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ASSESSMENT OF AIR POLLUTION MITIGATION STRATEGIES IN APAPA AND TIN CAN ISLAND SEAPORTS, LAGOS STATE, NIGERIA

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ABSTRACT

The objective of this study was to assess the air pollution Mitigation Strategies in Apapa and Tin Can Island Seaports Lagos State, Nigeria. The population of the study comprises of two thousand four hundred and thirteen (2413) staff of Agencies in the seaport, port operators, buker supply companies. Using Taro Yammene formula three hundred and forty-three (343) samples were selected and questionnaires distributed which were appropriately distributed out of which the same number were accurately filled and returned. The study revealed that the air mitigation strategies in use in both seaports include a truck call-up, cleaner fuel like LNG and scrubber technology for vessels, installing emission control technologies, such as catalytic converters, on trucks and other vehicles to reduce emissions of pollutants like nitrogen oxides (NOx) and particulate matter (PM) as well as campaign and training for drivers and the port community among others. The researchers concluded that the port operators and ship-owners to a certain level comply with best practices in

environmental sustainability regulations thereby harnessing the blue economy for sustainable development.

Keywords: Air Pollution; Mitigation Strategies: seaport; environment; vessels.

1.0 INTRODUCTION

The air around Lagos's bustling Apapa and Tin Can Island seaports often carries more than just the scent of saltwater, it bears the heavy burden of diesel fumes, suspended particulates, and noxious emissions from thousands of trucks, vessels, and cargo-handling equipment. These seaports, though central to Nigeria's economy, have become hotspots of environmental degradation, particularly in the form of air pollution, threatening both ecological balance and human health (Afolabi et al., 2021; Okonkwo & Adeyemi, 2020). As global maritime trade expands and Nigerian ports strive to maintain their relevance in international shipping, the sustainability of port operations has become increasingly imperative (International Maritime Organization [IMO], 2020). Air pollution at seaports is not only a local environmental concern but also a critical issue that affects public health, port worker safety, and urban living conditions in adjacent communities (World Health Organization (WHO), 2021). The situation in Lagos is particularly alarming given the high volume of traffic, aging infrastructure, and limited enforcement of emission standards (Adebayo et al., 2019). Despite policy initiatives and isolated interventions, a cohesive and strategic approach to air pollution mitigation remains lacking (Nigerian Ports Authority (NPA, 2022). A crucial yet underexplored dimension of this discussion is its connection to the blue economy, a sustainable use of ocean resources for economic growth, improved livelihoods, and ocean ecosystem health. In Nigeria, achieving a resilient blue economy demands that ports, as key coastal infrastructures, operate in an environmentally sustainable manner (United Nations Economic Commission for Africa [UNECA], 2021). Effective air pollution mitigation not only supports ecological goals but also enhances operational efficiency, economic performance, and Nigeria's standing in global maritime circles (Olalekan et al., 2020). While air pollution mitigation has gained attention in broader urban environmental policy, port-specific strategies remain fragmented, poorly implemented, or inadequately assessed (Ajayi &

Odugbemi, 2018). Existing literature in Nigeria largely emphasizes general urban pollution or water contamination, leaving a significant gap in focused empirical studies on air quality control within port environments (Afolabi et al., 2021). This neglect undermines the formulation of effective interventions and policy frameworks tailored to the unique operational realities of seaports like Apapa and Tin Can Island. The consequences of this knowledge gap are both practical and theoretical. Practically, stakeholders from port authorities to regulatory agencies, lack actionable data and tested strategies to reduce air emissions. Theoretically, the absence of context-specific studies limits the development of models or frameworks that integrate environmental performance with port logistics, sustainability, and economic productivity (Ogunlana & Olusola, 2022). This study seeks to fill this void by offering a systematic assessment of air pollution mitigation strategies at Nigeria's busiest seaports. To combat these challenges, the IMO introduced MARPOL Annex VI, which sets international standards for controlling air pollution from ships. It also established Emission Control Areas (ECAs) in regions such as the Baltic Sea, North Sea, U.S. Caribbean Sea, and parts of the China Sea, where stricter emission standards are enforced. However, there remains a lack of clarity in the literature regarding the specific sources of air pollution at Apapa seaport, and the progress toward achieving Sustainable Development Goal (SDG) 13—Climate Action—remains limited in this context. Existing literature emphasizes that the major contributors to port-related air pollution are NOx, SOx, particulate matter, and greenhouse gases originating from vessels and port-related activities (Saxe & Larsen, 2004). These emissions have been linked to serious health issues, such as respiratory and cardiovascular diseases, and they also contribute to global climate change (Karagulian et al., 2015). Despite the severity of this issue, there is a significant research gap regarding Nigerian ports. While earlier studies have examined the environmental impact of seaports in general, few have assessed the specific air pollution control measures currently in place or evaluated their effectiveness (Nwokocha & Mgbechidinma, 2019). This study aims to address this gap by evaluating the existing air pollution mitigation strategies at Apapa and Tin Can Island seaports in Lagos State, Nigeria. Seaports are significant contributors to air pollution, primarily due to emissions from ships, cargo-handling equipment, and associated vehicular traffic. In developed countries, comprehensive strategies have been implemented to mitigate these emissions. For instance, the Ports of Los Angeles and Long Beach introduced the Clean Air Action Plan (CAAP), which led to substantial reductions in diesel particulate matter, nitrogen oxides (NO_x), and sulfur oxides

