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THE ROLE OF DIGITAL TECHNOLOGIES AND GOVERNMENT POLICIES IN ENHANCING SUSTAINABILITY AND EFFICIENCY IN MARITIME TRANSPORT

Akpudo Chijioke Udechukwu[1], Nwachukwu Tochi Clement[2] and Stephen Mobolaji Stephens[3]

[1,3]Dept. of Logistics and Transport Technology, Federal University of Technology, Akure, Nigeria

[2]Dept. of Logistics and Supply chain management, Nigeria defence academy, Afaka Kaduna State, Nigeria

Email address: cuakpudo@futa.edu.ng, **tochi@nda.edu.ng**, **msstephens@futa.edu.ng**,

Phone Number: 08035780614, 08039256986, 08030862846

*Corresponding Author: cuakpudo@futa.edu.ng Tel.: 08035780614

Abstract

The maritime industry is a vital component of global trade, but it faces significant challenges related to sustainability and operational efficiency. This study examines the role of digital technologies, including blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI), in optimizing fuel consumption, reducing greenhouse gas (GHG) emissions, and improving operational efficiency in maritime transport. Additionally, the study evaluates the influence of government policies and regulatory frameworks in promoting green innovation and fostering sustainable maritime practices in Nigeria. A mixed-methods research design was employed, incorporating surveys, interviews, and secondary data analysis to collect insights from maritime stakeholders, including shipowners, port operators, regulatory agencies, and environmental experts. Findings indicate that 50% of maritime organizations have adopted IoT, 45% AI, and 30% blockchain, leading to measurable improvements in fuel efficiency (10-15% reduction), emissions

control, and supply chain optimization. However, challenges such as high implementation costs (40%), lack of technical expertise (35%), and weak digital infrastructure (30%) hinder widespread adoption. Furthermore, government policies such as the MARPOL regulations, NIMASA's environmental policies, and the Nigerian Port Authority's sustainability initiatives have played a moderate role in driving green innovation. Despite 55% of respondents acknowledging MARPOL's influence, policy enforcement remains weak, with 45% rating government regulations as only "somewhat effective." Financial constraints and limited regulatory incentives further hinder compliance with green maritime policies. The study concludes that while digital technologies have the potential to transform Nigeria's maritime sector, stronger regulatory enforcement, increased financial incentives, and investment in digital infrastructure are required for effective implementation. Key recommendations include tax reliefs, subsidies for green technologies, improved training programs, and partnerships between the government and private sector to enhance sustainability and efficiency in maritime operations.

Keywords: Maritime Sustainability, Digital technologies, Government Policies, Green Shipping, operational Efficiency.

1.0 INTRODUCTION

Maritime transport plays a central role in global trade, facilitating the movement of over 80% of international goods by volume and connecting regions across the globe (UNCTAD, 2022). Despite its economic significance, the industry faces critical challenges, particularly in addressing environmental degradation and inefficiencies in operations. The International Maritime Organization (IMO) has consistently highlighted the urgent need for sustainable practices in maritime transport, as the sector remains a significant contributor to greenhouse gas (GHG) emissions, marine pollution, and resource inefficiencies (Lloyd's Register, 2021). These issues underscore the necessity for transformative strategies that balance operational efficiency with environmental responsibility.

Digital technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence (AI) have emerged as game-changers in addressing these challenges (International Maritime Organization, 2023). Blockchain enhances transparency and reduces inefficiencies across supply chains, IoT enables real-time monitoring of vessel performance and emissions, and AI-driven analytics optimize fuel consumption and predictive maintenance (Lu *et.al.* 2021). These

technologies collectively have the potential to revolutionize maritime transport, enabling the sector to reduce its environmental footprint while improving overall efficiency (International Maritime Organization, 2023).

Government policies and regulatory frameworks play an equally pivotal role in this transformation. By incentivizing the adoption of green innovations, establishing emissions reduction targets, and fostering collaborations among stakeholders, governments can act as catalysts for sustainable maritime operations (European Maritime Safety Agency, 2023). For instance, policy-driven mandates for cleaner fuels and digital integration have already yielded significant progress in regions like Scandinavia.

However, according to Jović *et.al.* (2020) the adoption of digital technologies in the maritime industry faces notable challenges, including cybersecurity threats, high implementation costs, and the need for standardized regulations. These obstacles highlight the importance of a strategic approach that aligns technological advancements with supportive policy measures.

