourcing (Saarikko *et al.*, 2017). This advanced digital infrastructure enables machines to process information, communicate across networks, and share critical data across the purchasing interface of the petroleum downstream sector (Mourtzis *et al.*, 2016).

The ultimate objective of industry 4.0 applications in this study is to connect machines, human systems, and external suppliers through virtual networking to facilitate seamless data communication within corporate procurement activities. The integration of cyber physical systems and the internet of things into purchasing processes is intended to inject flexibility into sustainable procurement practices (Jabbour *et al.*, 2018). By doing so, this digital architecture enables complex operations within the petroleum downstream sector to overcome historical environmental externalities and structural inefficiencies, ultimately translating sustainable procurement practices into superior firm performance.

Literature Review

Cyber Physical Systems

Many scholars consider cyber physical systems to be the foundational architectures of industry 4.0 applications (Xu *et al.*, 2018). These systems integrate data processing with physical operations to allow autonomous infrastructure, such as self-driving transit units and automated processes, to communicate continuously with their surrounding environments (Kulauzovic, 2018; Lu, 2017). Previous studies demonstrate that the application of cyber physical systems across domains like mobility, healthcare, corporate logistics, and industrial production introduces significant changes to daily business operations and eases cross-organizational communication (Kulauzovic, 2018). Within an industrial context, cyber physical systems offer substantial potential, generating value both for individual companies and entire economies (Lu, 2017). Technically, these frameworks draw on the modular and flexible logic of embedded computing systems to interact directly with the physical environment (Lasi *et al.*, 2014).

While the technical interpretation of cyber physical systems focuses on the integration of data and physical processes, their practical application is deeply tied to human relations and organizational structures (Kulauzovic, 2018). Essentially, these systems bridge the interaction between the physical and the virtual world (Fatorachian & Kazemi, 2018; Mourtzis *et al.*, 2016). For example, software entities observe and comprehend physical phenomena through networks of sensors that gather information to be processed as actionable corporate data (Ehret & Wirtz, 2017). In terms of corporate purchasing, organizations utilize cyber physical systems to achieve higher levels of procurement tracking, greater efficiency in sourcing operations, tighter cooperation across supply activities, and improved firm performance (Nagy *et al.*, 2018). Within the broader value network, this represents a system constructed by interconnected, autonomous entities communicating across physical levels, from individual distribution elements to regional networks (Liu *et al.*, 2015).

Such an architecture can handle complex, diverse operations and make real-time decisions to secure optimal and robust outcomes (Nagy *et al.*, 2018). The expected benefits of cyber physical systems include security enhancement, self-maintenance, predictability, and contract accountability (Lu, 2017). Incorporating these digital technologies into supply chain activities improves the capacity of smart organizations to operate with high atomic precision (Ehret & Wirtz, 2017). Within the petroleum downstream sector, for instance, remote monitoring achieved by applying radio frequency identification transmitters for surveillance can link downstream distribution directly to digital procurement databases. These internet of things devices can trace fuel shipments through pipelines and tankers via cyber physical systems, validating supplier compliance and delivery volumes in real time (Abubakar, 2014; Liu *et al.*, 2015).

Internet of Things

The internet of things is an emerging paradigm consisting of distinct technological approaches based on the seamless connection between physical objects and the internet (Gökalp *et al.*, 2017). It is defined as an integrated system where physical devices communicate through a broad network architecture (Fatorachian & Kazemi, 2018; Saarikko *et al.*, 2017). This technology connects physical world objects—equipped with sensors, actuators, and communication infrastructure—directly to the internet, spanning multiple application domains such as manufacturing, health, transport, and energy management (Bonilla *et al.*, 2018; Lu, 2017).

