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MORALITY BEFORE KNOWLEDGE

The causal dynamics between ship calls and environmental quality: A granger causality analysis

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ABSTRACT

Background: Maritime transportation has rapidly growth handling more than 80% of International global trade and nearly one million ship calls annually in Indonesia. Considering Indonesia's vast archipelago, shipping is the backbone of its logistics and people mobility. However, it simultaneously degrades the environment quality in certain areas. This study aims to assess the causal dynamics between the frequency of ship call and Environmental Quality Index (EQI) in 25 major Indonesian ports. **Methods:** This research used time series data from 2014 - 2023 and applied the Granger Causality Test to investigate the predictive causal nexus between variables. **Findings:** The results indicate that the causal relationship between ship calls and the Environmental Quality Index (EQI) is not uniformly significant across provinces. Significant Granger causality appears only in several major ports, showing regional variation in environmental impact. In these areas, increased ship call frequency tends to precede changes in EQI, suggesting environmental pressure from maritime activity. However, the relationship varies by province due to differences in industrial structure and environmental governance. Evidence of reverse causality—from EQI to ship calls—is generally weak, indicating that environmental quality does not significantly influence maritime traffic. **Conclusion:** These results provide crucial empirical findings for a geographically targeted, non-uniform policy approach for environmental sustainability in the Indonesian maritime sector. **Novelty/Originality of this article**: This research may contribute to the first known attempt to analyze the predictive cause-and-effect relationship between Ship Call and the EQI at the provincial level in Indonesia using the Granger Causality method, offering a preliminary fundamental evidence base for policymakers to balance maritime economic activity with environmental protection.

KEYWORDS: Environmental Quality Index (EQI); Granger causality test; Indonesian ports; maritime transportation; ship calls.

1. Introduction

The rapid growth of global trade is largely driven by maritime transportation throughout the shipping movement reaching more than 10 billion annually (Walker et al., 2019). This underscores the critical role of maritime shipping by 80% of the international trade volume (OECD, 2024). This rapid growth also drive's a significant demand of the transportation users, especially for archipelago countries like Indonesia. According to Indonesian Statistic Agency / BPS (2023) there are approximately nearly one million ship visits in 2023 from within and outside the country. Maritime transportation is, in fact, the

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backbone of Indonesian logistics, responsible for roughly 88% of the country's total freight volume (Zaman et al., 2015). This suggests the critical importance of maritime shipping as a backbone for global and national trade, that highlights the need of policies that ensure sustainable development to balance the commercial demands to the environmental conservation for future ecological robustness.

Maritime transportation demonstrates a paradoxical relationship with environmental quality, whereby its considerable economic contributions are accompanied by significant adverse environmental externalities, particularly in the form of air pollution and greenhouse gas emissions (Rodrigue, 2024; Psaraftis & Kontovas, 2020). This paradox is further driven by the local environmental degradation directly caused by port activities (Zhou et al., 2023). The physical impacts of maritime operations including noise, artificial light, wildlife collisions, and shoreline erosion along with air emissions that contribute to rising levels of greenhouse gases (GHG), sulfur oxides (SOx), nitrogen oxides (NOx), and other particulate matter, are significant drivers of environmental degradation in marine and coastal zones (Jägerbrand et al., 2019). This impact probably will rise in the future considering the high rate of the shipping operators in the future.

Globally, the marine environment has become a major focus, where efforts to manage risks and pollution from transport activities are one of the critical industry agendas (Yan et al., 2013; Brandt et al., 2024). Maritime transportation has a paradoxical relationship, where we consider the economic advantages to concurrently lead to major environmental damage via pollution and emissions. This problem is exacerbated by the intrinsic uncertainty and volatility in shipping and ports (Notteboom & Lam, 2014) as well as the direct physical effects resulting from port operations. Therefore, a deep understanding of the causal interaction between the growth of maritime activity and environmental conditions in Indonesia's major port areas is urgently needed. This also can prove the common assumptions about ship impacts, where in some cases the environmental degradation is caused by various physical impacts from port and ship activities. Thus, efforts to identify these casualties are not only academicallsy important, but also crucial for validating common assumptions about ship impacts, thereby enabling more effective decision-making to the regional level.

Indonesia is the world's largest archipelagic nation, making sea transportation essential as the foundation of its national logistics and passenger movement. Maritime transportation fundamentally supports its logistics network, accounting for approximately 85-90% of the nation's total freight volume (Ministry of Transportation, 2022; Munim & Schramm, 2018). The drastic increase in shipping activity, reflected by nearly one million ship callsin 2023, simultaneously triggers serious concerns regarding marine environmental quality. Most of Indonesian shipping problems have occurred due to the oil spill cases that also cause major incidents in the last five years at Balikpapan Bay (March 2018), Kepulauan Seribu Coast (April 2018), Karawang Coast (July 2019), and Kepulauan Riau Coast (Kurniawan et al., 2024). Therefore, acquiring a deep understanding of the causal effect of the ship's frequency and environmental quality can be considered for creating policies as a preliminary indication. This strategy enables us to achieve maritime economic advantages while simultaneously upholding environmental standards.

