CARGO HANDLING EQUIPMENT MAINTENANCE AND GREEN PORT PERFORMANCE: EVIDENCE FROM TANZANIA'S SEAPORTS

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ABSTRACT
Purpose: This study investigates the effect of cargo-handling equipment maintenance on green port performance at Tanzania's three major seaports: Dar es Salaam, Tanga, and Mtwara.
Design/methodology/approach: A quantitative, cross-sectional research design was employed. Structured questionnaires were administered to 101 port personnel from operational, engineering, and environmental departments. Descriptive statistics summarized maintenance practices and outcomes. Reliability was tested using Cronbach's Alpha, and Simple Linear Regression (SLR) was used to examine the predictive relationship between preventive maintenance and green port performance.
Findings: The study's findings show that preventive maintenance is commonly practiced and positively affects both environmental and operational performance. Key benefits include reduced fuel consumption, lower emissions, and improved equipment reliability. However, inconsistencies were noted in adherence to maintenance schedules and electricity savings. Regression analysis indicated that inspections and servicing significantly predict green port performance at one percent significance level (β=0.436, p=0.001), accounting for 19% of the observed variance.
Research limitations/implications: The study is limited to three Tanzania's seaports and relies on self-reported data, which may introduce bias. Cross-sectional design also restricts long-term causal interpretations. Equipment heterogeneity across ports could have influenced the results.
Practical implications: The findings provide strong justification for institutionalizing preventive maintenance as a strategic pillar of port's operational management. The Tanzania Ports Authority should strengthen compliance enforcement, invest in energy-efficient equipment, and adopt predictive and eco-conscious servicing frameworks to improve sustainable performance.
Originality/value: The novelty of this paper hinges on empirical evidence on the strategic role of preventive maintenance in promoting green port performance within African contexts. It highlights the value of aligning technical operations with environmental policy, positioning maintenance practices as key drivers of decarbonization and trade competitiveness.

Keywords: Preventive maintenance; cargo-handling equipment; energy efficiency; emission reduction; green port performance.

1. Introduction

Ports are vibrant in the international supply chain, facilitating global trade and supporting economic growth, but they also contribute substantially to environmental degradation through high energy consumption, air pollution, and greenhouse gas (GHG) emissions (Okere, 2022; European Commission, 2023). Cargo-handling equipment (CHE), which is central to port operations, often relies on diesel engines that emit large volumes of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM). Poorly maintained equipment consumes more fuel, produces higher emissions, and suffers from frequent breakdowns, which undermine port efficiency and reliability (Zhu et al., 2023; Sadiq et al., 2021). Preventive maintenance, through structured inspections and servicing, has been widely recognized as a critical practice that reduces fuel consumption, enhances energy efficiency, and prolongs equipment lifespan (Poulsen et al., 2018; Yu et al., 2022).

Globally, ports are under increasing pressure to embrace sustainability and align with international decarbonization agendas (Yu et al., 2022). Initiatives such as the IMO's decarbonization strategy and the European Commission's "Fit for 55" framework emphasize the role of ports in reducing carbon footprints and promoting green logistics (IMO, 2023; European Commission, 2023). Leading ports, including Los Angeles and several across Europe and Asia, have integrated greener technologies and predictive maintenance frameworks, demonstrating that systematic servicing contributes directly to emission

reduction and operational resilience (Yu et al., 2022; Zhu et al., 2023). In Africa, however, the transition toward green port operations has been slower, hindered by obsolete equipment, inadequate investment, limited technical expertise, and servicing delays (Kamau & Otieno, 2020; UNCTAD, 2023). Evidence from East Africa shows that preventive and planned maintenance are increasingly critical for sustaining operational efficiency and reducing emissions (Kimbwi & Mwangoka, 2022). The Tanzania Ports Authority (TPA) has introduced modernization initiatives such as energy-efficient equipment and electronic maintenance systems, but challenges persist, including high GHG emissions, limited adoption of eco-friendly technologies, and gaps in compliance with maintenance schedules (TPA, 2023; Kunambi & Zheng, 2024; Budiyanto et al., 2024).

Although global literature demonstrates the benefits of preventive maintenance in enhancing energy efficiency and reducing emissions (Alamoush et al., 2020; Budiyanto et al., 2024), empirical studies in African ports remain scarce. This inadequacy of evidence undermines the investigation on the effect of cargo handling equipment maintenance on green port performance at Tanzania's ports. Addressing this gap is essential for aligning national port operations with global climate objectives while strengthening competitiveness in regional trade. This study investigates the regular inspections and servicing of cargo-handling equipment on green port performance in Tanzania's seaports.