As an evolving corporate asset, the internet of things combines diverse hardware devices and networking methods to link physical operations with digital databases (Bonilla *et al.*, 2018). Within corporate environments, this enables operational networks and asset systems to communicate and share information in real time, creating a highly collaborative and effective sourcing structure (Tiwari, 2017). Integrated cloud computing systems enable firms to store massive amounts of supply data that can be securely accessed from any global location (Rahmani *et al.*, 2018). This type of application is uniquely useful for the Nigerian petroleum downstream sector to improve organizational sustainability. By utilizing the internet of things, downstream firms can eliminate communication gaps between their purchasing departments, logistics providers, external vendors, and the broader economic environment.

Trends in Industry 4.0 Application Research 2009 to 2018

In a bid to understand the historical trends of industry 4.0 applications, a bibliometric study of publications was conducted within the Scopus database. This analysis evaluated two primary dimensions of industry 4.0 applications: cyber physical systems and the internet of things. The analysis of cyber physical systems across the top ten most productive fields revealed that out of 2,392 retrieved research publications, engineering accounted for the highest volume with 765 publications (30.8%), followed closely by computer science with 605 publications (24.3%). The third most popular field was mathematics with 298 publications (12.0%), while material sciences represented the fourth most populous field with 152 publications (6.1%).

Furthermore, evaluating the pattern of research in cyber physical systems indicated that the business, management, and accounting field was the least developed area, containing only 54 publications, which accounted for a mere 2.2% of the total research output. Conversely, concerning research trends on the internet of things, the results showed that out of 8,810 total publications, computer science maintained the highest volume with 2,987 publications (33.9%), followed by engineering with 2,597 publications (29.5%). The third most popular field was physics and astronomy with 539 publications (6.1%), and material sciences stood as the fourth most populous field with 482 publications (5.5%). Looking into the publication patterns for the internet of things, the business, management, and accounting field ranked ninth, yielding 188 publications (2.1%). This historical distribution underscores a significant gap in corporate literature, highlighting the necessity of studying how these technologies moderate business-centric practices like sustainable procurement to influence overall firm performance.

Methodology

Design

This study utilizes a quantitative research approach. A cross-sectional survey design was adopted to collect the relevant data required for the evaluation of the relationships between sustainable procurement practices, industry 4.0 applications, and firm performance. In a cross-sectional survey design, the researcher measures both the structural outcomes and the exposures within a survey population at a single point in time (Levin, 2006; Setia, 2016). This design is highly appropriate for examining the moderating effects of digital technologies across a broad corporate network within a specific timeframe.

Participants

The participants in this study consisted of senior management and head staff members drawn from the unbundled business units and affiliates operating under NNPC Limited within the petroleum downstream sector in Nigeria. A sample of 365 key personnel, comprising both male and female professionals, was targeted across the downstream value chain. The respondents were selected using a stratified random sampling procedure to ensure proportionate representation across the diverse commercial units of the petroleum downstream sector. This probability sampling technique was selected because the target institutional population is large, highly specialized, and organized into distinct operational strata across the country (Creswell & Creswell, 2017). The structured questionnaires were administered directly to the selected corporate respondents to optimize response rates and ensure data quality, which represents an effective selection strategy for structural studies involving corporate organizations within a cross-sectional framework (Levin, 2006).

Measures

The data collection instrument was a structured questionnaire comprised of scales that were newly developed, adapted, and pre-validated prior to field administration. The metrics explicitly evaluated sustainable procurement practices, firm performance, and industry 4.0 applications. To capture the variance in organizational responses, participants were asked to state their level of agreement for each item using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Data Analysis

The primary data obtained from the corporate respondents were coded, scored, and meticulously entered into a Microsoft Excel database. Following data cleaning and the screening for missing values or outliers, the dataset was formatted appropriately for the specialized statistical software required to execute the analysis. Descriptive statistics were initially computed to summarize the demographic characteristics of the respondents and the operational features of the firms.