This study explores the integration of digital technologies and the role of government policies in achieving sustainability and operational efficiency in maritime transport, with a focus on addressing environmental challenges and fostering green innovations. The objectives of the study are to: evaluate the potential of digital technologies, including blockchain, IoT, and AI, in optimizing fuel consumption, reducing greenhouse gas emissions, and improving operational efficiency in maritime transport; and analyze the influence of government policies and regulatory frameworks in promoting green innovations and fostering sustainable practices within the maritime industry. By evaluating their individual and synergistic contributions, through a comprehensive analysis, it will provide valuable insights for policymakers, industry leaders, and researchers seeking to promote environmental responsibility and economic resilience in the maritime sector.

2.0 LITERATURE REVIEW

The integration of digital technologies in maritime transport has been extensively studied, highlighting their potential to enhance efficiency and sustainability. These empirical studies explore various aspects of digital connectivity, government policies, and industry innovations in

the maritime sector. For instance, Lu, *et.al.* (2021) investigates how the adoption of digital technologies impacts shipping firms' efficiency. The findings suggest that digital adoption leads to significant improvements in operational efficiency, emphasizing the importance of embracing digital tools in the maritime industry. Pavlinović *et.al.* (2023) emphasize that digitalization is essential for the sustainable development of the maritime industry. Their research indicates that implementing digital technologies leads to significant cost savings and improved vessel efficiency, transparency, and market access. The study also highlights that the COVID-19 pandemic has accelerated digitalization and innovation within the sector. Enyinda (2024) explores the transformative impact of IoT technologies in maritime transport. The study reveals that IoT-enabled predictive maintenance has reduced vessel downtime from 50 hours per month in 2018 to 20 hours per month in 2023. Additionally, real-time monitoring has increased safety compliance from 60% to 85% over the same period, underscoring the role of IoT in enhancing operational performance and safety standards. Jović *et al.* (2020) investigate the application of blockchain technology in maritime transport, focusing on its potential to improve sustainability. Their findings suggest that blockchain facilitates more efficient information exchange, leading to reduced environmental impact and enhanced transparency in shipping operations. The International Maritime Organization (IMO) has been instrumental in advocating for reduced carbon emissions in shipping. Dominguez (2024), the head of the IMO, urges the industry to adopt measures such as optimizing ship routes and transitioning to cleaner fuels like hydrogen and ammonia to meet emission reduction targets. Norway serves as a case study for effective government intervention, mandating zero emissions for ships in UNESCO World Heritage fjords by 2032. Norwegian companies are pioneering technologies like hydrogen fuel and hybrid electric power to comply with these regulations, demonstrating a collaborative effort between government and industry to achieve sustainability goals. European Maritime Safety Agency, (2023) focuses on the sustainable development of transportation companies, examining how digital transformation drives green innovation. It highlights the challenges transportation companies face in securing diverse sources of capital and attracting social investment, which are crucial for implementing green innovations. International Maritime Organization (2023) analyzes the impact mechanism of digital innovation on carbon emissions in the transportation industry, exploring spatial effects to help government departments set policy goals and exploit emission reduction potential. UNCTAD (2022) systematically analyzes publications on intelligent shipping technology and green port

construction, providing insights into the current state and future directions of sustainable maritime transport. Wang, *et.al.* (2020) evaluates the high-quality development of the shipping industry and digital innovation in China's coastal provinces, offering insights into how digital innovation drives industry development.

The reviewed studies collectively underscore the transformative potential of digital technologies in enhancing the efficiency and sustainability of maritime transport. Key findings show that digital adoption leads to significant improvements in operational efficiency and drive high-quality development within the maritime industry particularly in coastal regions.

While the existing literature provides valuable insights into the role of digital technologies in maritime transport, several gaps remain. There is a need for in-depth studies examining how government policies can effectively incentivize the adoption of digital innovations for sustainability in the Nigeria maritime sector.

3.0 METHODOLOGY

The study employed a mixed-methods research design, integrating qualitative and quantitative approaches to comprehensively analyze the role of digital technologies and government policies in achieving sustainability and operational efficiency in Nigeria maritime transport. The target population of the study includes diverse stakeholders in the maritime sector, such as shipowners and vessel operators, port operators and logistic managers, technology service providers, shipping companies, environmental expert and regulators. To ensure robust and representative data collection, two sampling methods were employed:

i. Stratified Random Sampling (for quantitative surveys)

   This method was used to gather survey data from a broad and diverse pool of stakeholders. The population was divided into six distinct strata based on professional categories: Shipowners and vessel operators, Port authority staff, Shipping and logistics company employees, Technology solution providers, Environmental experts, Regulatory agency officials (e.g., NIMASA, Ministry of Transport). From each stratum, participants were selected randomly to avoid selection bias and ensure

balanced representation across the maritime value chain. A total of 100 structured questionnaires were distributed, with approximately 15 - 20 participants selected from each stratum based on their availability and willingness to participate.

ii. Purposive Sampling (for qualitative interviews and focus group discussion).