The causal relationship between ship call frequency and the Environmental Quality Index (EQI) in Indonesia's main ports is a critically under-researched area and uncommon to compare the environment, especially sea port areas as the variables. To address this gap, this study seeks to answer whether there is impact on Ship Calls to EQI and EQI to Ship Calls or no. This study also tries to apply Granger Causality Analysis to determine if a bidirectional cause-and-effect relationship exists. Although other research has underscored the significance of operational risk analysis and quantitative methodologies in shipping (Nguyen et al., 2019; Bowo et al., 2023), none has directly examined this particular causality. This study adds the ship calls frequency and EQI as the indicators to understand its causal nexus in selected ports, which consisted of 25 major ports in Indonesia to represent the maritime activity from the western to eastern part of Indonesia. Previously, empirical testing of this hypothesis in the Indonesian context was limited specifically in the use of EQI as an environmental variable. Therefore, this study aims to bridge that gap, thereby providing a fundamental evidence base for policymakers to develop strategies that balance maritime economic activity with ecological protection (Huang & Zhao, 2019).

2. Methods

2.1 Research design

This research evaluates the causal nexus between sea transportation activity and environmental quality by examining ship calls and the Environmental Quality Index (EQI). Recent empirical research highlights the intricate causal link between environmental sustainability, economic growth, and maritime transportation, emphasizing the need to move beyond simple correlation toward predictive causal modelling within the Blue Economy framework (Pires Manso et al., 2025). The maritime sector, including ship activity, can generate significant impacts not only on economic performance but also on environmental sustainability, thereby necessitating empirical investigation of its environmental consequences (Bekteshi et al., 2024). Furthermore, high ship call frequency generated from supply chain movements and port operations may contribute to environmental pressures when not managed efficiently, influencing overall environmental performance (Ayaz, 2022). In addition, studies employing advanced econometric approaches, such as the Generalized Method of Moments (GMM) and the Toda–Yamamoto version of Granger causality, demonstrate that the impact of maritime investment and trade activity on national wealth often appears gradually due to significant time lags between maritime development and realized economic outcomes (Arlı et al., 2025; Mohamed et al., 2025). These findings justify the use of time-series causality modelling to capture delayed and dynamic interactions between maritime transportation intensity and environmental quality.

Based on these empirical considerations, this study applies a quantitative time-series approach covering a ten-year period from 2014 to 2023. The Granger Causality test is employed to identify predictive relationships and potential feedback mechanisms between ship calls and EQI. This method is specifically designed to detect time-series relationships and dynamic interactions between variables. Following standard assumptions for a two-variable analysis, the causal relationship may be interpreted as unilateral or bilateral depending on statistical significance, based on the framework proposed by Gujarati &. Porter (2009).

2.2 Data sources

The data were obtained from secondary government publications. Data on ship calls were sourced from *Badan Pusat Statistik* (BPS), while environmental quality data were collected from the Ministry of Environment and Forestry. The observation period spans from 2014 to 2023. The use of official government data ensures consistency and comparability across provinces and port areas.

2.3 Study population and sampling

For the transportation aspect, the dataset was selected from 25 strategic ports categorized as Main Ports based on Indonesia's National Port Master Plan of Sea Transportation Decree No. KP 432 of 2017 issued by the Ministry of Transportation of Indonesia. The policy categorizes ports according to their hierarchies: Main Ports (PU), Feeder Ports (PL), and Local Ports. Main Ports are defined as ports operating at domestic and international scales that serve substantial cargo flows, container activities, and passenger mobility. This study focuses exclusively on Main Ports due to their strategic economic and operational significance.

2.4 Variables and measurement

2.4.1 Ship calls

Ship calls refer to the total number of vessel arrivals recorded at each selected port during the observation period. This variable represents maritime transportation activity and reflects the operational intensity of port services, supply chain movements, and logistical flows occurring within the port area. In this study, ship calls are used as a proxy to capture the scale and dynamics of sea transportation activity.

