

# DECARBONIZING MARITIME LOGISTICS IN NIGERIA’S OIL AND GAS SECTOR: BUSINESS MANAGEMENT STRATEGIES AND TECHNICAL POLICY IMPLICATIONS FOR SUSTAINABLE GROWTH

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# Abstract

Maritime logistics are important to maintaining functional links for Nigeria’s oil and gas operations and contribute significantly to the economic growth. However, it faces many challenges related to rising carbon pollutants, inefficient operations, and deteriorating infrastructure quality. Therefore, the study evaluated the impact of business management strategies and technical policy implications on Nigeria's sustainable growth and decarbonisation of maritime logistics. The study was conducted using questionnaire developed on five point and PLS-SEM was used to conduct the analysis. The findings revealed that the sustainable initiatives, technology and operational efficiency have positive and significant impact on sustainable growth. Adoption of green technology and meeting regulatory compliance do not make a difference to sustainability.

**Keywords:** Maritime Logistics, Decarbonising, Business Management Strategies, Sustainable Growth, Technical Policy Implications

# Introduction

Maritime logistics are crucial in maintaining functional links for Nigeria’s oil and gas operations, transporting crude oil, refined petroleum products, and vital supplies. Nigeria sustains its position as the top petroleum producer in Africa by using maritime transport to export oil products, which fuels economic expansion (Coleman 2023). However, the maritime sector deals with multiple critical issues, including rising carbon pollutants, inefficient operations, and deteriorating infrastructure quality. Greenhouse gas (GHG) emissions have also been one of the critical challenges in maritime logistics, as maritime transport contributes about 3% to overall GHG emissions. Experts expect this figure to increase if no efficient preventive measures are implemented (Osuji and Agbakwuru 2024). The International Maritime Organization (IMO) established two environmental regulations through the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) to make maritime transportation more ecologically sustainable (GAVA et al. 2024). The global standards demand strict adherence from Nigeria because it needs to sustain its position in international oil and gas markets.

Nigeria encounters multiple difficulties in its sustainability path because it struggles with inadequate regulatory enforcement, insufficient green technologies integration, and limited financial capabilities for sustainability initiatives (Akujor et al. 2022). Developing a sustainable maritime ecosystem requires business management strategies to integrate with technical policy implementations to improve operational efficiency. (Ezinna, Nwanmuoh, and Ozumba 2021)

indicated that business management strategies and technical policy interventions affect sustainability performance within Nigeria's maritime logistics sector operating in the oil and gas industry. According to (Mallouppas and Yfantis 2021), the five major strategies for decarbonization implementation include adopting green technology and making sustainability investments while improving operational effectiveness, maintaining regulatory compliance, and developing technological innovation. This combination of factors supports carbon emission reduction, enabling better maritime energy efficiency and sustainability-focused operations.

The previous studies lack in exploring the integration of business management strategies with technical policies for sustainable maritime logistics in Nigeria’s oil and gas sector. Specifically, there is limited understanding on how these strategies can address regulatory enforcement challenges, green technology adoption and financial constraints to attain significant decarbonisation. Therefore, this research evaluates the impact of business management strategies and technical policy implications on Nigeria's sustainable growth and decarbonisation of maritime logistics.

# Literature review

**Decarbonization in Maritime Logistics: A Global Perspective**

Maritime logistical decarbonization stands as a crucial target which gained momentum because of escalating environmental problems together with regulatory mandates. The International Maritime Organization (IMO) serves as the main authority for reporting shipping industry GHG emissions which total 3% worldwide (Okpara and Oparanmma 2023). They have projected an upcoming rise unless effective mitigation approaches are established. As part of its environmental regulations the International Maritime Organization (IMO) created three key frameworks which establish EEXI and CII limits while developing the 2050 decarbonization plan to improve maritime sector efficiency (Vidović et al. 2023). The sustainability regulations operate as worldwide standards to drive the shipping industry toward adopting environmental technologies while boosting operational performance. Research has thoroughly studied how these regulatory policies affect maritime sustainability. (Wu et al. 2022) establishes that developed economies manage to incorporate green shipping technology yet African countries together with other developing nations battle with access to funding and infrastructure resources for regulatory compliance. The process of digitalization using smart shipping technologies and automated port systems and AI-driven logistics serves as an essential element for carbon emission reductions according to (Czermański et al. 2020). Developing economies face challenges in sustainable maritime logistics transition because of high technology expenses and lacking expertise in technical areas.