(SO_x) through measures like shore power implementation, vessel speed reduction programs, and the use of cleaner fuels. Similarly, European ports have adopted Environmental Management Systems (EMS) and Emission Control Areas (ECAs) to monitor and control air pollutants . These initiatives often involve stakeholder engagement, stringent regulatory frameworks, and the integration of advanced technologies. In contrast, ports in developing countries face challenges such as limited resources, inadequate infrastructure, and less stringent environmental regulations. Studies in Vietnam have highlighted the potential of green port development, emphasizing the need for policy reforms and investment in cleaner technologies . In Ghana, research at the Tema Port revealed high levels of air pollutants due to outdated equipment and lack of emission control measures, (Gulyás & Kinra (2025). These studies underscore the importance of tailored strategies that consider local contexts, including economic constraints and technological capabilities. They also highlight the need for capacity building and international support to implement effective mitigation measures. In Nigeria, research on port-related air pollution is emerging. A study by Olukanni and Esu (2018) estimated greenhouse gas emissions from vessel operations at Lagos and Tin Can ports, identifying anchorage and maneuvering as significant emission sources. Another study by Ezenwa et al. (2023) measured concentrations of pollutants like CO, NO_2, and SO_2 in Apapa and Tin Can Island ports, finding levels exceeding national and international standards. These studies indicate the presence of emission inventories and highlight the critical need for comprehensive source apportionment to identify and target major pollution sources effectively. However, limitations such as short monitoring durations and lack of continuous data collection hinder the development of robust mitigation strategies. Comparing methodologies across studies reveals variations in data collection techniques, pollutant focus, and analytical approaches. While developed countries often employ continuous monitoring and advanced modeling, studies in Nigeria have relied on periodic measurements and simpler analytical methods. This disparity affects the depth and reliability of findings, emphasizing the need for standardized methodologies and capacity enhancement in developing contexts. Furthermore, inconsistencies in regulatory enforcement and stakeholder engagement in Nigeria contrast with the more coordinated efforts observed in developed ports. These differences highlight the necessity for integrated policies, stakeholder collaboration, and investment in infrastructure to improve air quality management in Nigerian seaports.

2.0 MATERIALS AND METHODS

The research design selected for this study is based on the focus of the study as indicated in the objectives of the research. This study adopted a survey research design. The survey design involved an exploratory cross sectional survey design. The cross-sectional survey involves studies which are done at one or more points in a given time period (Anyanwu, 2016). The research design is justified since the research was conducted in the terminals of Nigerian seaports at the same time period. The research was conducted at Nigeria's major seaports, particularly Lagos Port Complex and Tin Can Island Port, which are among the busiest and most industrially significant ports in the country. These locations are chosen due to their high levels of activity and likely contribution to air pollution. The sea port locations in Lagos Nigeria which is at the South Western coasts of the country, Lagos Sate is on Latitude 6.6080º N, Longitude 3.6218ºE (Figure 1).