2. Literature Review

2.1 Theoretical Underpinning

This study draws on Total Quality Management (TQM) theory, which emphasizes continuous improvement through structured processes such as the Plan-Do-Check-Act (PDCA) cycle. Preventive maintenance and systematic inspections, central to TQM, directly support efficiency and emission reduction in CHE. These principles align with the focus of the study on how routine servicing enhances green port performance. However, effective implementation requires strong leadership commitment, which remains a challenge in resource-constrained contexts such as East African ports.

2.2 Cargo Handling Equipment Maintenance and Green Port Performance

2.2.1 Regular Inspection and Servicing of Cargo Handling Equipment for Energy Efficiency

Empirical studies consistently show that regular inspections and servicing of CHE are central to improving energy efficiency in port operations. Preventive maintenance ensures machinery operates at optimal performance, lowering fuel and electricity consumption while minimizing emissions (Sadiq et al., 2021; Yuen & Lam, 2020). Predictive approaches have also proven effective in reducing unnecessary energy waste and extending equipment lifespan (Tuan & Navon, 2016; Yu et al., 2022).

Evidence from global ports reinforces these benefits. At the Port of Los Angeles, Zhu et al. (2023) found that routine maintenance maximized the energy-saving potential of hybrid and electric cranes, while Van der Meer et al. (2018) showed that systematic servicing reduced energy waste in European container ports. Studies in Asia similarly confirm that regular inspections support efficiency and cost reduction (Yu et al., 2022; Zakaria et al., 2022).

In East Africa, however, inconsistent maintenance practices remain a barrier to efficiency. Kamau and Otieno (2020) observed that delays in servicing at Mombasa increased energy consumption and operational inefficiencies, while Muro et al. (2024) reported similar challenges at Dar es Salaam, where irregular maintenance contributed to higher fuel use and emissions. Despite modernization efforts, inadequate maintenance has limited the potential of energy-efficient technologies (TPA, 2023). Kimbwi and Mwangoka (2022) emphasize that structured inspections are essential for ensuring modernized equipment delivers expected energy savings. The literature demonstrates that preventive and predictive maintenance significantly enhance energy efficiency and operational performance. While global evidence highlights strong gains from structured servicing, Tanzanian and regional studies reveal that the absence of systematic maintenance undermines both energy efficiency and sustainability outcomes.

2.2.2 Regular Inspection and Servicing of Cargo Handling Equipment for Emission Reduction

Cargo-handling equipment (CHE) is a major source of greenhouse gas (GHG) emissions in ports, releasing CO_2, NO_x, SO_2, and particulate matter when poorly maintained. Empirical studies confirm that routine inspections and servicing reduce these emissions by ensuring machinery operates efficiently. For example, Buhaug et al. (2019) found that well-maintained CHE in Scandinavian ports emitted 20% less CO_2, while Zakaria et al. (2022) observed reduced NO_x and particulate matter at Malaysia's Port of Tanjung Pelepas. Similarly, Martínez-Álvarez et al. (2019) reported emission reductions of up to 18% in Spanish ports following structured maintenance programs. Incorporating technological innovation with preventive servicing has amplified results. Zhu et al. (2023) showed that properly maintained hybrid and electric cranes cut CO_2 emissions by up to 70% compared to diesel units, while Poulsen et al. (2018) highlighted the role of maintenance in calibrating emission-control systems in diesel-powered machinery. Studies in Asia and Europe thus demonstrate that preventive maintenance is essential for achieving emission targets.

In Africa, evidence points to challenges of neglect. Kamau and Otieno (2020) found that poor maintenance at Mombasa increased fuel use and emissions, while Muro et al. (2024) showed that irregular servicing at Dar es Salaam contributed to higher CO_2 and particulate matter. Recent modernization efforts (TPA, 2023) and recommendations by Kimbwi and Mwangoka (2022) emphasize that structured inspections, combined with energy-efficient technologies, can substantially reduce emissions. Global evidence shows that preventive maintenance is a proven strategy for reducing pollutants, while African studies reveal gaps in consistent implementation. This highlights the importance of strengthening systematic inspections and servicing practices in Tanzanian ports to align with international decarbonization commitments and improve green port performance.