# Maritime Logistics and Sustainability Challenges in Nigeria

The maritime logistics sector plays an essential role in Nigeria’s oil and gas operations through its management of crude oil and refined petroleum substance transportation along with various critical commodities. The maritime sector maintains high carbon intensity because old vessels and inefficient port operations together with weak regulations emit large amounts of pollutants (Ikpogu 2021). Although Nigeria formally signed multiple international environmental agreements such as the MARPOL Convention and the Paris Agreement it continues facing hurdles when trying to establish and execute effective maritime decarbonization strategies (Amuka and Ezinna 2021). The existence of weak environmental governance together with

corruption and insufficient monetary motivation stands as main obstacles that prevent low- carbon logistics transition in the maritime sector. (Lloyd et al. 2019) conducted research about green technology implementation barriers in Nigeria's maritime sector by identifying high capital requirements as the main impediment together with restricted international funding and insufficient government support.

The sector requires public-private partnerships for funding sustainable shipping programs to boost its market competitiveness according to his assessment. (Grzelakowski, Herdzik, and Skiba 2022) illustrates that Nigeria’s substandard maritime infrastructure creates obstacles for industry players seeking to adopt alternative fuel solutions including LNG, hydrogen and biofuels. The examination of port operations and carbon footprint minimization through Nigerian research shows that performance-related inefficiencies such as port backlog along with dated material handling tools and weak supply chain planning elevate emissions levels (Halim et al. 2018). Modern port infrastructure together with digital tracking systems along with emissions monitoring technologies are needed to resolve these operational problems. A clear regulatory structure supported by enforcement tools is needed for the maritime logistics sector to experience sustainable change because lack of these factors would lead to slow progress (Mohajan 2020).

# The Role of Green Technologies in Maritime Decarbonization

The maritime sector requires green technologies to accomplish its decarbonization goals according to widespread recognition. (Grzelakowski, Herdzik, and Skiba 2022; Lloyd et al. 2019) demonstrate that energy-efficient designs along with different propulsion systems supported by shore power solutions create substantial reductions in global emissions. Three effective methods for decreasing maritime emissions include hybrid ships with electric power systems and wind-powered propulsion and carbon removal solutions. The use of these solutions remains restricted in Nigeria because existing infrastructure falls short and companies lack financial incentives and the technologies cost too much money (Vidović et al. 2023).

The research conducted by (Halim et al. 2018) shows how onshore power supply (OPS) systems allow ships to disconnect from fuel-based generators by using cleaner power resources at their docking positions. OPS systems successfully operate throughout Europe together with specific Asian territories, yet they have minimal use throughout Western Africa because of unreliable power grids along with elevated investment costs. Dynamic shipping operations benefit from blockchain and IoT-based logistics systems as (Mohajan 2020) detail their role in optimal shipping route planning and supply chain transparency enhancement and fuel consumption reduction. The good potential of these innovations needs extensive digital infrastructure investments which Nigeria currently struggles to implement.

# Hypothesis Development

Green Technologies require immediate integration in maritime logistics to lower carbon emissions through applications of hybrid ships together with renewable energy sources and shore power technology. (Felix 2024) state that alternative propulsion systems along with energy-efficient designs show remarkable potential for emission reduction. Nigeria faces two major obstacles to large-scale deployment of these technologies due to high costs and insufficient infrastructure according to (Bunza 2023). The development of green technologies remains fundamental to establishing environmental sustainability inside the maritime sector despite present obstacles. Sustainable practices based in operational efficiency enable shipping

routes to be optimized while reducing fuel usage in maritime operations. Using artificial intelligence in logistics and smart shipping technology helps. (GAVA et al. 2024) demonstrate ways to reduce energy utilization and release of emissions. The Nigerian maritime sector experiences elevated emissions which stem from outdated port facilities and operational inefficiencies as identified by (Al Issa and Abdelsalam 2021) making operational sustainability achieve greater importance.