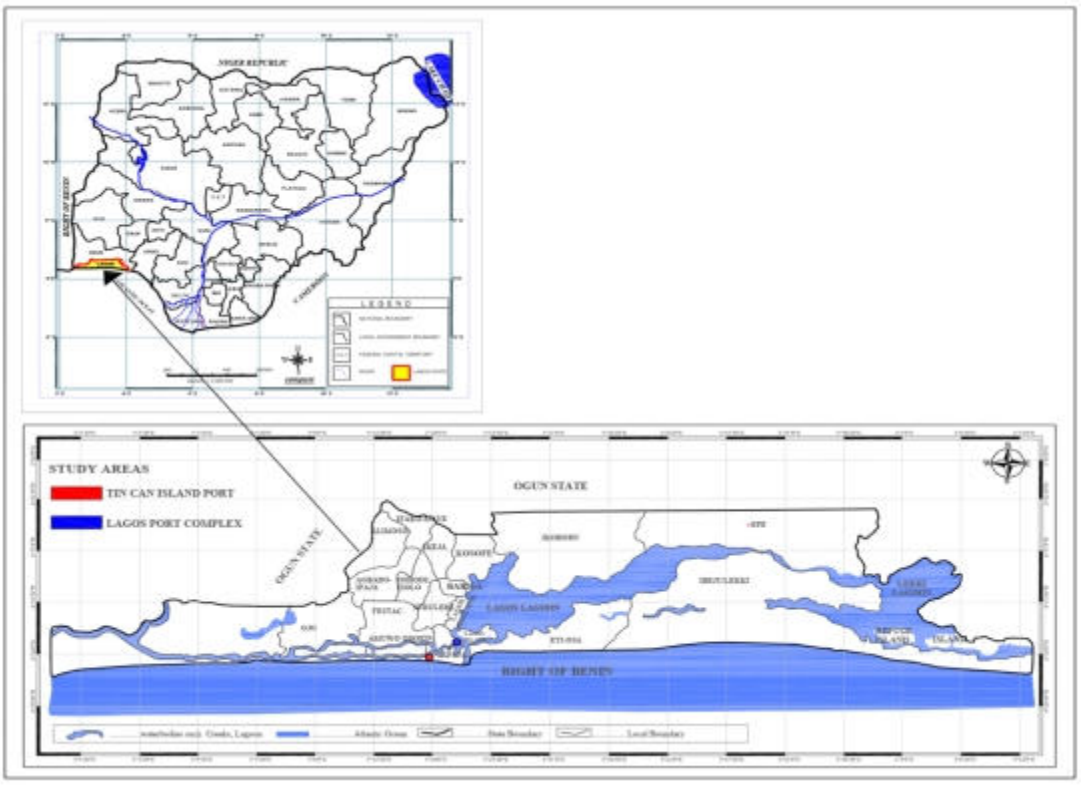


Fig. 1: Map of Lagos State showing the Apapa Port Complex (APC) and Tin Can Island port (TCIP). Source: Google Earth (2024)

The total population comprised of the staff of terminal operators, government agencies, as well as bunker supply companies that has business with the seaports. The staff of the above terminals formed the target population of this study. The total population of terminal operators, Agencies, private operators and companies as well as bucker suppliers in the port of Apapa and Tin Can Island is two thousand four hundred and thirteen (2,413). This study employed stratified random sampling, a probability-based sampling technique that enhances representativeness by dividing the population into homogeneous subgroups (strata) and randomly selecting respondents from each stratum. This method is particularly appropriate for a study of this nature due to the following reasons:

Heterogeneity of the Port Environment: Apapa and Tin Can Island seaports comprise various stakeholder groups including port administrators, environmental regulators, customs officers, freight forwarders, terminal operators, and logistics personnel. These groups differ significantly in roles, exposure to pollution, and perspectives on mitigation strategies. Stratified sampling ensures that each of these distinct subgroups is proportionately represented, thereby capturing the full diversity of experiences and knowledge. Stratified sampling increases precision and accuracy of estimates by reducing sampling error. Within each stratum, the variability is lower than in the overall population, making the estimates derived from stratified samples more reliable compared to simple random sampling. Since the study aims to perform statistical tests and inferential analyses, it is imperative to use a sampling method that supports the generation of generalizable and statistically valid results. Stratified random sampling meets this requirement more effectively than non-probability methods. In this study, the Taro Yamane formula was chosen due to its simplicity and historical usage in similar port-related studies in Nigeria. However, to improve statistical robustness, the sample size calculated using the Taro Yamane method was cross-checked against Cochran's formula, ensuring consistency with best practices in survey research. Taro Yamen Formular method which is represented by $n = \frac{N}{1+N(e)^2}$