2.4 Conceptual Framework

Figure 1 illustrates the relationship between variables in cargo handling equipment maintenance and green ports performance.

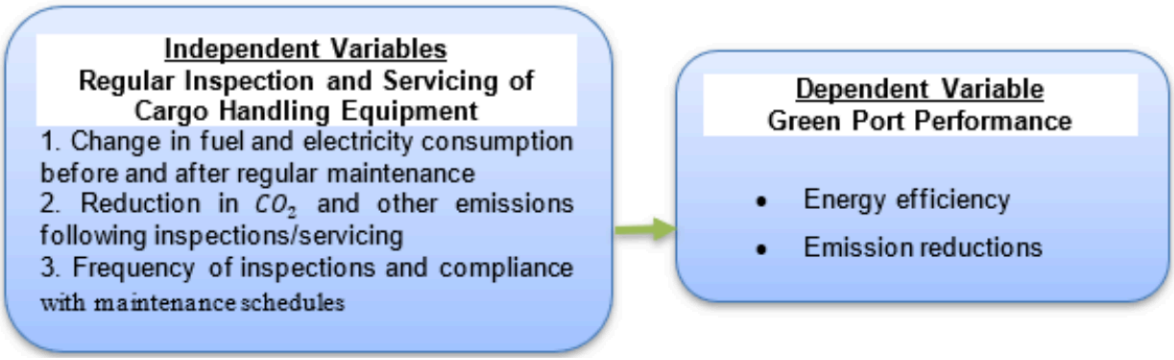

Figure 1: *Conceptual framework*

3.Research Methods

This study adopted a quantitative cross-sectional design to specifically examine the effect of regular inspections and servicing of CHE on green port performance in Tanzania's major seaports, Dar es Salaam, Tanga, and Mtwara. A sample of 101 respondents was drawn from a population of 133 staff in operations, engineering, and environmental departments, using Yamane's (1967) formula. Primary data were collected through a structured questionnaire with Likert-scale items capturing changes in fuel and electricity consumption, emission reduction, breakdown frequency, and compliance with maintenance schedules. The constructs were tested for reliability using Cronbach's Alpha, with results confirming acceptable internal consistency (Regular Inspections and Servicing $\alpha = 0.709$; Green Port Performance $\alpha = 0.720$). Ethical approval was secured from the relevant port authorities. Participation was voluntary, confidentiality was maintained, and no identifying information was collected. Data analysis was conducted using IBM SPSS version 25.0, applying descriptive statistics to establish key descriptive findings and simple linear regression to test the predictive effect of maintenance practices on green port performance.

Model assumptions of linearity, normality, homoscedasticity, and absence of influential outliers were tested and satisfied the necessary assumptions. The general regression model was constructed as:

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \varepsilon.$$

Where $\hat{Y}$=GPP represents the Green Port Performance index (DV), X_1 = Regular Inspections and Servicing is the preventive maintenance index (IV), β_0 is the constant, and ε is the error term.

4. Results and Discussion

4.1 Demographic Information

A total of 101 respondents participated, drawn from Dar es Salaam (40.6%), Tanga (29.7%), and Mtwara (29.7%), ensuring balanced geographic representation. The sample was predominantly male (77.2%), reflecting the gender composition of technical and engineering roles in port operations. The workforce was relatively youthful but experienced: Regarding age, 36.6% were aged 30–39 years, 23.8% were 40–49, while 28.7% were under 30. By role, 48.3% were operations staff and 43.8% maintenance engineers, both directly relevant to equipment servicing and inspections, while 5.6% were environmental staff. Departmental distribution aligned with where 58.4% from Engineering and Maintenance and 36.6% from Operations. Work experience was evenly spread, with about one-third in each category (1–5 years, 6–10 years, and over 10 years), allowing the study to capture both current practices and insights from seasoned professionals (Table 1).