Subsequently, partial least squares structural equation modeling was used to analyze the structural data and test the hypothesized moderation model. Methodological literature establishes that partial least squares structural equation modeling effectively accounts for measurement errors, handles complex latent constructs, and presents highly accurate calculations for interactive and moderating paths (Chin *et al.*, 2003). In line with standard analytical protocols, the evaluation was conducted in two distinct sequential stages: the validation of the measurement model, followed by the assessment of the structural model (Hair *et al.*, 2017).

Results and Discussion

Measurement Model

The measurement model was evaluated following the recommendations of Hair *et al.* (2017) by examining indicator loadings, composite reliability (CR), and average variance extracted (AVE). Indicator reliability was assessed using factor loadings, with a minimum threshold of .70 indicating that an item adequately represents its underlying construct. During the initial estimation, most indicators measuring sustainable procurement practices (SPPs), Industry 4.0 applications, and firm performance (FP) exceeded the recommended threshold. Indicators with inadequate loadings were removed during model refinement to improve the psychometric quality of the scales. Following this purification process, all retained indicators demonstrated acceptable factor loadings (Figure 1), supporting indicator reliability. In addition, all latent constructs achieved satisfactory CR and AVE values, confirming adequate internal consistency and convergent validity.

As illustrated in Figure 1, the refined measurement model demonstrates that the retained indicators adequately represent their respective constructs. The structural relationships further show that sustainable procurement practices (SPPs) exert a strong positive effect on firm performance (FP), $\beta = .914$, $p < .001$, indicating that organizations with stronger sustainable procurement practices tend to achieve superior overall performance outcomes. Among the dimensions contributing to SPPs, Industry Regulations (IR) showed the strongest positive contribution ($\beta = .860$, $p = .056$), followed by Contract Conditions (CC) ($\beta = .471$, $p = .254$), Environmental Data (ED) ($\beta = .287$, $p = .031$), and Green Procurement (GP) ($\beta = .182$, $p = .200$), whereas Integration and Information Exchange Mechanisms (IEM) exhibited a negative, non-significant association ($\beta = -.174$, $p = .550$). For firm performance, Operational Performance (OOP) displayed the strongest positive association ($\beta = .758$, $p = .175$), followed by Environmental Performance (EC) ($\beta = .136$, $p = .246$), while Economic Performance (EP) was negatively related to the higher-order construct ($\beta = -.690$, $p = .341$). Collectively, these findings provide evidence that the measurement model possesses satisfactory reliability and validity, while the structural results highlight sustainable procurement practices as a substantial predictor of firm performance within the study context.

Structural Model

To test the hypothesized moderating influence of industry 4.0 applications, the structural model must be successfully evaluated. Methodological frameworks recommend observing the coefficient of determination, standardized path coefficients or beta values, and the corresponding t-statistics and p-values generated through a bootstrapping procedure (Hair *et al.*, 2017). Additionally, researchers must report the effect sizes of the predictors to make robust empirical decisions regarding the strength of the relationships (Ringle *et al.*, 2015). For a hypothesis to be supported, the standardized path coefficient must account for a meaningful impact within the structural model, achieving a statistical significance level of at least 0.05, which corresponds to a critical t-statistic greater than 1.96.

To test the study hypotheses, the structural model must be successfully assessed. Methodological literature recommends evaluating the R^2, path coefficients (β), and corresponding t-values obtained via a bootstrapping procedure (Hair et al., 2017). It is also recommended that, in addition to these necessary measures, researchers should report the effect sizes (f^2) in order to make robust empirical decisions (Ringle *et al.*, 2015). The structural model path algorithm of this study is mapped out to capture the interactive influence of the moderator.

In consideration of these methodological recommendations, the results obtained from the structural model were used to address the study's hypotheses. To accept or reject the hypotheses, the β, corresponding t-values, p-values, and f^2 were systematically evaluated. For a hypothesis to be supported, the β value needs to account for a meaningful impact within the structural model at a significance level of at least 0.05, and the corresponding t-value must be greater than 1.96.