Where, n = sample size

N = Population

e=error margin represented by 0.05

Therefore, the sample size is

$$n = \frac{2413}{1+2413(5\%)^2} = 343$$

Questionnaire instrument was used to obtain primary data. For the identification of mitigating strategies available and in use in the study area, we examined the different sources of air pollution and ascertain measures, operational or technical, put in place to reduce pollution from these sources. This instrument comprised two (2) sections: sections A, & B. Section A of the instrument was used to collect the demographic characteristics of the respondents which includes; name of the department, gender of the respondents and experience. Section B of the instrument was used to collect information on air pollution mitigation technology. The section is structured in 5-points likert scale with the options of Strongly Agree (5 points), Agree (4 points), Undecided (3 points), Disagree (2 points), and Strongly Disagree (1 point). This section formed the core of the study, comprising 10 close-ended items designed to assess respondents' identifiable air pollution mitigation strategies in Apapa and Tin Can Island seaports. The items were grouped into thematic sub-sections. All items were phrased using clear, concise, and non-leading language to reduce ambiguity and were measured using a 5-point Likert scale: Respondents were given space to suggest additional strategies or provide comments on the challenges of air pollution control in their specific port operations. The draft questionnaire was submitted to a panel of five experts in environmental science, transport logistics, and public health, including professionals from the Nigerian Ports Authority (NPA) and two university professors specializing in environmental policy. Experts were asked to evaluate each item on a 4-point relevance scale (1 = Not Relevant, 4 = Highly Relevant). The Content Validity Index (CVI) was calculated, and items with a CVI below 0.75 were revised or removed. The revised questionnaire was pilot-tested with 20 respondents across both ports. Feedback from the pilot helped to refine item wording, remove redundancies, and confirm clarity and appropriateness for the study context. Descriptive statistics such as frequency counts, percentages, means, and standard deviations were used to summarize: To investigate whether demographic characteristics influence perceptions of air pollution mitigation strategies, the following inferential techniques were employed. Chi-square (χ^2) Tests of Independence: Used to assess relationships between categorical demographic variables (e.g.,

professional role, education level) and responses to selected Likert-scale items recoded into ordinal or binary categories.

3.0 RESULTS AND DISCUSSIONS

Table 1: What are the strategies in use to mitigate air pollution in the Apapa and Tin Can Islan Seaports?

S/N	What are the strategies in use to mitigate air pollution in the Apapa and Tin Can Islan Seaports?	SA	%	A	%	UD	%	D	%	SD	%	Total	%
1	To reduce congestion and emissions, a truck call-up system has been implemented.	87	25.4	132	38.6	51	14.9	38	11.1	34	9.9	343	100
2	Development of alternative routes and the establishment of satellite parks for trucks have also been recommended to prevent long lines of trucks within the ports. This ensures a smoother flow of traffic and reduces emissions from vehicles.	46	13.4	152	44.3	46	13.4	65	19	34	9.9	343	100
3	There is increase in automation within port operations to help reduce the time trucks spend at the ports,	83	24.2	140	40.8	44	12.8	33	9.6	43	12.5	343	100
4	Encouraging the use of cleaner energy for port operations, such as electrification of cranes and other port equipment, (AMP)	117	34.1	122	35.6	29	8.5	41	12	34	9.9	343	100
5	The enforcement of strict emission standards for industries around the port	68	19.8	158	46.1	50	14.6	33	9.6	34	9.9	343	100
6	Switching to low-sulfur diesel and other cleaner fuels (eg LNG) in trucks and ships operating within the Apapa and Tin Can port as a strategy to mitigate air pollution.	95	27.7	123	35.9	47	13.7	38	11.1	40	11.7	343	100
7	Installing emission control technologies, such as catalytic converters, on trucks and other vehicles to reduce emissions of pollutants like nitrogen oxides (NOx) and particulate matter (PM) has been implemented	108	31.5	133	38.8	37	10.8	31	9	34	9.9	343	100

