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Impact of ship operational intensity and ship exhaust emissions on the environment around Tanjung Priok harbor

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Abstract : The purpose of this study is to find out how ship exhaust emissions affect the environment, especially the air around Tanjung Priok port. The quantitative method used SmartPLS 4 software. A questionnaire was distributed to 150 people around Tanjung Priok port. Air pollution around Tanjung Priok port is a major problem. This is due to the increasing number of ships that dock and operate at the port each year. These ships emit exhaust emissions containing various harmful substances, including sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM). Air pollution affects human health and comfort, global warming, and poorer air quality.
Keywords: *Air pollution, Tanjung Priok Port, Ship operational intensity, Ship exhaust emissions, Marine transportation*

1. Introduction

In the modern world, the number and types of marine transportation services continue to grow. Ports are an important part of the marine transportation network, and marine transportation has many advantages, including lower costs, large capacity, and the ability to transport heavy and bulky goods. As a result, marine transportation has become very popular (Erliyana & Oktaviana, 2020). The growth of both domestic and foreign trade is causing ports to become more industrialized places. Over 80% of foreign trade is transported by the port sector, which is significant (Prasetyo, 2021) ; (Octavianus et al., 2020) ; (Isdiana & Aminata, 2019) ; (Betta, 2022) ; (Saputra, 2020) ; & (Anjasmara, 2022).

However, as the port industry has grown, environmental pollution has become a major problem. The air quality around ports is deteriorating every year, and this issue has become a global concern in recent years (Arsantyo, 2022). While ships are docked and operating in the port, their exhaust emissions can be up to ten times those generated by overall port operational activities, contributing 3% to conventional pollutants and greenhouse gases (Zulfikar et al., 2023) ; (Susanto, 2023) ; (Manopo & Rusirawan, 2024) ; (Wahyudi & Fachruddin, 2020) (Mahendra & Fadilah, 2023) ; & (Kamal et al., 2024).

One of the main causes of air pollution around ports is ship exhaust emissions, which include a variety of hazardous materials like sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM). These compounds

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are derived from combustion-produced fuels like Marine Fuel Oil (MFO), B-35, or B-30. Air pollution affects human health and comfort, global warming, and poorer air quality (Wachjoe et al., 2020) ; (Rusdi, 2023) ; (B. Purnama et al., 2021) ; (Kusuma et al., 2019) ; (Amir & Efendi, 2021) ; & (Priyanto & Jayamahendra, 2024).

Tanjung Priok Port is one of the largest and busiest ports in Indonesia. This is because 70% of goods leave and enter Indonesia through it every year, making it a barometer of the Indonesian economy (Putra & Susilowati, 2022) ; (Casym & Oktiara, 2020) ; (Simanjuntak et al., 2024) ; (Agistra, 2023) ; (Purnama, 2022) ; & (Amrullah et al., 2023).

Figure 1. Ship call

NATIONAL AND INTERNATIONAL SHIP CALL AT TANJUNG PRIOK PORT,2022-2023					
NO	MONTH	UNIT		GROSS TONAGE	
		2022	2023	2022	2023
1	JANUARY	1.251	1.215	12.605.065	13.185.452
2	FEBRUARY	1.148	1.134	10.808.059	12.359.700
3	MARCH	1.279	1.381	12.419.066	13.523.453
4	APRIL	1.160	1.078	11.249.962	11.024.621
5	MAY	1.042	1.244	10.681.072	12.444.376
6	JUNE	1.257	1.266	12.051.613	12.848.561
7	JULY	1.242	1.232	12.194.692	12.649.113
8	AUGUST	1.304	1.314	13.164.026	13.181.007
9	SEPTEMBER	1.248	1.220	11.855.975	12.034.931
10	OCTOBER	1.290	1.296	13.540.763	12.865.341
11	NOVEMBER	1.296	1.298	13.395.929	13.628.455
12	DECEMBER	1.258	1.330	13.163.644	14.272.930
TOTAL		14.775	15.008	147.129.866	154.017.940

Source : https://simpadu-inaportnet.dephub.go.id/

The aforementioned figure illustrates how the number of ships anchored and in operation at Tanjung Priok port increased from 2022 to 2023, reaching 233 ships with a gross tonnage of 6,888,074. This situation may persist annually, unknowingly contributing to air pollution from ship exhaust emissions (Dewantara et al., 2020). As ships reach the port, they contaminate the surrounding air. When a ship is in port, its engines are kept running to suit its needs, particularly for power. Ships release exhaust pollutants when their engines are running.