2.4.2 Environmental Quality Index (EQI)

This research utilizes the Environmental Quality Index (EQI), locally referred to as *Indeks Kualitas Lingkungan Hidup* (IKLH), as an indicator of environmental quality. The index refers to the criteria established in Ministerial Regulation No. 27/2021 concerning the Environmental Quality Index. The EQI is a composite indicator incorporating water, air, land, and seawater environmental components. At the provincial level, the index is calculated using a weighted aggregation of four primary environmental components, namely the Water Quality Index (WQI/IKA), the Air Quality Index (AQI/IKU), the Land Quality Index (LQI/IKL), and the Seawater Quality Index (SWQI/IKAL), which together represent the overall environmental performance within a province. The provincial EQI formulation is defined as follows:

$$EQI = (0.340 \times WQI) + (0.428 \times AQI) + (0.133 \times LQI) + (0.099 \times SWQI) \qquad \text{(Eq. 1)}$$

The EQI is categorized into five classifications: very good (90–100), good (70–<90), moderate (50–<70), poor (25–<50), and very poor (<25). In this study, EQI is treated as a key determinant of environmental conditions and as an endogenous variable within the predictive causality framework. Its inclusion in the dynamic time-series model enables the assessment of both contemporaneous and lagged interactions with maritime transportation activity, thereby allowing a more rigorous evaluation of potential directional and feedback effects over the observed period.

2.5 Econometric model specification

To estimate predictive causality between transportation activity and environmental conditions, this study employs the Granger Causality Test using time-series data. The use of environmental composite indices in dynamic econometric modelling has been shown to enable the estimation of potential reverse causality effects and feedback mechanisms between economic activity and environmental performance (Suharyono & Digdowiseiso, 2020). This approach allows for a more dynamic interpretation of the interaction between maritime transportation activity and environmental quality.

The Granger Causality approach was chosen due to its effectiveness in determining predictive relationships in two directions and in capturing dynamic interactions between macroeconomic and environmental variables, as widely applied in previous empirical studies (Aldonat Beyzatlar et al., 2012).The econometric model adopted in this research follows the standard framework proposed by Gujarati & Porter (2009) within a Vector Autoregression (VAR) specification to examine the predictive causal relationship between ship calls and environmental quality. The estimated equations are specified as follows:

$$EQI_t = \sum_{i=1}^{n} \alpha_i \, ShipCall_{t-i} + \sum_{j=1}^{n} \beta_j \, EQI_{t-j} + \mu_{1t} \qquad \text{(Eq. 2)}$$

$$ShipCall_t = \sum_{i=1}^{n} \alpha_i \, EQI_{t-i} + \sum_{j=1}^{n} \beta_j \, ShipCall_{t-j} + \mu_{2t} \qquad \text{(Eq. 3)}$$

Where EQI_t refers to the Environmental Quality Index; $ShipCall_t$ represents total ship arrivals; n denotes the maximum lag; α_i and β_j are estimated coefficients; μ_{1t} and μ_{2t} are error terms assumed to be uncorrelated; and t denotes time periods. This specification allows each variable to be explained by its own past values and by the lagged values of the other variable, thereby identifying whether ship calls Granger-cause EQI, whether EQI Granger-causes ship calls, or whether a bilateral feedback relationship exists.

2.6 Lag selection and model estimation

Prior to conducting the analysis, the data were processed using EViews statistical software. To ensure model validity and efficiency, the optimal lag length was determined using the Akaike Information Criterion (AIC). The lag structure with the smallest AIC value was selected to prevent overfitting and to maintain statistical robustness in identifying causal relationships.

2.7 Hypothesis testing and interpretation

The null hypothesis (H_0) was tested using probability values (p-values) at the 5% and 10% significance levels, and the statistical interpretation follows the framework provided by Gujarati & Porter (2009). Two hypotheses are examined, namely that ship calls do not Granger-cause EQI and that EQI does not Granger-cause ship calls. The interpretation of the results is categorized into three possible outcomes: if statistical significance appears only in one direction, the relationship indicates one-way causality; if both directions are statistically significant, bilateral causality or a feedback effect is identified; and if neither direction is significant, it indicates that no causal relationship exists between ship calls and EQI during the observed period.

3. Results and Discussion

3.1 Overview of study area

As an archipelagic country, the role of ports is fundamentally essential in driving sustainable economic growth, inter-island connectivity, and balanced regional development. In Indonesia, ports function not only as logistics nodes but also as strategic growth poles that stimulate industrial clusters, trade flows, and hinterland integration. This study focuses on 25 strategic ports in Indonesia based on the annual publication of the Indonesian Statistical Agency (BPS), *Statistics of Indonesian Transportation*. The port selection was based on the strategic port designation in Decree No. KP 432 of 2017, ensuring proportional representation across all port hierarchies, with all selected ports classified as main ports.