8	Engaging the local population, truck drivers, and port workers in awareness campaigns about the impact of air pollution and the importance of adopting cleaner practices is essential.	94	27.4	145	42.3	31	9	44	12.8	28	8.2	343	100
9	Strengthening the capacity of enforcement agencies, like the Lagos State Environmental Protection Agency (LASEPA), to monitor and regulate air pollution in Apapa is a key strategy	106	30.9	141	41.1	35	10.2	29	8.5	32	9.3	343	100
10	Planting more trees and creating green spaces around Apapa can help improve air quality.	100	29.2	145	42.3	39	11.4	28	8.2	31	9	343	100

Source: Survey

From table 1 above, the respondents were asked if a truck call-up system has been implemented to reduce congestion and emission in the seaport, the responds indicated that 87(25.4%) of the respondents Strongly agreed, 132(38.6%) agreed, 51(14.9%) were neutral while 38(11.1%) disagreed and 34(9.9%) of the respondents strongly disagreed. When asked if development of alternative routes and the establishment of satellite parks for trucks have also been recommended to prevent long lines of trucks within the ports for smoother flow of traffic and emission reduction from vehicles. the responds indicated that 46(13.4%) of the respondents Strongly agreed, 152(44.3%) agreed, 46(13.4%) were neutral while 65(19%) disagreed and 34(9.9%) of the respondents strongly disagreed. The respondents were asked if there is increase in automation within port operations to help reduce the time trucks spend at the ports, the responds indicated that 83(24.2%) of the respondents Strongly agreed, 140(40.8%) agreed, 44(12.8%) were neutral while 33(9.6%) disagreed and 43(12.5%) of the respondents strongly disagreed. Also, where the respondents were asked if encouraging the use of cleaner energy for port operations, such as electrification of cranes and other port equipment, (AMP) is one of the mitigation strategies adopted in the port, the result indicated that 117(34.1%) of the respondents Strongly agreed, 112(35.6%) agreed, 29(8.5%) were neutral while 41(12%) disagreed and 34(9.9%) of the respondents strongly disagreed. When asked whether enforcement of strict emission standards for industries around the port is one of the ports' mitigation strategies, the results show that 68(19.8%) of the respondents Strongly agreed, 158(46.1%) agreed, 50(14.6%) were neutral while 33(9.6%) disagreed and 34(9.9%) of the respondents strongly disagreed. The respondents were further asked

whether switching to low-sulfur diesel and other cleaner fuels (eg LNG) in trucks and ships operating within the Apapa and Tin Can port as a strategy to mitigate air pollution in the seaports, the result indicated that 68(19.8%) of the respondents Strongly agreed, 158(46.1%) agreed, 50(14.6%) were neutral while 34(9.9%) disagreed and 34(9.9%) of the respondents strongly disagreed. The respondents were asked whether if installing emission control technologies, such as catalytic converters, on trucks and other vehicles to reduce emissions of pollutants like nitrogen oxides (NOx) and particulate matter (PM) has been implemented as mitigation strategy in the ports, the result indicated that 108(31.5%) of the respondents Strongly agreed, 133(38.8%) agreed, 37(10.8%) were neutral while 31(9.%) disagreed and 34(9.9%) of the respondents strongly disagreed. The respondents were asked whether engaging the local population, truck drivers, and port workers in awareness campaigns about the impact of air pollution and the importance of adopting cleaner practices is essential is one of the strategies used to mitigate air pollution in the port, the result indicated that 94(27.4%) of the respondents Strongly agreed, 145(42.3%) agreed, 31(9%) were neutral while 44(12.8%) disagreed and 28(8.2%) of the respondents strongly disagreed. On if strengthening the capacity of enforcement agencies, like the Lagos State Environmental Protection Agency (LASEPA), to monitor and regulate air pollution in Apapa is a key strategy, the result indicated that 106(30.9%) of the respondents Strongly agreed, 141(41.1%) agreed, 35(10.2%) were neutral while 29(8.5%) disagreed and 32(9.3%) of the respondents strongly disagreed. Finally, when as asked if planting more trees and creating green spaces around Apapa can help improve air quality is a strategy in use, 100(29.2%) strongly agreed, 145(42.3%) agreed, 39(11.4%) were neutral while 28(8.2%) disagreed and 31(9%) of the respondents strongly disagreed.