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2. Literature review

A port is a body of water protected from waves that has marine terminal amenities like docks for ships to moor, cranes for unloading cargo, marine warehouses and storage areas for goods to be unloaded at designated times, and warehouses for longer-term storage of cargo before shipment to its destination. Railways and roadways are available at these terminals. According to Shipping Law Number 17 of 2008, a port is a place consisting of land and/or waters with certain boundaries used for government and business activities, used as a place for ships to dock, embark and disembark passengers, and/or load and unload goods, and is equipped with terminals and ship berths equipped with safety and security facilities (Zurkiyah & SriAsfiati, 2021) ; (Saputra, 2020) ; (Dewantara & Saputro, 2022) ; (Sipahutar, 2021) ; (Rumbia et al., 2022) ; (Oktarina & Budi, 2021) ; & (Putri et al., 2021). The English word intensity, which meaning powerful, hard, or great, is adopted as the word intensity. The Big Indonesian Dictionary defines intensity as a state of level or a measure of intensity (KBBI). An activity that is performed consistently is called intensity. Intensity is also correlated with frequency, or the regularity of an action (Ningsih & Utami, 2022) ; (Sabekti, 2019) ; (Wahyuliarmy & Sari, 2021) ; (Lestari et al., 2021) ; (Maulina & HMZ, 2021) ; (Nizar & Hajaroh, 2023) ; (Dalila et al., 2021) ; (Mumu et al., 2019) ; (Dewi, 2019) ; (Roseliyani, 2019) ; & (Ningrum & Prihantoro, 2020). According to the description, the intensity in question is the quantity or frequency of ships that dock and operate at the port.

Operational refers to a process of using daily resources to produce a product, either a barang or a service, in order to meet goals. Operational can also be defined as a learning tool and as a willingness to participate in a particular activity or work project (Prabowo, 2019) ; (Cuandra et al., 2023) ; (Faiq et al., 2021) ; (Landang et al., 2021) ; (Suganda & Purnamasari, 2022) ; (Julyanthry et al., 2020) ; (Mariani, 2022) ; (Syaifullah, 2022) ; (Rosita et al., 2020) ; (Marcella et al., 2022) ; & (Anwar, 2020). Exhaust emissions are produced by the engine's combustion process, which also releases sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO The exhaust pipe is used to release this exhaust gas.), carbon dioxide (CO2), and particulate matter (PM). The exhaust system is used to release these exhaust emissions (Lapisa et al., 2022) ; (Kurniawan et al., 2019) ; (Syaief et al., 2019) ; (Insani, 2021) ; (Muhajir, 2020) ; (Sudarwanto et al., 2020) ; (Syahruji & Ghofur, 2019) ; (Primasanti & Aryani, 2021) ; (Dewi et al., 2022) ; (Fajri et al., 2023) ; & (Listiyono et al., 2019).

A ship is a waterborne vehicle used to transport people or cargo and connect the land and the sea. The Ship Shipping Law Number 17 of 2008 states that a ship is any water vehicle of a specific shape and type that is propelled by wind, mechanical power, or another energy source, towed, or delayed. This definition also includes vehicles with dynamic carrying capacities, submerged vehicles, floating devices, and stationary floating structures. A few ship kinds are tugboats, passenger ships, freighters, tankers, icebreakers, containerships, warships, and pilotage ships (Mallira, 2023) ; (Dwiono et al., 2021) ; (Wahyuni, 2020) ; (Purnamasari, 2022) ; (Hayat, 2023) ; (Wardani, 2019) ; & (Nurhidayat, 2022). The environment comprises a space consisting of all objects, forces, conditions, and living things, including humans and their

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behavior. It impacts the continuity of life and well-being of humans and other living things (Salam et al., 2021) ; (Sari, 2022) ; (Sompotan & Sinaga, 2022) ; & (Nugroho, 2022).