These ports collectively represent the Indonesian maritime gateway system stretching from the western to the eastern regions of the archipelago, reflecting spatial diversity in economic structure, shipping intensity, and environmental pressure. The selection of the 25 main ports, which are frequently examined in Indonesian maritime research, captures the structural complexity of the national logistics network. This network critically encompasses both major coastal seaports and functionally significant river ports that serve as vital connectors to inland economic zones. The categorization of "main ports" is therefore analytically important, as it includes facilities that play a pivotal role in cargo handling, throughput performance, and multimodal integration, regardless of whether they are located along the coastline or situated upstream on major navigable rivers. Such classification ensures that the analysis reflects the operational realities of Indonesia's geographically fragmented maritime system.

The spatial distribution of the ports in this study spans three major development corridors across Indonesia, allowing for comparative regional analysis. The Sumatera and Java corridor consists of 12 ports, including Belawan, Batam, Tanjung Priok, and Tanjung Perak, which generally record the highest shipping traffic density and serve as primary national and international trade hubs. The Kalimantan and Sulawesi corridor comprises six ports, such as Banjarmasin, Balikpapan, and Makassar, which primarily support resource-based industries and regional economic expansion. Meanwhile, the Bali, Nusa Tenggara, Maluku, and Papua corridor includes seven ports, including Benoa, Sorong, and Jayapura, facilitating connectivity and reducing regional disparities in eastern Indonesia.

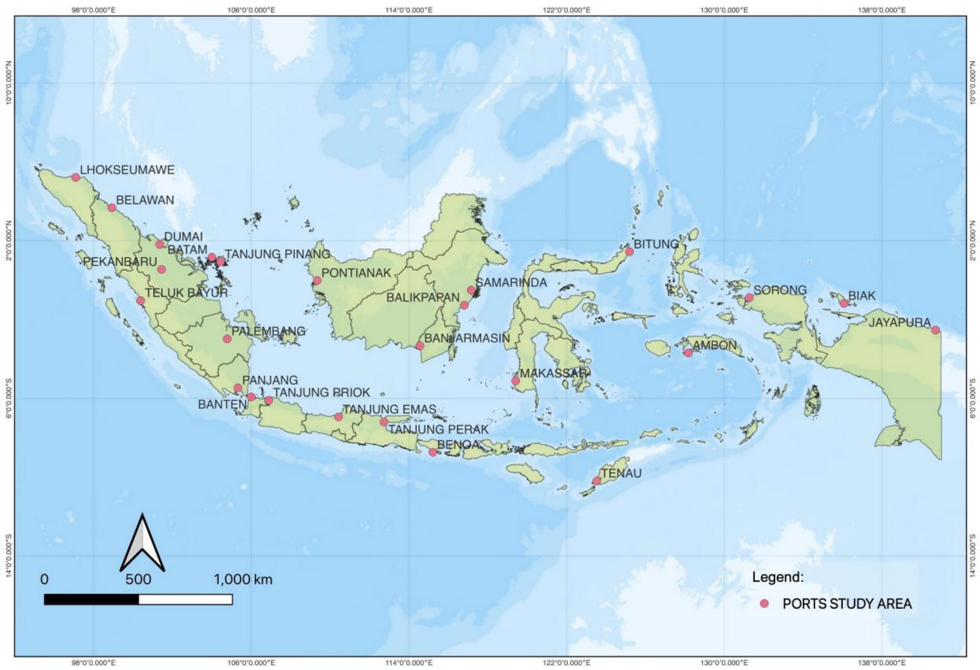

Fig. 1. Ports distribution of study area

This geographically diverse configuration enhances the robustness of the empirical analysis by capturing variations in port scale, traffic intensity, economic specialization, and environmental vulnerability. Consequently, the findings are expected to provide comprehensive and spatially nuanced insights into the interaction between maritime activity and environmental quality across Indonesia's heterogeneous regional landscape. Figure 1 illustrates the distribution of the ports within the study area.

3.2 Relationship pattern between ship calls and environmental quality

This research derives from the paradoxical conflict between economic growth from maritime activity and environmental degradation. Where there is a common view indicating a direct relationship between a high volume of ship calls and environmental degradation in the surrounding port area. This belief needs to be empirically proven using an integrated method that includes qualitative and quantitative data to establish the trend. Consequently, this research focuses solely on examining this causal relationship using secondary data. Therefore, the analysis of the causal relationship between Ship calls volume and the EQI in this study is underpinned by global and national policies to contextualize this phenomenon.

Based on data from 2014 to 2023, the ship calls pattern reveals a dynamic relationship between areas. The major port hubs like Batam and Tanjung Priok have recorded the highest volume of the ship arrivals, each port reaching nearly 100,000 units and consistently rising above 11,000 units per year. In contrast, the EQI score for this area shows a relative decrease with the score below the average of other selection ports. Tanjung Priok port for example, the EQI score showing an improvement trend and it remained at the lowest national level in 2023 with a score only 54.57. Conversely, the ports with smaller activity scales are observed mainly in Eastern Indonesia, Port of Sorong and Jayapura have the range of ship calls between hundreds to thousands of units with the EQ score consistently high with the average above 80 for a decade. This condition can possibly happen if the public environment plays a vital role for improving port sustainability (Shen et al., 2024).