Table 2a: Descriptive Statistics

	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6
Valid	342	343	343	343	343	343
Mean	3.58	3.32	3.55	3.72	3.56	3.57
Std. Error of Mean	.068	.065	.070	.071	.065	.071
Median	4.00	4.00	4.00	4.00	4.00	4.00

Mode	4	4	4	4	4	4
Std. Deviation	1.255	1.210	1.297	1.312	1.197	1.314
Variance	1.575	1.465	1.681	1.723	1.434	1.726
Range	4	4	4	4	4	4
Minimum	1	1	1	1	1	1
Maximum	5	5	5	5	5	5
Sum	1226	1140	1216	1276	1222	1224

Table 2b: Descriptive Statistics

	Question 7	Question 8	Question 9	Question 10
Valid	343	343	343	343
Mean	3.73	3.69	3.76	3.74
Std. Error of Mean	.068	.067	.067	.066
Median	4.00	4.00	4.00	4.00
Mode	4	4	4	4
Std. Deviation	1.268	1.237	1.239	1.218
Variance	1.608	1.531	1.535	1.484
Range	4	5	4	4
Minimum	1	1	1	1

Maximum	5	6	5	5
Sum	1279	1265	1289	1284

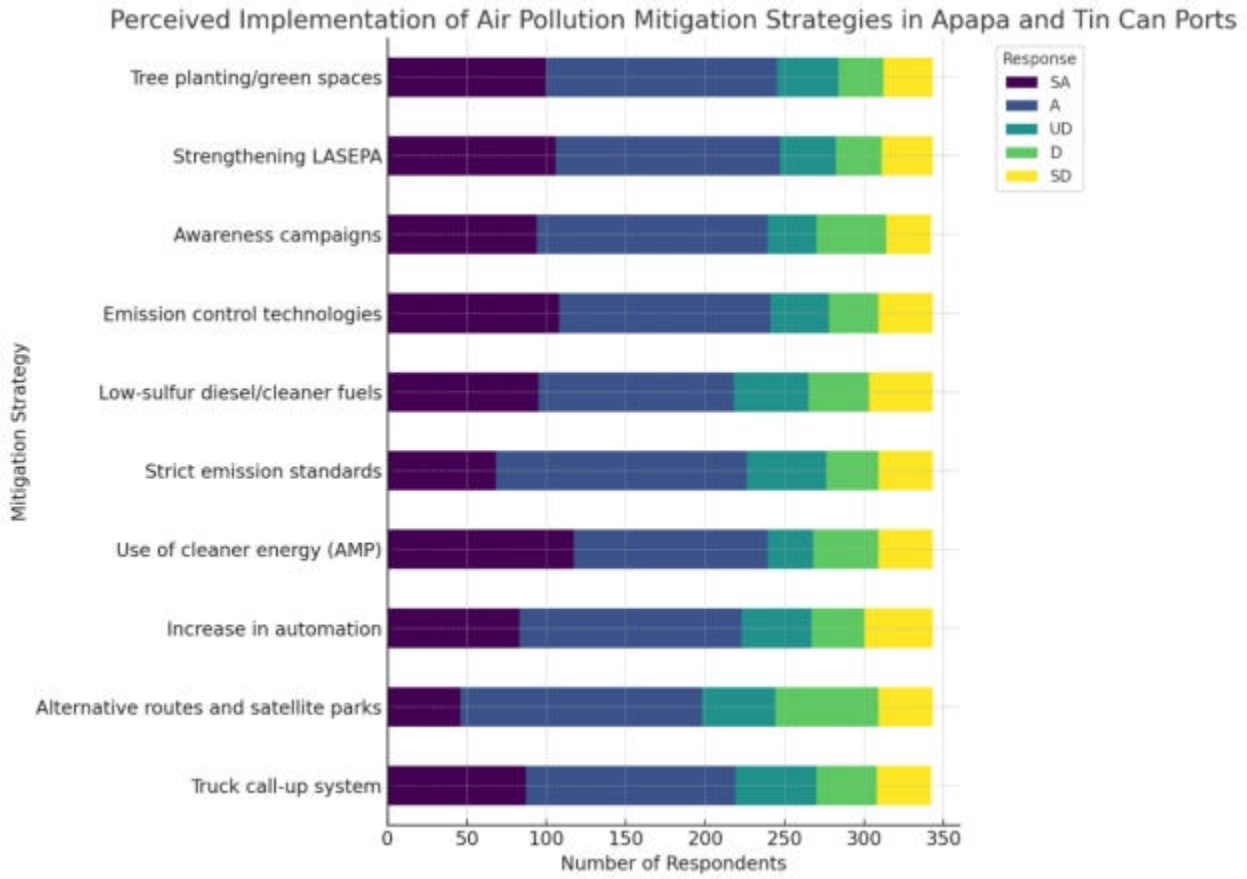


Fig. 1: Perceived implementation of air pollution mitigation strategies in Apapa and Tin Can Ports

An enhanced and structured analysis of the results from Table 1 along with a bar chart visual and mean score comparison: A stacked horizontal bar chart (see image above) visually represents the degree of agreement across all strategies, enhancing clarity and reader engagement.

3.1 KEY PATTERNS AND TRENDS

3.1.1 Most Implemented Strategies:

Strengthening of LASEPA (Mean = 3.76): This strategy received the highest mean score, indicating broad consensus on the need for enhanced regulatory enforcement. Tree planting and green space creation (Mean = 3.74) and installation of emission control technologies (Mean = 3.73) were also highly rated, showing strong support for both natural and technological interventions.

Moderately Implemented Strategies

Strategies like awareness campaigns (Mean = 3.68) and electrification of port equipment (Mean = 3.72) were perceived to be moderately implemented, indicating room for improvement.

3.1.2 Least Supported or Perceived Strategies

Development of alternative routes and satellite parks (Mean = 3.32) had the lowest mean rating. This could reflect challenges in land use or bureaucratic delays in executing infrastructural plans. Automation in port operations (Mean = 3.55) and emission standards enforcement (Mean = 3.56) scored lower than expected, potentially due to partial or delayed implementation.

3.2 STATISTICALLY SIGNIFICANT OBSERVATIONS

There is a clear preference for regulatory and structural interventions (e.g., strengthening LASEPA) over operational or systemic changes (like route development). The relatively lower rating for automation might reflect either its limited visibility to stakeholders or its limited scope of impact.

4.0 DISCUSSION

The findings of this study reveal a multifaceted picture of air pollution mitigation strategy implementation in the Apapa and Tin Can Island seaports. This section discusses the results in light of the research objectives and synthesizes them with existing literature, particularly studies from other port regions globally and within developing countries. The strategy rated highest by respondents was strengthening the capacity of enforcement agencies like the Lagos State Environmental Protection Agency (LASEPA) (Mean = 3.76). This aligns with findings from