3. Research method

Quantitative research methods were used in this study. It uses statistical techniques and numerical data to analyze the formulation of problems and research objectives, measure variables, and evaluate how each variable interacts with each other. To collect data, questionnaires were distributed to the community around Tanjung Priok port. In this study, simple random sampling was used. Since the population size is not known exactly, it is recommended that the sample size be at least five to ten times the indicator variables, Joseph F. Hair's formula was used to calculate the sample size. As a result, the total indicators were 15 times 10 (15 times 10 = 150) (Aulia et al., 2023). As a result, the formula's calculation indicates that the study's sample size is 150 population. The SmartPLS 4 program was used to process the data that was gathered for this investigation.

Table 1. Indicator variable

Variable	Operational definition	Operational definition	Source
Ship operational intensity	Vessel operational intensity refers to the level of vessel activity that includes the frequency, duration, and quality of vessel operations while operating in the port, which can affect the surrounding environmental conditions. The intensity of vessel operations in a port can be measured through several key dimensions, namely the frequency and duration of operations, the capacity and size of vessels, the type of operations performed, the operating time, and	1. Environment 2. Comfort 3. Appreciation 4. Frequency 5. Duration	(Zuhri, 2021) (Cendra & Gazali, 2019)

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	the level of loading and unloading activities. These dimensions provide a comprehensive picture of how often, long and large vessel activities take place, as well as the type and intensity of activities performed, which overall affect the environment around the port.		
Ship exhaust emissions	Ship exhaust emission refers to the amount and type of pollutants released into the air by the combustion of ship fuel while the ship is operating in port, which contributes to air pollution around the port. Ship exhaust emissions can be measured through various dimensions such as pollutant type and concentration, emission source, duration of emission release, control technology used, and impact on the environment. These dimensions provide a comprehensive picture of the magnitude and type of emissions produced by ships, and how these affect air quality and health around the port.	1. Air Quality 2. Health 3. Comfort 4. Environment 5. Global Warming	(Syarifudin et al., 2023) (Saputro et al., 2022)

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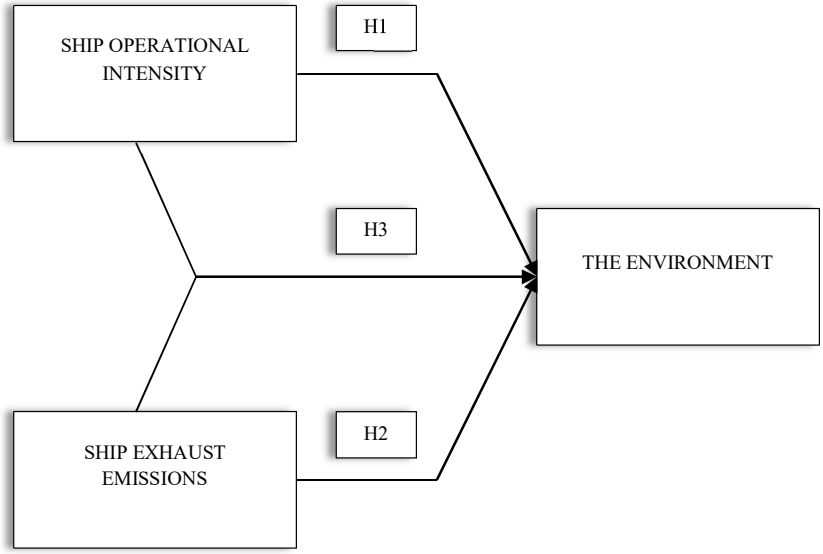
The environment	The air environment around the port can be measured through the dimensions of air quality and cleanliness, the comfort felt by the community, and its impact on local climate change and public health. In addition, public perception of air conditions is also an important indicator. These dimensions provide a complete picture of how much air quality in the port affects the comfort and health of nearby residents.	1. Air Quality 2. Health 3. Comfort 4. Appreciation 5. Environment	(Sa'diah & Sudarti, 2022)