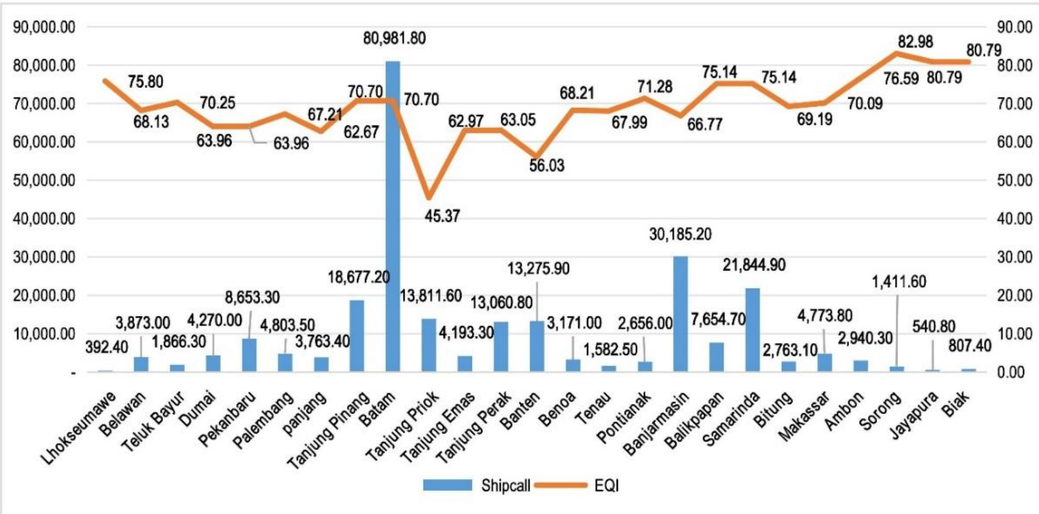

Fig. 2. Average ship calls and EQI score in 10-year period

The complex correlation between EQI and Ship calls over the ten years period reveal that there are several ports having the average high frequency of ship. It is found in Batam, Banjarmasin and Samarinda. In the most significant average, Batam port is counted to have 80981 units with EQI around 70 which are categorized as good indices. Tanjung Priok port has relatively average units but its EQI has been identified as having the lowest value over a period. Other port records to have the lowest average Ship calls such as the port of Lhokseumawe (392.4) and Jayapura (540.8) have good EQI score.The ten-year average analysis clearly identifies that the Environmental Quality Index (EQI) scores are better than in the Eastern Indonesia region compared to those recorded in the western area. This phenomenon suggests that port activity may not automatically lead to environmental degradation, and there must be a further investigation regarding these findings. Figure 2 illustrates the average Ship calls and EQI trend in 2014 - 2023.

The overall findings suggest that the correlation is not always absolute, as high EQI scores demonstrated in statistical tests do not necessarily align with conventional assumptions. Prior research focusing on the relationship between transportation infrastructure and environmental pollution also reveals a weak nexus between these variables (Tiwari et al., 2020). This evidence highlights the complexity of environmental degradation in port areas, particularly in ports with high ship call frequency and in areas exhibiting the lowest EQI levels. The need to examine cause-and-effect relationships suggests that the observed statistical trends may extend beyond direct shipping activities, encompassing factors such as operational efficiency, regulatory enforcement, and environmental management practices.

3.3 Granger causality test between ship calls frequency and environmental quality index

This study aims to investigate the causal dynamics between the frequency of ship calls and EQI in 25 major Indonesian ports by using the Granger Causality test over a ten - year period (2014-2023). The results show less significant causal relationships at 5% and 10% level in a few of Indonesia's strategic port areas, and are not uniformly distributed. This research may contribute to the first known attempt to analyze the predictive cause-and-effect relationship between Ship calls and the EQI at the provincial level in Indonesia using the Granger Causality method. The selected port is categorized as the main ports across Indonesia, this variable is also based on regulation of the ministry of transportation and Statistics agency. The selection criteria ensure the robustness representation of the national shipping network including major coastal and river ports. To show the more comprehensive spatial insight, the ports are categorized into Islands corridors: Sumatra to Papua with more than 20 ship trajectories. This diversified spatial framework ensures the research findings reflect Indonesia's maritime challenges from west to east.