Aboagye and Mohd (2021), who highlighted that strong regulatory frameworks and institutional capacity are pivotal to effective air quality management in ports across Sub-Saharan Africa. Similarly, tree planting and green infrastructure (Mean = 3.74) received strong support, consistent with ecological design solutions recommended in ports in Southeast Asia (Lee & Nam, 2018). Also notably rated were the installation of emission control technologies such as catalytic converters (Mean = 3.73) and the electrification of port equipment and vehicles (Mean = 3.72). These findings are in agreement with studies in ports such as Rotterdam and Singapore, where advanced emission reduction technologies have significantly curbed particulate matter and nitrogen oxide emissions (Jiang et al., 2020; International Maritime Organization [IMO], 2019).

The findings indicate a moderate level of implementation and perception for public awareness campaigns (Mean = 3.68) and switching to cleaner fuels such as low-sulfur diesel or LNG (Mean = 3.57). Although these strategies are globally recognized as effective (Corbett & Winebrake, 2014), their implementation in Nigerian ports appears constrained. Similar challenges were identified in studies from India and Kenya, where access to cleaner fuels and public environmental literacy remains limited (Kumar & Dash, 2022; Odhiambo et al., 2020). Strategies such as the development of alternative routes and satellite parks (Mean = 3.32) and increased port automation (Mean = 3.55) were rated the lowest. This is particularly significant considering that traffic congestion and idle time are major sources of air pollution in port areas (Gonzalez-Aregall et al., 2017). The underwhelming score may reflect implementation gaps or delays in infrastructural development—an issue similarly reported in the Port of Mombasa (Mwangi et al., 2021). It is worth noting that while truck call-up systems are intended to address congestion and emissions, the mean score (3.58) suggests limited public confidence in their effectiveness—possibly due to operational inefficiencies or limited coverage. While comprehensive emission inventories for Apapa and Tin Can ports remain scarce, preliminary efforts such as the Lagos State Environmental Protection Agency's 2019 Air Quality Report have acknowledged industrial and vehicular emissions as primary contributors to pollution in the region. However, there remains a significant gap in detailed source apportionment studies or quantitative emission modeling, which limits the ability to fully assess the efficacy of individual mitigation strategies. This lack of data is consistent with findings from West African ports where similar environmental monitoring limitations persist (Biney et al., 2020). The observed variability in the perceived implementation of strategies may