Figure 2. Research hypothesis



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Based on the theoretical framework of thought above, a hypothesis can be formulated in this study as follows:

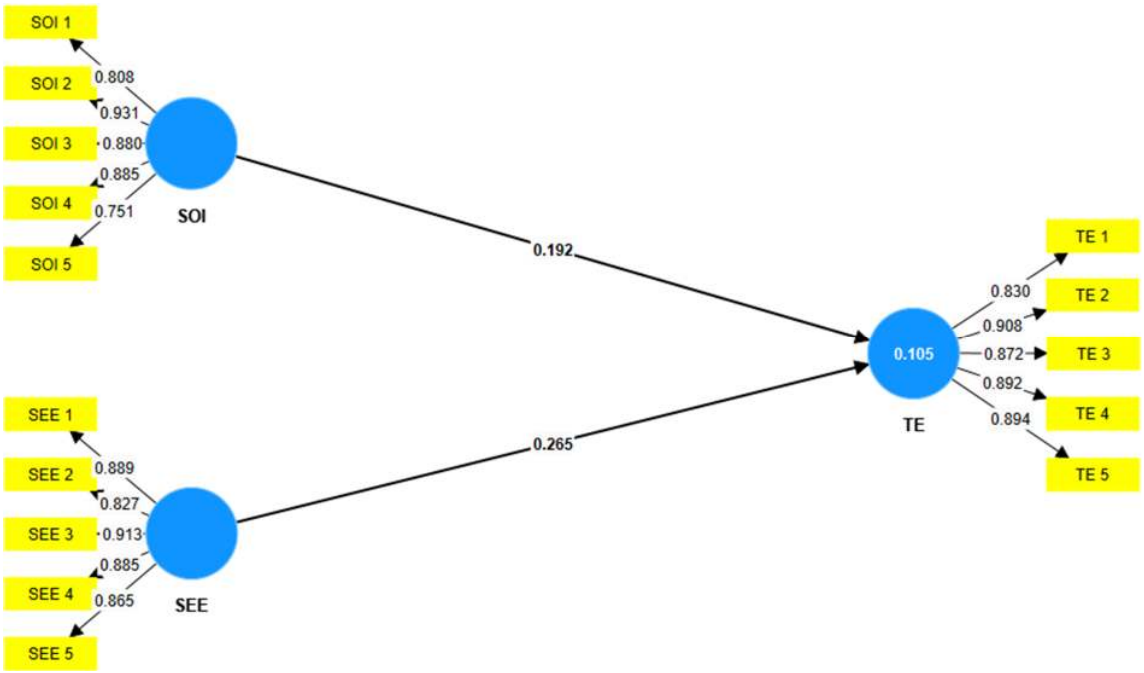
Hypothesis 1 (H1): It is suspected that there is a positive and significant influence between ship operational intensity on the environment.

Hypothesis 2 (H2): It is suspected that there is a positive and significant influence between ship exhaust emissions on the environment.

Hypothesis 3 (H3): It is suspected that there is a positive and significant influence between ship operational intensity and ship exhaust emissions on the environment.

4. Results and discussion

Figure 3. SmartPLS data processing



Source: Processed by researchers using SmartPLS 4

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Outer model

Convergent validity and reliability

Table 2. Convergent validity and reliability

Variabel	Indicator	OL	AVE	CA	CR(rho a)	CR(rho c)
SOI	SOI 1	0,808	0,729	0,910	1,058	0,930
	SOI 2	0,931				
	SOI 3	0,880				
	SOI 4	0,885				
	SOI 5	0,751				
SEE	SEE 1	0,889	0,768	0,927	0,989	0,943
	SEE 2	0,827				
	SEE 3	0,913				
	SEE 4	0,885				
	SEE 5	0,865				
TE	TE 1	0,830	0,774	0,927	0,940	0,945
	TE 2	0,908				
	TE 3	0,872				
	TE 4	0,892				
	TE 5	0,894				

Source: Processed by researchers using SmartPLS 4

With a fairly high Outer Loading (OL) range (OL > 0,70), the outer loading values for the indicators on the SOI, SEE, and TE variables collectively demonstrate in this table that each indicator has a strong and consistent contribution to its respective latent variable. This shows that every indicator on the measurement scale for these variables is highly relevant and effectively explains its latent construct. Excellent convergent validity (AVE > 0,50) and very high reliability (CA and CR > 0,70) were demonstrated by all variables SOI, SEE, and TE, demonstrating the accuracy and consistency of the items used to measure these variables in indicating the constructs being measured. Since every item satisfies extremely high standards, none need to be changed.