Meeting sustainability requirements demands companies’ compliance with international regulations specifically including the EEXI and CII standards set by the IMO. (Felix 2024) points out that Nigerian authorities face challenges in enforcing regulations because the country lacks strong governance institutions and required infrastructure. The maritime industry keeps to global standards through strong regulatory compliance which results in less environmental impact and promotes sustainable business operations. Technological innovation including Blockchain technology and Internet of Things (IoT)-based logistics management and emissions detection tools possess substantial potential to build sustainability through supply chain enhancement and minimalized fuel usage (Duong). The poor digital infrastructure status of Nigeria acts as a barrier to implement innovative solutions that would advance maritime sustainability. Sustainable investments require funds from sustainable programs such as green finance and sustainability-linked bonds to finance green technologies. The insufficient development of green finance frameworks in Nigeria causes financial obstacles to obtain required funding (Alalabiaye 2023)

H1: The adoption of green technologies has a positive impact on maritime sustainability. H2: Operational efficiency practices positively influence maritime sustainability.

H3: Regulatory compliance significantly enhances maritime sustainability. H4: Technological innovation positively impacts maritime sustainability.

H5: Investment in sustainability initiatives positively influences maritime sustainability.

# Conceptual Framework

A structured framework presented in this paper deals with the relationship between business management strategies, technical policy factors, and the sustainability performance of maritime logistics in Nigeria’s oil and gas sector. The independent variables (IVs) part stand for the adoption of green technologies, operational efficiency practices, regulatory compliance, technological innovation, and investment in sustainability initiatives. They will however cause these variables to sustainability outcome that is measured by carbon emissions reduction and energy efficiency. The strategic and policy interventions that can bring sustainable maritime logistics operations to the stage are explored in the framework.

Adoption of

Green technologies

Operational Efficiency Practice

Regulatory Compliance

Maritime Sustainability

Technological

Innovation

Investment in

Sustainable Initiatives

# Materials and Methods

The research uses quantitative methodology to understand how business strategies combine with technical policy elements to impact sustainability results in the maritime logistics sector of Nigeria. The data was collected using the structured questionnaires which served as the primary research tool. The research instrument depended on existing material about maritime sustainability together with information about green technology adoption and regulatory compliance and sustainability investments. The survey was based on a Likert-type scale that featured closed-ended questions which operated on a 5-point scale from 1 (Strongly Disagree) to 5(Strongly Agree) for participants to rate sustainability practices. The questionnaire consists of items that assess sustainability initiative results as well as the uptake of green technology adoption.

This research focused on important maritime logistics stakeholders from Nigeria who consist of shipping firms, port administration bodies, environmental assessment professionals and policy-makers together with regulatory bodies. The chosen participants included decision- makers together with environmental officers and logistics managers who held active roles during maritime operations. The selected experts demonstrate strong expertise in maritime business operations and sustainability regulation, which makes them qualified to participate in this research. The survey reached out to 500 potential participants from which 400 responses were completed.

Recruitment for participants involved reaching out to industry networks as well as holding conferences and sending emails to potential participants. The study tried to achieve diversity by reaching out to public and private sector stakeholders. All research participants received a document that described the study's purposes together with its resulting benefits and moral framework. People took part in this study voluntarily, while the researchers guaranteed all participants free participation with assured confidentiality and anonymity.

The study has used Partial Least Squares-Structural Equation Modelling (PLS SEM) to conduct the analysis using SmartPLS4. The PLS-SEM consist of two major steps. The first step is to

conduct confirmatory factor analysis (CFA). In this step, the instrument is tested for the validity and reliability using factor loadings, Cronbach alpha, composite reliability, average variance extracted (AVE) and discriminant validity. Furthermore, the second step includes the path analysis which involve analysing the hypothesis of the study and establishing the relationship between the variables.