Hypotheses Testing (Direct Relationship)

In line with established statistical recommendations, the structural model results are used to obtain and interpret the β, corresponding t-values, p-values, and the f^2. The sustainable procurement practices focus fundamentally on integrating environmental, social, and economic criteria into the upstream supplier selection and purchasing processes of the value chain. In contrast, firm performance is evaluated based on the economic, environmental, and operational outcomes realized by the organizations within the sector. The structural model assessment in partial least squares structural equation modeling reveals the evaluation of these hypothesized relationships.

Particular emphasis is placed on the bootstrap procedure because it produces the relevant variance statistics for estimating the statistical significance of the path coefficients (Hair *et al.*, 2017). The bootstrapping procedure involves a re-sampling process generated from the original sample with replacement; in this study, a total of 5000 re-sampling iterations was used in executing the bootstrapping process to ensure the stability and accuracy of the parameter estimates (Mainali *et al.*, 2014; Ramayah *et al.*, 2017).

Hypothesis 1: There is a significant relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector

As presented in Table l, sustainable procurement practices overall have a significant relationship with firm performance in Nigeria's petroleum downstream sector ($\beta = 0.914$, $t = 5.072$; $p < 0.05$; $R^2 = 0.835$). Therefore, the results revealed that the hypothesis was supported because the relationship is statistically significant. Thus, there is a significant relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector.

Hypotheses Testing (Moderating Effect)

To test the hypothesis and assess the moderating role of industry 4.0 applications on the relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector, a moderation analysis was conducted. The moderating analysis was executed using the statistical software by applying the bootstrapping procedure with 5000 sub-samples. The results are presented in the following order.

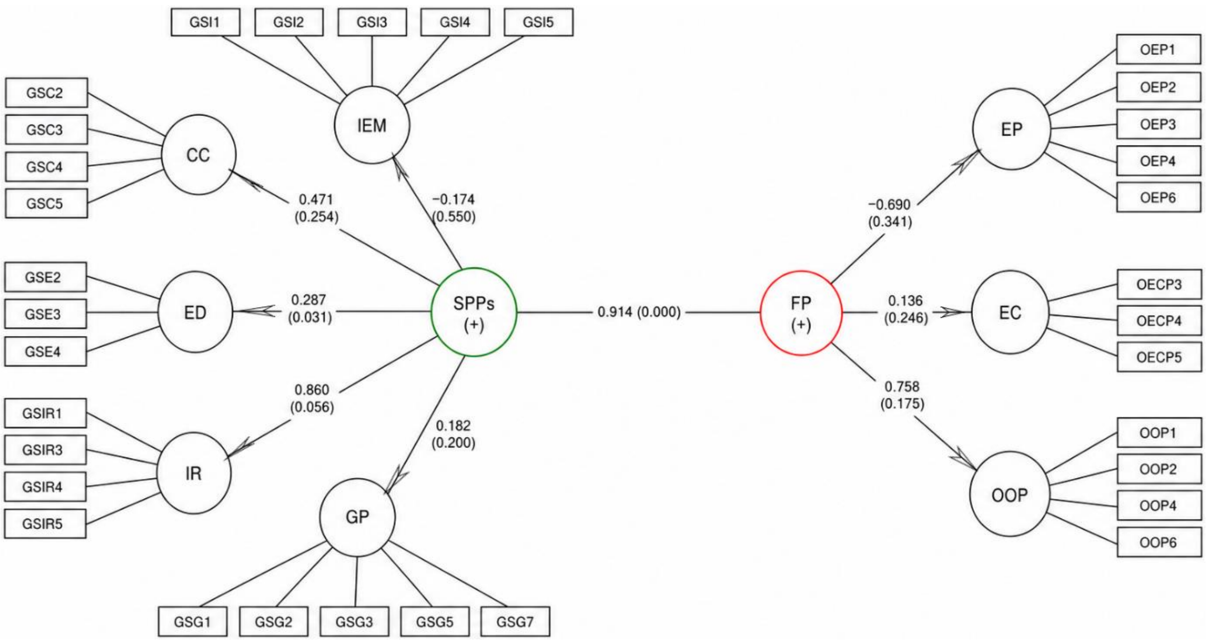

Figure 1. Measurement Model

Table 1. Structural Estimates (Direct Effect)

No.	Path	*β*	*t*	*p*	*R²*	Decision
H1	Sustainable Procurement Practices → Firm Performance	0.914	5.072	0.000	0.835	Supported

Notes: Critical t-values. *1.96 ($p < 0.05$).