Table 3. Discriminant validity – HTMT

	TE	SEE	SOI
TE			
SEE	0,253		
SOI	0,181	0,084	

Source: Processed by researchers using SmartPLS 4

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All three constructs SOI, SEE, and TE have good discriminant validity, which means they are distinct from each other in the model under study. The results show that a low HTMT value (HTMT < 0,90) usually indicates good discriminant validity, or that the measured constructs do not differ from each other. This value is the limit usually used to indicate that discriminant validity is not affected.

Inner model
(Multicollinearity and Hypothesis)

Table 4. VIF and hypothesis testing

	VIF	STDEV	T statistics	P values
SEE -> TE	1.000	0,075	3,550	0,000
SOI -> TE	1.000	0,093	2,066	0,019
SOI-SEE -> TE	1.001	0,266	7.475	0.000

Source: Processed by researchers using SmartPLS 4

The table shows that all of the tested variables have VIF values approximately 1, which indicates that there is no problem with multicollinearity in the model, as a low VIF value (VIF < 5) is a good indication. Additionally, the STDEV values show that there are differences in the estimated path coefficients for each relationship. Every independent variable in the model has a significant impact on the dependent variable TE, as the table above demonstrates. With a low P value (P < 0,05) and a high T statistics (T > 1,96), the SOI-SEE -> TE relationship has more data variability than the SEE -> TE and SOI -> TE relationships.
Hypothesis test results :

Hypothesis 1 (H1): There is a positive and significant influence between the intensity of ship operations on the environment.
Hypothesis 2 (H2): There is a positive and significant influence between ship exhaust emissions on the environment.
Hypothesis 3 (H3): There is a positive and highly significant influence between ship operational intensity and ship exhaust emissions on the environment.

Table 5. R-Square

	R-square	Description
TE	0,105	Weak

Source: Processed by researchers using SmartPLS 4

The coefficient of determination, or R-square value, shows how much of an impact the independent variable has on the dependent variable. Three categories are formed by R-Square

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values: strong (> 0,75), moderate (> 0,50), and weak (< 0,25). According to the R-Square Table above, the latent variable TE is classified as weak. Only 10,5% of the variation in the TE variable can be explained by the model, indicating a low predictive ability. This is indicated by the low R-square value. The model's components are not powerful enough to adequately explain the variations in the TE variable in this case, as indicated by the low R-square value.

Table 6. F-Square

	F-square	Description
SEE -> TE	0,078	Strong
SOI -> TE	0,041	Strong

Source: Processed by researchers using SmartPLS 4

In order to determine how the size of the independent variable affects the dependent variable, the F-square analysis is used. According to the table, the F-square value for the relationship SEE to TE is 0,078, while the F-square value for SOI to TE is 0,041. Although the F-square value is usually considered as the strength of the effect, such as (<0.02) is considered weak, (>0.15) is considered moderate, and (>0.35) is considered strong. The table above shows that both SEE and SOI have a strong influence on TE in the tested model.

Table 7. PLS-Predict

Q^2predict	PLS-SEM_RMSE	PLS-SEM_MAE	LM_RMSE	LM_MAE	IA_RMSE	IA_MAE
0,034	0,887	0,732	0,903	0,730	0,903	0,737
0,088	0,925	0,726	0,930	0,701	0,969	0,804
0,032	0,894	0,694	0,918	0,693	0,909	0,720
0,028	0,900	0,720	0,913	0,721	0,913	0,728
0,063	0,926	0,719	0,961	0,757	0,957	0,757