Table 1: Demographic Information (n=101)

Demographic Information	n	%
Region		
Mtwara	30	29.7
DSM	41	40.6
Tanga	30	29.7
Gender		
Male	78	77.2
Female	23	22.8
Age, Years		
Below 30	29	28.7
30 to 39	37	36.6
40 to 49	24	23.8
50+	11	10.9
Job Title		
Operation staff	43	48.3
Maintenance Engineer	39	43.8
Environmental/Sustainability Staff	5	5.6
Port Manager	2	2.2
Department/Section		
Operations	37	36.6
Engineering and Maintenance	59	58.4
Environmental Management	5	5.0
Years of Experience in Port Operations		
1 to 5	35	34.7
6 to 10	34	33.7

>10	32	31.7

Source: TPA field data, 2025

4.2 Regular Inspections and Servicing of Cargo Handling Equipment

4.2.1 Regular Inspections and Servicing of CHE for Energy Efficiency

The findings in Table 2 indicate that preventive maintenance is well institutionalized, with 62.4% of respondents reporting monthly servicing of cargo handling equipment. This practice was associated with operational gains where 52.5% observed reduced fuel consumption, 51.5% reported decreased electricity usage, and 71.3% noted that breakdowns occurred rarely after servicing. These results underline that structured inspections and servicing enhance reliability and contribute to energy efficiency, reduced downtime, and alignment with sustainability objectives.

4.2.2 Compliance and Perceived Effect of Maintenance

The results in Table 2 further revealed a generally positive commitment to structured maintenance, with 61.4% of respondents confirming adherence to servicing schedules, though full compliance with emission standards was limited, as only 18.8% of equipment met the highest benchmark. In terms of impact, 52.5% rated fuel reduction as moderate and 25.7% as high, highlighting maintenance as an effective contributor to energy savings. By contrast, perceptions of electricity efficiency were mixed, with 40.6% of respondents reporting no noticeable reduction, 25.7% of respondents noting moderate to significant improvements. These findings highlight preventive maintenance as a meaningful driver of green port performance through fuel efficiency and emission reduction, but they also reveal gaps in strict compliance and the need for broader investment in energy-efficient equipment.

Table 2: Regular Inspections, Compliance, and Their Effect on Green Port Performance

Inspections and Servicing	*N (%)*	*Compliance and Maintenance*	*N(%)*
Preventive maintenance		**Schedules properly followed**	
Weekly	26(25.7)	Yes	62(61.4)
Monthly	63(62.4)	Partially	21(20.8)
Quarterly	7(6.9)	No	10(9.9)
Not Scheduled	5(5)	Not Sure	8(7.9)
Fuel consumption changes after servicing		**Equipment compliance with emission standards**	
Decreased	53(52.5)	0–25%	15(14.9)
Same	27(26.7)	26–50%	12(11.9)
Increased	11(10.9)	51–75%	55(54.5)
Not Sure	10(9.9)	76–100%	19(18.8)
Electricity consumption changes after servicing		**Impact on reducing fuel use**	
Decreased	52(51.5)	Moderate Impact	53(52.5)
Same	14(13.9)	High Impact	26(25.7)
Increased	10(9.9)	Low Impact	15(14.9)
Not Sure	25(24.8)	No Impact	7(6.9)
Breakdowns after servicing		**Impact on reducing electricity use**	

Rare	72(71.3)	No noticeable reduction	41(40.6)
Frequent	22(21.8)	Moderate reduction (10–20%)	26(25.7)
Very Frequent	7(6.9)	Significant reduction (>20%)	25(24.8)
		Slight reduction (<10%)	9(8.9)

1st and 2nd Column=Regular Inspections and Servicing for Energy Efficiency. 3rd and 4th =Compliance and Perceived Impact of Maintenance.

Source: TPA field data, 2025

4.3 Contribution of Equipment Maintenance to Environmental and Operational Outcomes

The findings in Figure 2 demonstrate that structured maintenance significantly enhances environmental and operational outcomes in Tanzania's ports. Environmentally, 38.6% of respondents reported extensive reductions in carbon emissions, while 52.5% of respondents observed lowered air pollution, such as smoke and fumes, during cargo handling. These results show that preventive servicing directly addresses port-related pollution and supports Tanzania's alignment with global decarbonization targets. Operational benefits were equally strong, where 62.4% of respondents indicated that reduced breakdowns improved loading and unloading efficiency, while 67.3% of respondents confirmed that timely servicing enhanced equipment availability during peak demand. This reflects the dual role of preventive maintenance in extending equipment lifespan and improving service reliability, which are critical factors for sustaining competitiveness in international trade. In addition, 65.3% of respondents agreed that minimizing downtime through maintenance reduced congestion and delays, while 62.4% of respondents confirmed direct improvements in energy efficiency and overall green performance. These justify the adoption of predictive and eco-conscious maintenance frameworks as an institutional priority for the TPA, ensuring that technical interventions deliver both operational efficiency and environmental gains.