be explained by lack of uniform enforcement across different port operations, resource constraints impacting the adoption of expensive technologies and inconsistent stakeholder engagement, especially in infrastructure-dependent interventions. The moderate to high agreement on softer strategies such as awareness and agency empowerment may also suggest that stakeholders prioritize interventions that are perceived as more feasible within current political and economic realities.

4.1 CONCLUSION

The findings of this study provide a comprehensive assessment of air pollution mitigation strategies implemented at Apapa and Tin Can Island Seaports, revealing a moderate level of compliance with environmental sustainability regulations. Based on the survey responses, certain best practices such as the installation of emission control technologies, enforcement of stricter emission standards, and the electrification of port equipment are perceived to be implemented more effectively. These strategies show a relatively higher level of agreement among respondents, indicating more consistent application and awareness. The link between these mitigation efforts and the broader framework of the blue economy is significant. By reducing air pollution and enhancing environmental conditions around the ports, these strategies support the health of marine ecosystems, protect port-adjacent communities, and improve operational efficiency. This contributes to the sustainable development of seaports, aligning with the goals of the blue economy, which emphasizes economic growth alongside environmental protection and social inclusion. Cleaner energy adoption, reduced emissions from transport logistics, and green infrastructure such as urban forestry not only mitigate pollution but also foster resilience, innovation, and inclusive economic opportunities within the maritime sector. Nevertheless, this study acknowledges certain limitations. The use of stratified sampling, while appropriate for ensuring representation across stakeholder groups, may still introduce some bias, especially if strata were uneven or not exhaustive. Additionally, the survey responses are self-reported and subject to perceptual biases, which might affect the accuracy of assessments regarding implementation levels. These factors may influence the generalizability of the findings beyond the specific context of Apapa and Tin Can Island Seaports. Future research should include longitudinal and observational studies, incorporate air quality measurements, and examine the economic implications of mitigation strategies to offer a more holistic understanding of their impact. This

will further inform policy formulation aimed at harnessing the blue economy for sustainable seaport development in Nigeria and similar port environment**s.**

4.2 RECOMMENDATIONS

Based on the responses and findings from this study which aligned with globally recognized port environmental practices. Implementation of these below actions will help improve environmental sustainability, contribute to economic resilience, and advance Nigeria's goals within the blue economy framework. These include;

1. Enhance the Capacity of Environmental Enforcement Agencies: this can be achieved by providing targeted training and technical resources for LASEPA and port environmental units; increasing funding and deploy real-time air quality monitoring stations at strategic locations within the ports; As well as promoting inter-agency collaboration between NIMASA, NESREA, and LASEPA to ensure coordinated enforcement.
2. **P**romote cleaner fuels and technologies through encouraging the phased adoption of low-sulfur diesel and LNG for trucks and vessels through public-private partnerships; Providing import duty waivers or financial subsidies for cleaner energy conversion kits and alternative fuel vehicles.
3. Expand and institutionalize public awareness campaigns by regularly engaging truck drivers, port workers, and local communities through workshops, flyers, and radio programs on the impacts of air pollution and the benefits of mitigation strategies; partner with trade unions and community leaders to disseminate information and promote behavior change.
4. Improve infrastructure and logistics efficiency: Accelerate the development of truck call-up systems and electronic scheduling platforms to reduce congestion; continue developing alternative routes and satellite parks with adequate amenities to minimize idling and emissions.
5. **S**upport green infrastructure and urban greening: Designate and maintain green belts around the ports by planting pollution-absorbing tree species; implement a port-wide environmental sustainability plan that includes regular assessments of green coverage and air quality improvements.

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