# Results

The Analysis were performed using the PLS-SEM procedure through SmartPLS 4. The research utilised PLS-SEM because of its position as a robust predictive multivariate methodology under SEM that efficiently handles complex constructs together with small sample sizes and multicollinearity or missing variables. The method has unique value for research on elusive latent variables. PLS-SEM proves important for maritime logistics research because it analyses associations between business strategies and technical policy factors and decarbonisation outcomes better than OLS and CB-SEM while handling latent variables and requiring less data and normality constraints.

# Confirmatory Factor Analysis

**Table 1 RELIABILITY AND AVE INDICATORS**

The results from the reliability and validity assessment report both high consistency values together with strong construct validity throughout all measured variables. The reliability results show that Cronbach’s Alpha values surpass 0.7 indicating strong internal consistency among variables and Technology Investment (0.899) shows the highest reliability followed by Maritime Sustainability (0.900). Internal reliability for each construct reaches a reliable threshold as indicated by Composite Reliability values which exceed 0.9. The construct validity assessment through Average Variance Extracted (AVE) scores exceeds 0.5 which demonstrates strong convergent validity primarily because Technology Investment (0.832) and Investment in Sustainable Initiatives (0.823) have the highest AVE scores. The constructs prove suitable for measuring factors involved in maritime logistics decarbonization because they demonstrate reliability and validity according to these results. The confirmed measurement model enables researchers to trust in both the precision and repetitive quality of the data for structural modelling steps.

# Figure 1 Outer loadings Table 2 Outer Loadings

All indicators demonstrate reliable measurement quality because their outer loadings surpass the suggested threshold value of 0.60. The observed indicators demonstrate robust measurement properties because they exhibit a strong relationship with their corresponding latent constructs. The model displays internal coherence because all indicators remain intact without any exceptions. High outer loadings demonstrate that each indicator provides important information to define its construct which leads to enhanced explanatory power of the model. The constructive relation between variables validates the proposed theoretical design while demonstrating the appropriate character of the measurement model for empirical purposes. The indicators demonstrate both validity and reliability which strengthens the model's robustness so it can provide effective sustainability performance assessment for maritime sector applications.

# Table 3 DISCRIMINANT VALIDITY

The Heterotrait-Monotrait (HTMT) ratio served as the discriminant validity assessment to verify construct distinctiveness since it represents a stronger evaluation criterion. All HTMT values show numbers less than 0.85 which demonstrates that each construct keeps separate conceptual boundaries. Measures are checked to maintain acceptable levels of cross-loadings because such analysis prevents construct redundancy. The investigation of discriminant validity leads to a stronger theoretical model by ensuring every latent variable track distinct aspect of the phenomenon. Maintained construct separateness in the model leads to better predictive accuracy and reliability which supports its validity during subsequent structural path analysis. **Path Analysis**

# Figure 2: Path AnalysisTable 4 Path Coefficients

|  |  |  |
| --- | --- | --- |
| Path Coefficient | T  statistics | P  values |
| Adoption of Green Technologies -> Maritime Sustainability -0.019 | 0.450 | 0.653 |
| Investment in Sustainable Initiatives -> Maritime  Sustainability 0.750 | 22.353 | 0.000 |
| Operational Efficiency Practice -> Maritime Sustainability 0.079 | 2.214 | 0.027 |
| Regulatory Compliance -> Maritime Sustainability 0.023 | 0.462 | 0.644 |
| Technology Investment -> Maritime Sustainability 0.109 | 2.325 | 0.020 |
| The path coefficient analysis defines essential operative relations | between | maritime |

sustainability factors. Research findings demonstrate that Sustainable Initiative investments (β

= 0.750, p < 0.001) create the strongest significant relationship which supports H2 about the essential role of these investments in decarbonization. As confirmed by H5 (β = 0.109, p = 0.020) technology investment demonstrates a substantial positive relationship between these variables. The relationship between Operational Efficiency Practices (β = 0.079, p = 0.027) is moderate yet significant according to the study results which leads to H3 acceptance showing the value of efficient logistics operations. The adoption of green technologies shows no statistical correlation (β = -0.019, p = 0.653) toward sustainability performance and thus H1 is rejected. The regression analysis establishes that Regulatory Compliance (β = 0.023, p = 0.644) is not statistically significant thus rejecting H4 which demonstrates that regulatory compliance alone cannot lead to sustainability goals.