Table 2. Moderation Effect of Industry 4.0 Applications

Path	β	t	p
Industry 4.0 Applications → Firm Performance	-0.019	0.488	0.625
Sustainable Procurement Practices → Firm Performance	0.934	29.028	0.000
Moderating Effect1 → Firm Performance	-0.022	1.432	0.153

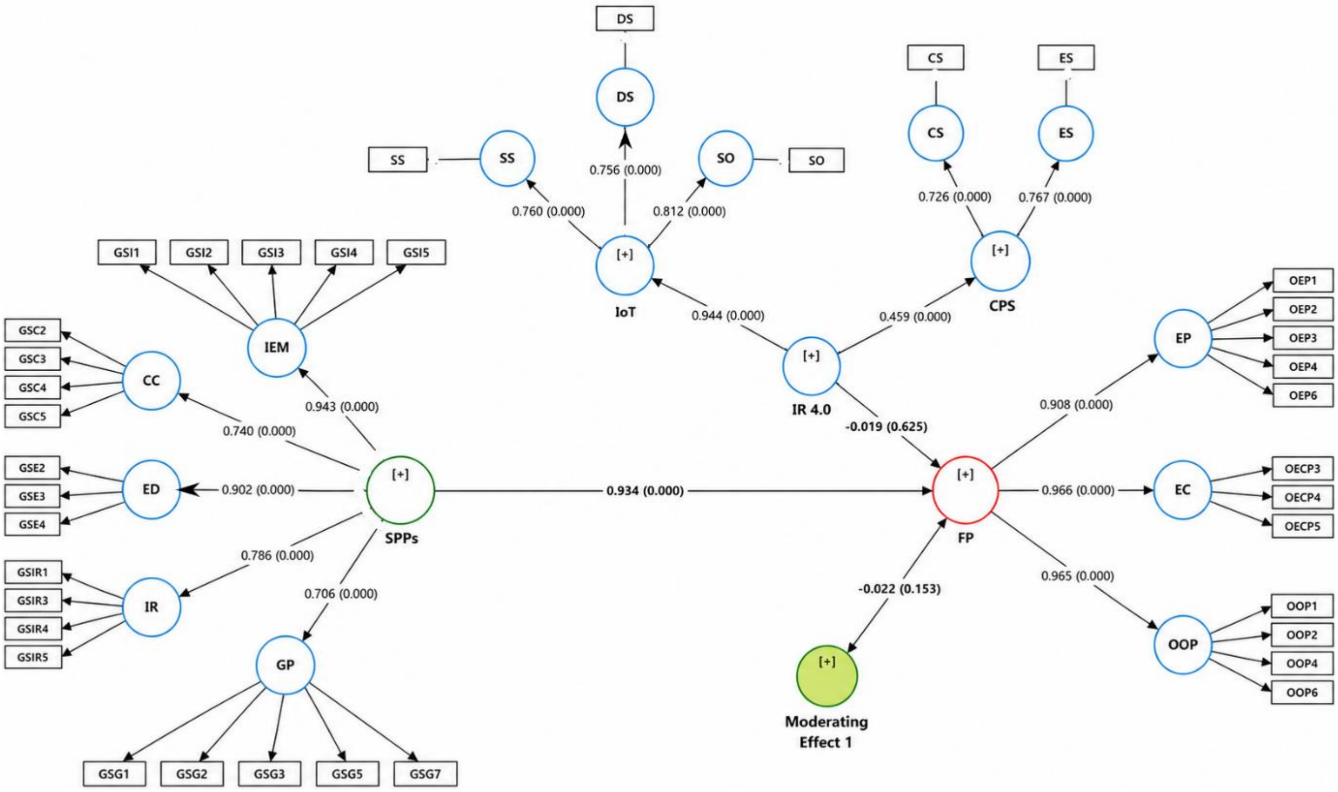

Figure 2. Structural Model

Hypothesis 2: Industry 4.0 applications moderate the relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector

The results obtained from the structural model were evaluated in line with standard statistical protocols (Hair *et al.*, 2017). The standardized β, t-values, and p-values are reported to decide on the hypothesis. The β value needs to account for a meaningful impact within the model at least at the significance level of 0.05, and the t-value should be greater than 1.96 (Hair et al., 2017).

As presented in Table 2 (and illustrated in Figure 2), industry 4.0 applications have no significant moderating effect on the relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector (β = -0.022, t = 1.432; $p > 0.05$). This statistical outcome indicates that variations in the level of industry 4.0 applications do not significantly change or strengthen the baseline relationship between sustainable procurement practices and firm performance. Thus, this empirical finding does not support the hypothesis, which states that industry 4.0 applications significantly moderate the relationship between sustainable procurement practices and firm performance.

Conclusions and Recommendations

The findings of this study revealed that Industry 4.0 applications do not significantly moderate the relationship between sustainable procurement practices and firm performance in Nigeria's petroleum downstream sector ($\beta = -0.022$, $p = .153$). Although sustainable procurement practices demonstrated a strong positive influence on firm performance, the addition of Industry 4.0 technologies did not strengthen this relationship. This suggests that the mere presence of digital technologies is insufficient to enhance the performance outcomes of sustainable procurement practices within the sector.

A plausible explanation for this finding lies in the contextual realities of Nigeria's petroleum downstream industry. Industry 4.0 technologies such as the Internet of Things (IoT), cyber-physical systems (CPS), advanced analytics, and integrated digital platforms require reliable digital infrastructure, stable electricity supply, high-quality telecommunications networks, and substantial organizational investment. However, many firms within the Nigerian business environment continue to face infrastructural deficiencies, frequent power disruptions, inadequate broadband connectivity, and high technology acquisition and maintenance costs. These constraints may limit the effective deployment and integration of Industry 4.0 technologies across procurement and supply-chain activities, thereby reducing their ability to generate measurable performance gains.

Furthermore, the implementation of Industry 4.0 often requires significant organizational capabilities, including digital skills, data governance frameworks, cybersecurity systems, and workforce readiness. In contexts where these complementary resources are underdeveloped, digital technologies may operate as isolated tools rather than as integrated strategic enablers. Consequently, firms may adopt elements of Industry 4.0 for operational purposes without achieving the level of digital maturity necessary to amplify the benefits of sustainable procurement practices. The non-significant moderating effect observed in this study therefore suggests that technological adoption alone does not guarantee enhanced procurement-performance outcomes; rather, the value of Industry 4.0 depends on the broader institutional and organizational ecosystem in which it is implemented.

These findings have important implications for policymakers and industry stakeholders. Efforts to leverage Industry 4.0 for sustainable procurement should extend beyond technology acquisition to address the underlying infrastructural and capability constraints that hinder effective utilization. Investments in digital infrastructure, stable energy supply, broadband accessibility, workforce digital competencies, and sector-wide interoperability standards are essential for realizing the transformational potential of Industry 4.0 in the petroleum downstream sector.

Accordingly, policymakers, regulators, and industry leaders should prioritize the development of enabling digital ecosystems that support the integration of sustainable procurement practices with advanced technologies. Organizations should also invest in employee training, cybersecurity capabilities, supplier digital integration, and data-driven procurement systems. By addressing these structural barriers, firms will be better positioned to translate Industry 4.0 investments into meaningful performance improvements and achieve long-term sustainable development objectives.

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