To evaluate the dynamic relationship between ship calls and environmental quality, this study applies the Granger Causality test. The analysis was conducted on 25 strategic ports across Indonesia, which were selected based on the annual Statistics of Transportation published by Statistics Indonesia (BPS) and based on the regulation from the Ministry of Transportation. These selected ports are generally identified as the major ports across Indonesia, capable of representing port activity from the western to the eastern parts of the country. Concurrently, the EQI has been widely used as the environmental indicator, offering a comprehensive insight into environmental quality at the province level. The data used to construct this generalized environment quality index have been meticulously calculated from the Ministry of Environment and Statistics Indonesia (BPS). This study evaluates two potential causal directions: whether the frequency of ship calls influences the Environmental Quality Index (EQI), and conversely, whether environmental quality affects ship traffic.

The result of p-values established by Gujarati and Porter (2009) describes three potential correlations: unidirectional causation, bidirectional causality, or independence/ no relationship. The analysis of the Granger Causality test outlines the dynamic relationship between Ship calls volume and EQI, this is fundamentally classified into three distinct relational patterns based on the statistical significance of p-values in relation to the predetermined 5% and 10% thresholds. Firstly, unidirectional (One-Way) Causality is established when the p-value of only one variable either Ship calls or EQI is predicted to have statistically significant at or below the 5% or 10% level, indicating that one variable can predict the other, but not the reverse, thereby it is generally demonstrating a strictly one-directional relationship. Secondly, Feedback or Bilateral Causality is established if the p-values for both variables exhibit in two directions of statistical significance, ideally at or below the 5% threshold, indicating a mutual, reciprocal relationship where both Ship calls and EQI can predict each other. Thirdly, Independence or No Relationship is definitively established when the probability values for both Ship calls and EQI are statistically insignificant, exceeding the 5% and 10% coefficient thresholds, thus indicating the variables are independent and less predictive.

The analysis of the Granger Causality test results, designed to elucidate the dynamic relationship between Ship calls volume and the Environmental Quality Index (EQI), is primarily classified into three distinct relational patterns based on the statistical significance of the probability values (p-values) in relation to the established 5% and 10% thresholds. Firstly, Unidirectional (One-Way) Causality is established when the p-value of only one variable (either Ship calls or EQI) is statistically significant at or below the 5% or 10% threshold, indicating that one variable can predict the other, but not the reverse, thereby confirming a strictly one-directional relationship. Secondly, Feedback or Bilateral Causality is established if the p-values for both variables exhibit concurrent statistical significance, ideally at or below the 5% threshold, thereby indicating a mutual, reciprocal relationship in which both Ship calls and EQI can predict one another. Independence or No Relationship is definitively established when the probability values for both Ship calls and EQI are statistically insignificant, exceeding the 5% and 10% coefficient thresholds, thereby indicating that the variables are independent and lack a discernible predictive relationship. This study employs significance levels of 0.05 and 0.10 as primary thresholds to rigorously ascertain predictive causality between Ship calls and environmental quality, facilitating a thorough evaluation of the causal relationship within both stringent (5%) and marginally supportive (10%) confidence intervals, consistent with standard methodologies for analyzing macroeconomic or policy-sensitive data trends. Table 1 describes the model estimation derived from a decade of analysis.

Table 1. Overall Result of model estimation result of Causality Granger test in 25 strategic ports in Indonesia 2014 - 2023

Ports	Provinces	PValue		Statistical interpretation
		Ship calls - EQI	EQI - Ship calls	
Lhokseumawe	Aceh	0.0908**	0.1142	One-way relationship
Belawan	North Sumatra	0.2340	0.7446	No relationship
Teluk Bayur	West Sumatra	0.1534	0.9980	No relationship
Dumai Pekanbaru	Riau	0.3246	0.0972**	One-way relationship
Palembang	South Sumatra	0.1741	0.1520	No relationship
panjang	Lampung	0.0683**	0.8674	One-way relationship
Tanjung Pinang Batam	Kepulauan Riau	0.4088	0.2878	No relationship
Tanjung Priok	DKI Jakarta	0.3862	0.9021	No relationship
Tanjung Emas	Central Java	0.5111	0.8706	No relationship
Tanjung Perak	East Java	0.3797	0.5235	No relationship
Banten	Banten	0.0324*	0.3583	One-way relationship
Benoa	Bali	0.9811	0.3346	No relationship
Tenau	NTT	0.9924	0.2996	No relationship
Pontianak	West Kalimantan	0.1776	0.5439	No relationship
Banjarmasin	South Kalimantan	0.5526	0.5926	No relationship
Balikpapan Samarinda	East Kalimantan	1.0000	0.6180	No relationship
Bitung	North Sulawesi	0.0699**	0.0899**	Bilateral causality
Makassar	South Sulawesi	0.1156	0.7254	No relationship
Ambon	Maluku	0.0085*	0.0554*	Bilateral causality
Sorong	West Papua	0.7745	0.0967**	One-way relationship
Jayapura Biak	Papua	0.8142	0.8408	No relationship