Discussion

The research investigated maritime sustainability elements in Nigeria's oil and gas sector by studying business management approaches together with technical policy requirements for decarbonization. PLS-SEM revealed detailed understandings about essential variables relationships between Investment in Sustainable Initiatives and Technology Investment and Operational Efficiency Practices and Adoption of Green Technologies and Regulatory Compliance. The study reveals meaningful as well as insignificant pathways which deliver useful insights for attaining sustainable maritime logistics practices in the industry. Maritime sustainability demonstrates the strongest connection with the variable Investment in Sustainable Initiatives at β = 0.750 (p < 0.001). Financial and strategic commitments prove essential for advancing decarbonisation programs because of their vital role. The strategic investment in renewable energy solutions and vessel modernisation programs together with carbon-neutral logistics systems produces dual benefits for carbon reduction and environmental performance enhancement (Akujor et al. 2022). The findings aligns with international research demonstrating that sustainability investments act as vital elements for creating logistics systems with low carbon emissions (Ezinna, Nwanmuoh, and Ozumba 2021). The maritime infrastructure in Nigeria stands below international standards so these investments create a powerful double impact on environmental progress and operational enhancement (Mallouppas and Yfantis 2021). To increase these investments policymakers along with industry stakeholders, need to establish financial incentives partnerships and grant programs.

The study results indicate Technology Investment has a direct influence on maritime sustainability (β = 0.109, p = 0.020) which supports H5. The study shows how advanced technology systems positively impact operations management by reducing environmental impact. The combination of predictive analytics with real-time emission monitoring technologies alongside digital route optimization tools creates efficient sustainable maritime operations (Okpara and Oparanmma 2023). The lower path coefficient value for Investment in Sustainable Initiatives indicates that technological investments need additional financial platforms and strategic methods for maximum success. The technological benefits remain restricted in Nigeria due to limiting factors which include high implementation costs and inadequate expert personnel together with insufficient infrastructure (Vidović et al. 2023). The sustainability benefits of technology become achievable when barriers are removed through capacity-building programs and public-private partnerships and government subsidies (Wu et al. 2022). The outcome demonstrates why logistics operations require optimization specifically regarding route planning and port efficiency as well as cargo handling since these methods reduce carbon emissions. Operational efficiency practices achieve environmental gains and cost savings through their ability to cut both fuel use and ship travel times.

This study demonstrates modest change because operational enhancements without technological backing and investment might be insufficient to create transformative change. The operational gains from improvements are hindered by ongoing port congestion and outdated equipment and inefficient logistics operations in Nigeria (Czermański et al. 2020). The achievement of major sustainability results depends on uniting operational procedures with modern infrastructure improvements as well as technological advancements. The investigation did not reveal the expected direct association of adoption of green technologies with shipping sustainability (β = -0.019, p = 0.653), which indicated that H1 should be rejected. This was concluded on the basis that the green technologies may possibly have no effect aligning with

the research that as in this case the level of their presently poor adoption or its inefficiency in Nigeria`s is too low to make enough provision for environmental stability (Ikpogu 2021).

The high cost of the adoption of green technology, limited availability of advanced technologies, and a lack of technical expertise can explains the outcome of this study. The existing technologies may be inadequate or harmful in the specific operation and environmental issues of the maritime sector in Nigeria (Amuka and Ezinna 2021). It clearly demonstrates the necessity of a more effective ecosystem, which comprises such instruments as money, knowledge, and technology transfer through the collaboration of the Nigerian government and international technology providers. Research findings show that the Adoption of Green Technologies failed to affect maritime sustainability levels (β = -0.019, p = 0.653) thus H1 was rejected. Current adoption levels of green technologies and their effectiveness in Nigeria do not produce meaningful sustainability improvements (Lloyd et al. 2019). Various reasons explain the result include the high expenses of implementing green technology and the restricted availability of modern technology and insufficient technical capabilities. The maritime sector of Nigeria faces operational and environmental conditions which currently require specific technologies different from what already exists (Grzelakowski, Herdzik, and Skiba 2022). This outcome proves the necessity of developing an enhanced supportive framework which combines funding programs with technology sharing platforms and international supplier networks to promote green technology adoption.