Source: Processed by researchers using SmartPLS 4

When compared to other methods, such as the Linear Model (LM) and Approach Indicator (IA) approaches, the PLS-Predict table above shows the model prediction results using the Partial Least Squares Structural Equation Model (PLS-SEM) approach. The predictive value of Q2, which ranges between 0.028 and 0.088, indicates that the model has a modest predictive ability. In addition, the RMSE (Root Mean Square Error) and MAE (Mean Absolute Error) values for each method are shown in the table. Based on the table, the PLS-SEM model shows good predictive performance, with RMSE values of 0.887 to 0.926 and MAE values of 0.694 to 0.732. The LM and IA approaches have slightly higher RMSE and MAE values, indicating that the PLS-SEM approach provides more accurate predictive results in this model than other

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approaches. This confirms that the PLS-SEM model provides more reliable predictions for the dependent variables tested in this study.

5. Conclusion

This study aims to identify the impact of exhaust emissions from ships on the environment, especially the air around the Tanjung Priok port area. This research also aims for the international maritime organization (IMO) to make a new policy on sulfur content in the fuel used by each ship in order to reduce the greenhouse effect and global warming. And this research also aims to be a study material by the central and regional governments in regulating the arrangement of areas between industrial activities, especially ports and community settlements. The results of this study are based on observation, documentation, and questionnaires with parties related to the problem, including local residents. The study shows that ship exhaust emissions at Tanjung Priok harbor endanger the environment and interfere with public health and comfort. Air pollution around Tanjung Priok port is a major problem. This is due to the increasing number of ships that dock and operate at the port each year. These ships emit exhaust emissions containing various harmful substances, including sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM). These compounds are derived from combustion-produced fuels like Marine Fuel Oil (MFO), B-35, or B-30. These substances can turn into particles and then into dust that flies into the surrounding streets and neighborhoods. These particles should not be underestimated even if they are small. Because if it continues to be inhaled by humans, it will seriously endanger people's health. In addition, the substance causes acid rain, the greenhouse effect and global warming. However, actually, the impact is not only felt by the general public, but also the entire community living around the port, including fishermen, port workers, and government officials. Therefore, to minimize the impact, control and support from the central and local governments, as well as other aligned concepts, are required. These substances can turn into particles and then the particles become dust that flies into residential areas and surrounding roads. Although very small in size, these particles cannot be underestimated. Because if it continues to be inhaled by humans, it will have a major impact on public health. In addition, these substances contribute to acid rain, the greenhouse effect, and global warming that triggers climate change. However, this impact does not actually only affect the community, all elements of society around the port such as fishermen, port workers, and government officials are also affected. Therefore, it is necessary to have control and support from the central government and local governments, or other concepts that are aligned so as to minimize these impacts.

6. Implications

Spatial planning: The environmental impact of port activities should be taken into account in order to lessen the impact of air pollution on the surrounding settlements. Buffer zones should be part of this plan.

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Substitute energy sources: Utilize low-emission or alternative fuels, which are more environmentally friendly, to lessen the detrimental effects on the air quality near ports.
Utilizing renewable energy: Burning fossil fuels results in air pollution, which can be decreased by using renewable energy. Both public health and air quality will benefit from this.
Environmental regulations: Tighter regulations are needed to reduce ship exhaust emissions. Lower emission regulations and the application of eco-friendly technologies during ship operations are examples of this.
Give instruction: Increase public knowledge of the risks posed by air pollution brought on by port operations. Public health and air quality maintenance are important topics that should be brought up with the local population living near ports.
Green Technology Development: In the shipping industry there is a need to develop and implement technologies that support the environment, such as the use of greener fuels and more efficient emission control systems. This can help reduce negative environmental effects.
International cooperation: To lessen the environmental impact of port operations, collaborate with ports around the world to exchange best practices and technological advancements.

7. Research limitations

There are a number of limitations to this study that can serve as guidelines and motivation for future investigators to improve research outcomes and broaden the field's understanding:
- The environment (air) is the only dependent variable in this study; the other two independent variables are ship operational intensity and ship exhaust emissions.
-The study only included 150 local residents of Tanjung Priok Port.
- From April to August of 2024, researchers studied the implementation period.

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