To obtain in-depth qualitative insights, purposive sampling was used to identify participants with specialized expertise or decision-making authority relevant to the study objectives. These participants included: Senior port managers, Heads of maritime regulatory agencies, Maritime environmental compliance officers, ICT and technology managers within shipping companies, Academics or consultants with publications in green shipping or maritime digitization. However, selection was based on the following criteria: A minimum of 5 years of professional experience in the maritime industry, Involvement in sustainability or digital transformation projects, Accessibility and willingness to participate in interviews or focus group discussions (FGDs). A total of 15 participants were selected for semi-structured interviews and 2 FGDs were conducted (each with 6–8 participants), ensuring that the perspectives of both public and private sector stakeholders were represented.

Quantitative data were collected using structured questionnaires with both closed and Likert-scale questions, distributed via email and in-person sessions. Qualitative data were gathered through recorded interviews and FGDs, guided by an interview protocol focusing on digital technology adoption, regulatory impact, challenges, and opportunities in green innovation.

Quantitative data were analyzed using SPSS, employing descriptive statistics (means, frequencies, percentages) and regression analysis to test the relationship between government policy variables and green innovation. Qualitative data from interviews and FGDs were transcribed and analyzed using thematic content analysis, identifying recurring themes related to digital transformation, sustainability challenges, and policy effectiveness.

The relationship between government policies and green innovation was evaluated using a simple linear regression model:

$$Green\ Innovation = \beta 0 + \beta 1(\text{Government policies}) + e$$

Where: Green Innovation represents the extent of technology adoption, emission reductions, and port efficiency improvements, Government Policies includes number of implemented policies, financial support, and enforcement mechanisms, $\beta 0$ is the intercept; β_1 is the regression coefficient; e is the error term.

4.0 RESULT AND DISCUSSION

4.1 The Potential of Digital Technologies for Operational Efficiency in Maritime Transport

The results in table 1 indicate that digital technologies play a crucial role in enhancing operational efficiency and promoting sustainability in Nigeria's maritime sector. The findings show that a significant proportion of maritime organizations have adopted digital tools such as IoT (50%), AI (45%), and blockchain (30%), and 40% use big data analytics. These technologies have resulted in measurable improvements, including:

a. Optimized Fuel Consumption: AI-driven predictive analytics and IoT-based monitoring systems have reduced fuel usage by 10–15%. An operations manager in one major port noted during interviews: "Since deploying AI and IoT sensors, we have seen monthly fuel bills drop significantly due to smarter route planning and engine monitoring." Mohamed *et.al* (2024) and Pavlinović *et al.* (2023) similarly highlighted that digital tools reduces fuel consumption and improve vessel efficiency.

b. Reduction in GHG Emissions: Blockchain and AI applications have improved compliance with global emission regulations. One environmental officer interviewed stated, "We now track emissions digitally in real-time, allowing us to stay compliant with MARPOL standards."

c. Operational Efficiency: AI-powered decision-making tools and predictive maintenance systems have reduced vessel downtime and improved supply chain reliability. A shipping company executive remarked: "Maintenance delays used to be a big issue. Now with

predictive analytics, we prevent problems before they disrupt operations." Otuaga *et.al* (2023) suuported the benefit of predictive analytics in reducing downtime.

Despite these benefits, several barriers hinder full-scale adoption: High Implementation Costs: 40% of respondents cited cost as the top barrier. Interviewees frequently mentioned financial limitations. One CEO of a mid-sized shipping firm explained, "The ROI is good, but the upfront investment is just too high for us without government support." Lack of Technical Expertise (35%): Interviewees emphasized the skills gap. A tech consultant noted, "Maritime staff need retraining to manage these systems. There's a shortage of digital skills." Poor Digital Infrastructure (30%): Weak internet connectivity and lack of digital tools in ports were major concerns highlighted in FGDs. Limited Awareness (25%): Many stakeholders were unaware of the full potential of digital tools. As one respondent said, "We hear about these innovations, but nobody shows us how to use them."

Overall, 75% of respondents expressed optimism about the potential of digitalization, provided there is adequate support from government and industry stakeholders. Nicholas (2021) and Emelogu (2023) confirmed the optimism among stakeholders, provided there is adequate support.