The analysis indicates no substantial relationship exists between Regulatory Compliance measures and maritime sustainability performance (β = 0.023, p = 0.644) thus leading to the rejection of H4. Environmental regulations by themselves do not create substantial sustainability improvement. The Nigerian regulatory frameworks face potential limitations because of weak enforcement together with corruption and insufficient monitoring systems. fundamental change in regulatory policies appears necessary based on this research finding (Halim et al. 2018). Monitoring systems need expansion to ensure transparency in regulatory processes because this improvement helps regulations deliver maximum impact. Results demonstrate that maritime sustainability depends heavily on specific influencing factors which form a clear organizational structure. Organizations invested principally in Sustainable Initiatives before focusing on Technology Investment and Operational Efficiency Practices among other aspects. The impacts of both Adoption of Green Technologies and Regulatory Compliance appeared minimal or insignificant. Financial and technological investments play the most crucial role in maritime sustainability because operational and regulatory enhancements maintain a supporting function (Mohajan 2020). The examined variables demonstrate possible collaborative effects on each other. Implementing technology integration with operational methods creates the best opportunity for maximizing sustainable gains. Technical solutions joined with regulatory structures through emission monitoring systems result in improved compliance regulations and enhanced transparency. The research offers substantive knowledge about sustainability elements which impact Nigeria's oil and gas maritime sector.

The research outcomes support the fundamental importance of capital investments coupled with technological innovation which receives additional backing from proper operational and regulatory practices. The successful decarbonization process requires removal of organizational barriers and active engagement from all stakeholders. The study provides new

information about sustainable maritime logistics which generates recommendations for policymakers and industry leaders.

# Limitation Of Research

The research analysis has several key restrictions which need to be considered. The PLS-SEM analysis conducted with a limited sample size reduces the ability to infer the study findings to the wider maritime logistics sector in Nigeria (Felix 2024). Further research needs to expand the sample size and diversity to strengthen both the reliability and external validity levels of obtained results. The cross-sectional approach used for data collection investigates point-in- time relationships between variables that may not demonstrate sustainability strategy development across timescales. A research design using longitudinal methods would yield better comprehension about the developmental patterns of maritime sustainability factors across time (Bunza 2023). The narrow concentration on Nigeria’s oil and gas sector creates barriers for generalizing study findings across different sectors operating under different operational circumstances. This study focused on direct variable relationships yet failed to investigate possible moderating or mediating effects between those variables. Research must explore multiple complex relationships to construct complete knowledge about the studied phenomena.

# Conclusion

Nigeria must decarbonize its maritime logistics sector because this action will assist with sustainability objectives in its oil and gas industry. The research explores how business management strategies with technical policy interventions affect maritime sustainability through identification of critical factors that influence decarbonization. Investments made for sustainability initiatives along with technological advances and operational efficiency practices show strong potential to lower carbon emissions while enhancing energy efficiency according to research findings. The study shows regulatory compliance with green technologies provides inadequate sustainability results since weak enforcement exists and adopting these technologies is too costly.

The study emphasizes the requirement for increased financial backing combined with strategic policy measures to sustain maritime logistics in Nigeria. Stakeholders combining efforts through the government alongside private sector players and international entities need to develop funding programs and policy-based incentives and regulatory frameworks which will enable shipping operations to transition toward low-carbon operations. To move sustainability goals toward practical implementation investors should focus on digitalization together with predictive analytics and smart port technologies to improve operational efficiency as well as environmental performance.

The research provides relevant information, but researchers should understand the study limitations which arise from the cross-sectional data analysis and small participant count and self-reported assessment processes. Potential future research must analyse sustainability developments through extended time periods using real-time emissions tracking systems as well as secondary data sources to prove study results. The analysis of possible moderator and mediating variables would lead to advanced comprehension of maritime industry decarbonization dynamics.