*Significant at 5%**
*Significant at 10%***

Generally, the Granger Causality test between EQI and ship calls in 25 strategic ports in Indonesia shows limited statistical significance, with only two ports exhibiting a predictive causality between the variables at the 5% significance level. The details of the overall result can be seen on Appendix. Ambon Port demonstrates a bilateral relationship, indicating that ship calls affect environmental quality (0.0085), and may also be influenced in return (0.0554). There is also a one-way predictive relationship at Banten Port (0.0324), where ship calls can be predicted to have a significant impact on environmental quality. From the perspective of a 10% significance level, Bitung Port depicts a potential bilateral relationship with p-values less than 10% on both sides: 0.0699 (ship calls - EQI) and 0.0899 (EQI - ship calls). Other ports, such as Panjang (0.0683), Lhokseumawe (0.0908), and Sorong (0.0967), indicate signs of a causal effect from ship activity on environmental quality.

Overall statistical tests show that 14 areas (have still predicted in categories of independent causality, and 7 areas have predicted to have a causal relationship between EQI and ship calls. In certain ports there is a possible cause of ship calls to the environmental quality and vice versa, whereas many ports have no significant connection on the number of ship activities to the environment and the environment quality may not affect the ship traffic to the 14 areas. These findings may imply that ship calls tend to have a greater impact on environmental quality, rather than the other way around. In fact, the density of maritime traffic is likely to cause measurable increases of environmental quality such as: air and water pollution and other environmental disturbances. These findings can offer critical insights for the formulation of environmental policies in port areas where the regulation is essential to support environmentally sustainable port operations. Figure 3 illustrates the effect of each variable based on the probability value result and its spatial distribution.

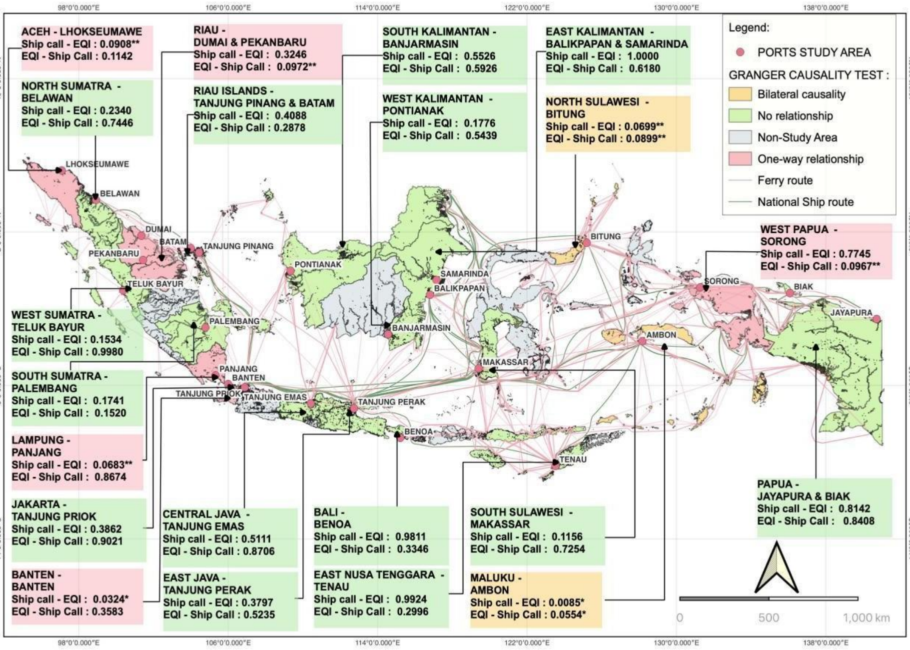

Fig. 3. Map of p-value distribution

The geographical patterns based on the visual map of Figure 3 reveal an interesting contrast. The Eastern region exhibits the clearest causal relationship at the statistical threshold, indicating a more significant impact, while causality in the Western region is largely restricted to a one-way relationship. This indicates the environmental impact may not solely be determined by the shipping activity, another finding reveals that some ports show a clear causal link, the dominance of areas exhibiting independent causality suggests that factors beyond direct shipping activity play a more significant role in determining actual environmental quality. These factors likely include port operational efficiency (e.g., waste and bunker handling), regulatory enforcement (zero-emission or low-sulfur regulations), and the port's own geographical characteristics. The environmental degradation is also caused by multi-dimensional factors of port management and operational practices and not just a shipping movement (Lam & Notteboom, 2014). The environmental risk is heavily influenced by the local factors and depends on the geographical characteristics including the typical ecosystem and ecological risk zones (Darbra et al., 2009). Therefore, effective environmental policy must not just focus on restricting vessel traffic but must adopt a multivariate approach that targets overall port operational practices to target the port sustainability. Future research needs to delve deeper into these specific internal and external port factors to develop mitigation strategies that are more geographical targeted, and sustainable for the Indonesian maritime sector.