Table 1: show the adoption, effectiveness, challenges and potential of the digital technologies for operational efficiency in maritime transport

Question	Response categories	Frequency (n)	Percentage (%)
Adoption of digital technologies	IoT	50	50%
	AI	45	45%
	Blockchain	30	30%
	Big Data Analytics	40	40%
	None	10	10%
Effectiveness of Digital Technologies (Average of rating out of 5	Fuel Optimization	4.2	84% Satisfaction
	Emissions reduction	3.8	76% Satisfaction
	Operational efficiency	4.5	90% Satisfaction
	Regulatory compliance	3.7	74%

			Satisfaction
Challenges to adoption	High implementation costs	40	40%
	Lack of technical expertise	35	35%
	Limited Awareness	25	25%
	Poor digital infrastructure	30	30%
Potential of Digitalization for maritime sustainability	Yes	75	75%
	No	10	10%
	Not sure	15	15%

The result of regression modeling (table 2) for the digital technologies impact on sustainability show that IoT Adoption has the highest coefficient (0.45), indicating its significant positive impact on maritime sustainability and has the strongest positive effect among the technologies investigated. Its p-value (0.000) confirms strong statistical significance. Blockchain Utilization also shows a substantial impact (0.35), with high statistical reliability (p-value 0.000). Blockchain contributes significantly, likely by improving transparency, reducing fraud, and enhancing regulatory compliance across the supply chain. AI Implementation has a smaller but meaningful coefficient (0.25), with statistical significance (p-value 0.001), emphasizing its complementary role in sustainability initiatives. Although smaller than IoT and blockchain, AI plays an important role in optimization and decision-making processes such as route planning, emissions forecasting, and smart scheduling. The constant term suggests baseline sustainability improvements even without these technologies, reflecting other potential contributing factors. Zheng et.al. (2021); and Raza, *et.al.* (2021) had similar findings on digital technology's role in reducing emissions and driving green innovation.

Table 2: Regression modeling table for digital technologies impact on sustainability

Variable	Coefficient	Standard error	T- statistic	P-value
IoT adoption	0.45	0.05	9.00	0.000
Block chain utilization	0.35	0.04	8.75	0.000
Al implementation	0.25	0.06	4.17	0.001
Constant	1.20	0.10	12.00	0.000

Source: Author finding's (2025)

4.2 **The influence of government policies and regulatory frameworks in promoting green innovations and fostering sustainable practices within the maritime industry.**

Survey and interview data revealed that while several policies exist (e.g., MARPOL, NIMASA environmental policies, NPA initiatives), their implementation is only partially effective. From Figure 1, 55% of respondents acknowledged MARPOL's influence, 40% recognized NIMASA policies, 35% cited NPA sustainability initiatives. However, 45% of respondents rated these policies as only "somewhat effective." Qualitative data provided further insight as follows: An environmental compliance officer stated, "We have the policies on paper, but there's minimal enforcement and no penalties for violations." Several interviewees mentioned corruption and bureaucracy as impediments. One regulator admitted, "Sometimes implementation is stalled by administrative bottlenecks and lack of clear directives." Financial constraints were repeatedly cited. A shipping firm owner said, "Grants or tax reliefs for green adoption would change the game. Right now, it's too costly to comply fully."