A successful pursuit of maritime sustainability in Nigeria demands a holistic strategy between business investments and technological advancements together with regulatory enhancements.

The country must solve financial problems while fixing policy issues to resolve technological barriers because this will help connect maritime logistics with international sustainability requirements to get long-term environmental advantages. The research directs policy makers and industry stakeholders to create efficient data-based strategies that will develop a sustainable low-carbon maritime industry within Nigeria.

# Managerial and Theoretical Implications

The findings of this study present significant managerial and theoretical implications for maritime logistics in Nigeria’s oil and gas sector. The study demonstrates for executives that maritime decarbonization success requires investments in sustainability programs and operational system enhancements and innovative technology developments. Commercial shipping operators and port control institutions and logistics service providers should make sustainability investments as a foundation for their extended success goals (Okpara and Oparanmma 2023; Vidović et al. 2023). Organizations must tactically use financial assets to support green technology acquisition along with digital logistics and energy-efficient vessel operations because these elements decrease carbon pollution and meet worldwide environmental requirements. Public-private partnerships enable stakeholders to acquire funding and training together with necessary infrastructure for implementing sustainable logistics practices successfully. This study adds to theoretical knowledge about maritime sustainability and green supply chain management and corporate environmental responsibility in developing economies (Amuka and Ezinna 2021). The empirical analysis presented in this study investigates decarbonization factors and obstacles that are specific to Nigeria's maritime logistics sector because past research had mostly targeted advanced market settings. The research develops the application of Partial Least Squares Structural Equation Modelling (PLS- SEM) for maritime sustainability studies by presenting a methodological approach that could help similar emerging markets. The study proves that sustainability achievement goes beyond regulatory compliance because investment funds and technological systems are the primary drivers of decarbonization outcomes. A necessity for theoretical models of maritime sustainability exists to incorporate financial and technological initiatives into established regulatory systems.

# Implications for Future Research

This study presents useful findings even though researchers have marked several directions for additional research. Researchers need to conduct extended studies which observe the lasting influence of sustainability programs upon maritime logistical systems. Cross-sectional research produces one-time pictures of present sustainability initiatives instead of longitudinal approaches which monitor strategy development across time periods (Ikpogu 2021). Future investigation needs to study the influencing mechanisms that connect core variables to each other. The study should evaluate the moderating effects of government incentives along with technological transfer agreements and financial accessibility on the association between sustainability investments and maritime sustainability results. Research expansion should involve examining digitalization as an important intervening factor that establishes links between operational practices and carbon reduction goals (Al Issa and Abdelsalam 2021). The effectiveness of maritime decarbonization practices in Nigeria can be better understood through comparisons with other nations in the petroleum sector. Researchers study advanced sustainability frameworks in Norway along with Singapore and the Netherlands to find

solutions that fit within Nigerian operational requirements. Future research should expand its data sources to include live emissions tracking, maritime operation satellite feeds and port efficiency data together with current studies based on researcher surveys (Duong). The improved data measurement through this approach would result in more precise sustainability assessments of maritime sector trends in Nigeria. Future investigations aiming to advance sustainable maritime logistics knowledge through practical insights should address identified gaps for policymakers and industry leaders and academic experts working to boost environmental responsibility in global maritime shipping.

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# Appendices Tables

**Table 1 RELIABILITY AND AVE INDICATORS**

Cronbach 's alpha

Composite reliability

Average variance extracted (AVE)

Adoption of Green

Technologies 0.853 0.854 0.773

|  |  |  |  |
| --- | --- | --- | --- |
| Investment in Sustainable |  | | |
| Initiatives | 0.892 | 0.893 | 0.823 |
| Maritime Sustainability | 0.900 | 0.901 | 0.771 |
| Operational Efficiency Practice | 0.812 | 0.814 | 0.728 |
| Regulatory Compliance | 0.881 | 0.881 | 0.808 |
| Technology Investment | 0.899 | 0.901 | 0.832 |
| **Table 2 Outer Loadings** |  |  |  |