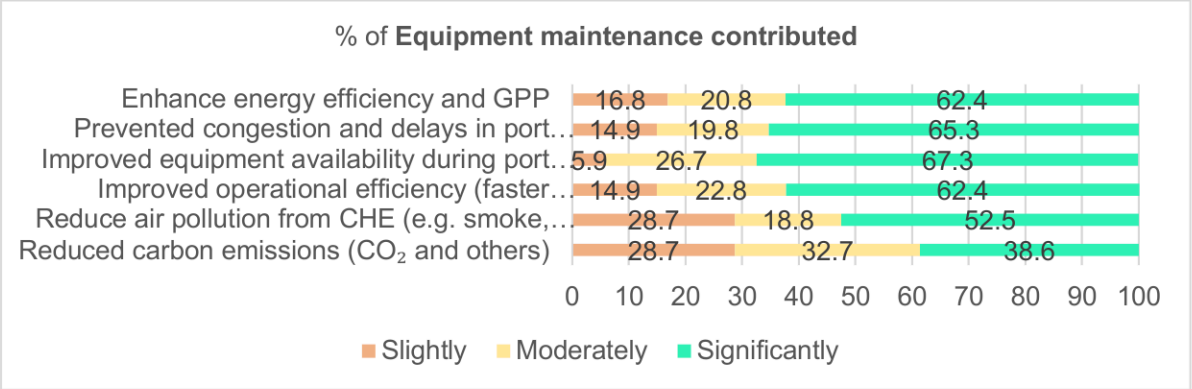

Figure 2: Contribution of Equipment Maintenance to Environmental and Operational Outcomes

Source: TPA field data, 2025

4.4 Regression Results

Table 3 presents regression analysis of the variables used in the empirical investigation. The results show that regular inspections and servicing of cargo handling equipment significantly predict green port performance, with an R^2 of 0.190, implying that nearly 19% of performance variation is explained by maintenance practices. The model was statistically robust ($F = 23.222$, $p < 0.001$; Std. Error = 2.877). Coefficients further highlight the strength of the relationship. The unstandardized coefficient ($B = 0.409$) indicates that a one-unit increase in the maintenance index raises green port performance by 0.409 units, while the standardized beta ($\beta = 0.436$) suggests a moderate-to-strong effect. This was strongly significant ($t = 4.819$, $p < 0.001$). This postulate institutionalizes preventive maintenance as a strategic pillar of port modernization. Improvements in inspection quality and servicing frequency directly translate into emission reduction, energy savings, and operational reliability, aligning TPA with global decarbonization and strengthening competitiveness in green trade corridors.

Table 3: Simple Linear Regression on Regular Inspections and Servicing of CHE

Model Summary	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	
	.436	0.190	0.182	2.877	
Coefficients[a]	***Unstandardized Coefficients***		***Standardized Coefficients***	***t***	***Sig.***
	B	Std. Error	Beta		
(Constant)	22.620	3.208		7.050	0.000*
Regular Inspections and Servicing of Cargo Handling Equipment	0.409	0.085	0.436	4.819	0.000*

*Statistically significantly; SLR: *Anova: F=23.222, sig=<0.001.* Std. Error = 2.877 Source: TPA field data, 2025

5. Discussion of Findings

The results provide strong evidence that regular inspections and servicing of cargo-handling equipment (CHE) are central to advancing both energy efficiency and environmental sustainability in Tanzania's ports. The predominance of monthly maintenance (62.4%) demonstrates an emerging culture of structured equipment care, consistent with global literature positioning preventive servicing as a cornerstone of sustainable port operations. Alamoush et al. (2020) emphasized that technical measures such as routine inspections minimize wasteful fuel consumption, while Kamau and Otieno (2020) confirmed similar benefits at Mombasa, where preventive maintenance reduced energy use and enhanced operational reliability.

The observed reductions in fuel (52.5%) and electricity (51.5%) consumption align with Budiyanto et al. (2024), who demonstrated that optimized maintenance cycles lower CO_2 emissions. Comparable studies from advanced ports, such as Yu et al. (2022) in Los Angeles, show that systematic monitoring improves energy efficiency, supporting that Tanzanian practices are consistent with international sustainability pathways, including the IMO's (2023) decarbonization strategy. However, the variability in electricity savings, where 40.6% of respondents saw no noticeable improvement, suggests that outdated or inefficient electric CHE may limit gains. Kunambi and Zheng (2024) argue that predictive maintenance and technological upgrades are essential to achieve consistent improvements in energy efficiency across electricity-reliant systems.