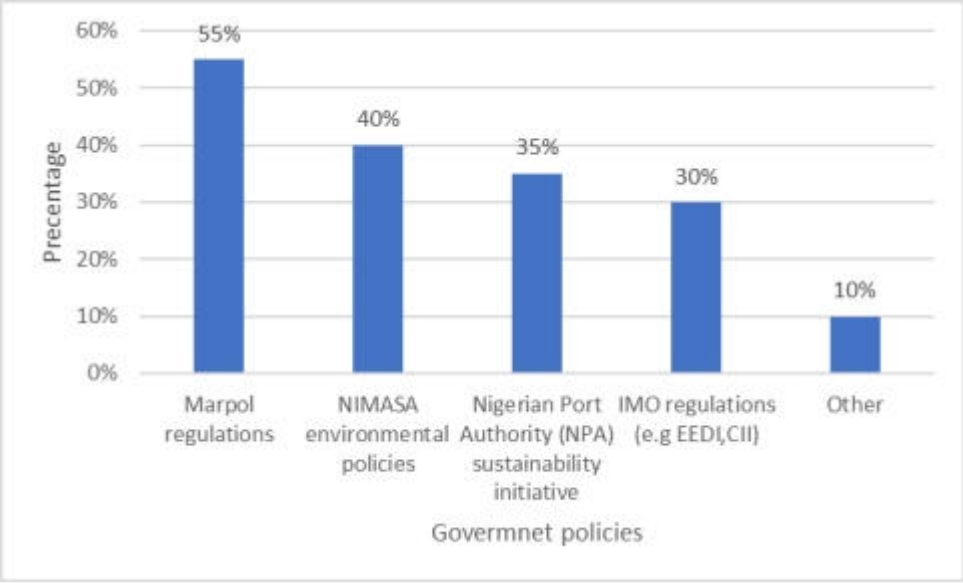


Figure 1: Government Policies on Green Innovation in Nigeria's Maritime Industry

Source: Author finding's (2025)

Table 3 show the result of regression analysis on the influence of government policies and regulatory frameworks in promoting green innovations and fostering sustainable practices within the maritime industry. The interpretation shows that if no government policies were implemented, the green innovation index would start at 33.1. For every additional policy implemented, the green innovation index increases by 5.43 points. The p-value of 1.18e-08 which is less than 0.001 indicates strong statistical significance, confirming that government policies significantly impact green innovation. The analysis reveals a strong positive correlation between government policies and green innovation in the Nigerian maritime industry. The high R-squared value (0.978) suggests that government policies account for nearly all the variation in green innovation adoption. The statistically significant p-values confirm that policy implementation is a key driver of green innovation.

Table 3: Impact of Government Policies on Green Innovation in the Nigerian Maritime Industry

Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**P-Value**
Intercept	33.107	1.706	19.41	1.18e – 08***
Policies Implemented	5.435	0.269	20.20	8.33e – 09***

Source: Author finding's (2025)

5.0 CONCLUSION AND RECOMMENDATION

The findings clearly demonstrate that digital technologies have significant potential to drive sustainable and efficient maritime operations. IoT adoption emerged as the most impactful, followed by blockchain and AI, with measurable improvements observed in fuel optimization (10 - 15% reduction), real-time emissions monitoring, and predictive maintenance. These outcomes affirm the value of digital transformation as a strategic tool for enhancing both environmental and operational performance in maritime transport. However, the study also reveals that the implementation of these technologies is constrained by high upfront costs, limited technical expertise, and underdeveloped digital infrastructure. These barriers highlight the need for systemic

support mechanisms, especially in developing economies like Nigeria, where capacity gaps are more pronounced.

On the second objective, the influence of government policies was found to be statistically significant in driving green innovation, as reflected in the strong correlation between policy implementation and innovation index scores. Nonetheless, qualitative insights from stakeholders pointed to weak enforcement, administrative bottlenecks, and financial constraints as critical limitations to policy effectiveness. While frameworks like MARPOL and NIMASA's environmental guidelines exist, their enforcement and incentives remain inadequate to fully catalyze transformation.

In conclusion, achieving sustainable maritime transport in Nigeria requires an integrated approach one that combines digital innovation with robust and enforceable government policy. The synergy between technological advancement and institutional support is essential for unlocking the full potential of green maritime practices. Strengthening this synergy through targeted financial incentives, regulatory reforms, infrastructure investments, and workforce training will be crucial for translating policy and technology into tangible outcomes.

However, the following recommendations were drive from the result of the study as follows:

a. For the Government and Regulatory Agencies

1. Financial Incentives and Subsidies: Introduce tax reliefs, grants, and subsidies for maritime companies adopting AI, blockchain, and IoT to improve sustainability.
2. Infrastructure Development: Invest in digital ports such as smart port infrsacture, high-speed data networks, and AI-powered monitoring systems to support the transition to smart maritime operations.
3. Stronger Policy Enforcement: Enhance compliance with international environmental regulations (e.g., IMO's GHG reduction strategy) by enforcing mandatory use of digital monitoring systems.

4. Capacity Building and Training: Establish training programs to improve digital skills among maritime professionals, ensuring effective implementation of new technologies.

b. For Maritime Organizations and Private Sector

5. Investment in AI and IoT Solutions: Companies should prioritize AI-driven fuel management systems and IoT-based predictive maintenance to optimize operations and reduce emissions.

6. Partnerships for Technological Advancement: Collaborate with tech firms and research institutions to develop tailor-made digital solutions for Nigeria's maritime industry.

7. Adopt Blockchain for Transparency: Utilize blockchain-based solutions for real-time tracking of fuel consumption and emissions reporting to improve regulatory compliance.

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