Investment

Adoption of in Operational

Green Technologies

Sustainable Initiatives

Maritime Sustainability

Efficiency Practice

Regulatory Compliance

Technology Investment

AGT1 0.878

AGT2 0.903

AGT3 0.856

ISI1 0.897

ISI2 0.939

ISI3 0.885

MS1 0.829

MS2 0.895

MS3 0.888

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| MS4  OEP1 | 0.898 | 0.819 |  |  |
| OEP2 |  | 0.897 |  |
| OEP3 |  | 0.841 |  |
| RC1 |  |  | 0.891 |
| RC2 |  |  | 0.921 |
| RC3 |  |  | 0.885 |
| TI1 |  |  |  | 0.903 |
| TI2 |  |  |  | 0.933 |
| TI3 |  |  |  | 0.900 |

# Table 3 DISCRIMINANT VALIDITY

Adoption of Green

Investmen t in

Operation

Maritime al

Technologie s

Sustainable Initiatives

Sustainabilit y

Efficiency Practice

Regulatory Compliance

Technology Investment

Adoption of Green Technologies

Investment in Sustainable

Initiatives 0.280

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Maritime  Sustainability | 0.317 | 0.921 |  |  | |
| Operational |  |  |  |
| Efficiency |  |  |  |
| Practice | 0.631 | 0.353 | 0.408 |
| Regulatory |  |  |  |  |  |
| Compliance | 0.719 | 0.496 | 0.503 | 0.557 |  |
| Technology  Investment | 0.616 | 0.482 | 0.521 | 0.470 | 0.733 |

# Table 4 Path Coefficients

|  |  |  |  |
| --- | --- | --- | --- |
|  | Path Coefficient | T  statistics | P  values |
| Adoption of Green Technologies -> Maritime Sustainability | -0.019 | 0.450 | 0.653 |
| Investment in Sustainable Initiatives -> Maritime  Sustainability | 0.750 | 22.353 | 0.000 |
| Operational Efficiency Practice -> Maritime Sustainability | 0.079 | 2.214 | 0.027 |
| Regulatory Compliance -> Maritime Sustainability | 0.023 | 0.462 | 0.644 |
| Technology Investment -> Maritime Sustainability | 0.109 | 2.325 | 0.020 |

Figures

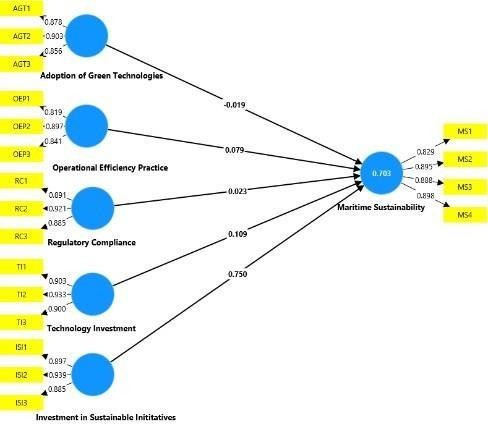


Figure 1 Outer loadings

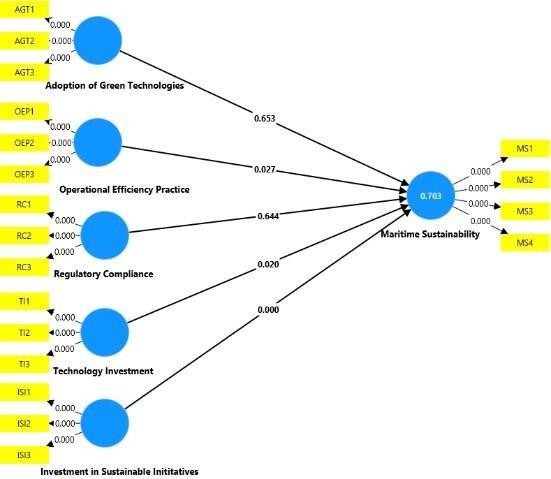


Figure 2: Path analysis