Compliance findings indicate progress but highlight gaps. While 61.4% confirmed adherence to maintenance schedules, only 18.8% of equipment achieved full emission compliance. This reflects resource and enforcement challenges noted by Kimbwi and Mwangoka (2022), who documented similar constraints in East African ports. Zakaria et al. (2022) likewise observed that hazardous cargo practices undermined environmental goals at Port of Tanjong Pelepas, emphasising that compliance gaps are a global challenge. For Tanzania, these results justify stronger institutional monitoring and alignment with international benchmarks, such as the IMO's decarbonization agenda.

The operational benefits are equally significant. Respondents highlighted fewer breakdowns (62.4%), improved equipment availability (67.3%), and reduced congestion (65.3%) as outcomes of timely servicing. These findings reflect Okere (2022), who linked preventive maintenance in Nigerian ports to improved reliability and service delivery, and Muro et al. (2024), who demonstrated that cargo-handling efficiency directly affects customer satisfaction in Tanzania's ports operations. Such evidence confirms that preventive servicing functions are an environmental tool and a driver of competitiveness in global logistics chains.

Regression analysis further validated these perceptions by showing that inspections and servicing of cargo handling equipment account for 19% of the variance in green port performance. This explanatory power is consistent with Wang and Notteboom (2014), who identified equipment servicing as a core component of

green port strategies, and Yuen and Lu (2020), who emphasized preventive maintenance as a lever for technological and environmental performance. The significant coefficient ($\beta = 0.436$, $p < 0.001$) strengthens the argument that structured servicing of cargo handling equipment directly translates into measurable improvements in emission reduction, energy conservation, and operational efficiency.

These findings demonstrate that preventive maintenance is a technical necessity and a strategic enabler of sustainable port performance. At the institutional level, they justify the TPA to embed preventive servicing as a pillar of modernization. At the policy level, the results align with global frameworks such as the European Commission's (2023) "Fit for 55" plan and the World Bank's (2023) call for sustainable port development in emerging economies. By institutionalizing structured inspections and servicing, Tanzania's ports can strengthen compliance with international decarbonization targets while positioning themselves as competitive green trade hubs in East Africa.

6. Conclusion and Recommendations

6.1 Conclusion

The study concludes that regular inspections and servicing of cargo handling equipment significantly advance green port performance in Tanzania by reducing fuel consumption, lowering emissions, improving energy efficiency, and enhancing operational reliability. Regression analysis confirmed that maintenance practices are statistically significant predictors of green port performance, underlining their strategic value. However, moderate compliance with servicing schedules and uneven electricity savings highlights the need for stronger enforcement and investment in modern, energy-efficient equipment. Overall, preventive maintenance emerges as a technical procedure and a critical enabler of sustainability, aligning Tanzania's ports with the global decarbonization targets and enhancing their competitiveness in regional and international trade.

6.2 Recommendations

To strengthen the effect of preventive maintenance on green port performance, several measures are recommended. Tanzania Ports Authority should establish stricter monitoring and accountability systems to ensure servicing schedules are consistently followed. Investment in modern, energy-efficient equipment and predictive technologies is necessary to address current gaps in electricity savings and emission control. Also, preventive maintenance should be fully embedded in TPA's green port strategies and aligned with international frameworks such as the IMO's (2023) decarbonization strategy and the EU's "Fit for 55" plan. Furthermore, building technical capacity through continuous training and professional development of staff involved in operations, maintenance, and environmental management will enhance the effectiveness of maintenance practices. Finally, TPA should adopt predictive and eco-conscious maintenance models by leveraging data-driven approaches, IoT-enabled diagnostics, and emission tracking systems to transition from reactive servicing to proactive, environmentally sustainable interventions.

6.3 Policy Implications

The findings carry important policy implications for both Tanzania and the broader East African region. Embedding preventive maintenance into national and regional sustainability frameworks would ensure consistency with global decarbonization strategies and enhance competitiveness in green trade corridors. At the EAC level, harmonizing maintenance standards could reduce disparities across ports and improve collective performance. Policies should balance regulatory enforcement with incentives such as subsidies for energy-efficient equipment and recognition for high compliance to accelerate Tanzania's transition toward sustainable and resilient maritime logistics.

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