3.4 Policy implication

On the global and national scale, the regulation of shipping activity throughout the environment has significant responsibility. The International Maritime Organization (IMO: 2023) has mandated the total decarbonization efforts of the shipping industry to the impact of climate change (Goal 13). Their regulation mentioned about the technical and operational instrument to reduce the greenhouse gas emission resulting from the shipping activity. For example, shipping uses ultra-low-pollution fuels to protect the coastal area. The importance of robust operational risk management can prevent major environmental disasters such as oil spills which has the potential to compromise all progress toward sustainability (Nguyen et al., 2019). Hence, in the global responsibility, the mandate of IMO is crucial to reduce the operational management risk in maritime shipping. A study to understand the causal interaction between shipping activity and environmental quality is needed to address the global challenge of maritime sustainability.

In the national context, it is yet clear that the overall predictive causality has less significance except in a few specific ports. The maritime environmental policy implications in Indonesia must be aligned with the existing regulatory framework, where Law No. 17 of 2008 on Shipping mandates the integration of environmental aspects into every Port Master Plan (RIP). This policy is reinforced by Ministry of Transportation Regulation No. PM 51 of 2015, which explicitly enforces the implementation of Sustainable Ports (EcoPort). The statistical findings from the Granger causality test provide critical empirical justification for adopting a geographically targeted (non-uniform) policy approach. This is important to increase the competitiveness of the nation's global sea trade. Indonesia is seemingly to not optimally utilize the international trade by sea with low competitiveness value (Ariadno et al., 2014). The study by Praharsi et al. (2025) outlines Key Performance Indicators (KPIs) for sustainable ports in Indonesia. Their research remarks "Environment" as a critical pillar of sustainable performance, integrating Green Port criteria and Political, Economic, Social, Technological, Legal (PESTL) factors. Instead of using a single, overall macroeconomic index like the EQI, the KPIs for this dimension look at operational and measurable metrics like port energy use (electricity and fuel), emissions tracking (NOx, SOx, CO2, PM), and how well hazardous and non-hazardous waste is managed. However, the EQI does not yet include these indicators. Thus, the idea of combining the EQI with the KPI can help the IMO's (2023) international mandate that ships must lower their emissions as the main rule for port operators.

The research findings indicate that the correlation between ship call frequency and the Environmental Quality Index (EQI) is not always linear or absolute. These results provide strong empirical support for Indonesia's Green Port regulatory framework in promoting sustainable maritime transportation. Spearheaded by the Ministry of Transportation through Regulation PM 51 of 2021 and the Green Port Criteria, this policy appropriately shifts the focus away from restricting vessel traffic and toward improving environmental management practices within port operations. Instead, the regulation justifies the necessary shift in focus towards factors that our research identified as more significant determinants of EQI, such as energy efficiency, proper waste management, and air/water quality control stemming from overall port operations. Consequently, these multidimensional and detailed Green Port criteria, rather than merely ship quantity, constitute a valid and appropriate policy strategy for effectively managing the complexity of environmental causality in Indonesian port areas (Lalla-Ruiz et.al, 2019).

Ports that demonstrate a one-way causality between Ship Calls and EQI, such as Banten, Panjang, Lhokseumawe, and Sorong, can be prioritized for the full implementation of Green Port standards because ship activity in these locations acts as a significant driver of environmental risk. In contrast, ports exhibiting bilateral causality, such as Ambon and Bitung, require a dual policy approach. This approach involves enforcing stricter regulations on incoming vessels, for example through emission standards to control pollution, while simultaneously establishing the Environmental Quality Index (EQI) as a binding Key Performance Indicator (KPI) for managerial performance. The latter is particularly important because causality running from EQI to Ship Calls indicates that environmental quality has become a direct predictor of port traffic and competitiveness. Meanwhile, ports with no significant causal relationship can proactively utilize EQI baseline data as a preemptive strategy to anticipate future traffic growth. This approach aligns with the principle of sustainable operational optimization without substantial investment (Haris, 2017). Although these statistical findings provide an initial foundation for policymaking, they require further empirical testing and in-depth analysis to strengthen and validate the statistical evidence.

There are several supporting arguments on how EQI can impact ship calls in terms of port management and regulation. Firstly, if the EQI score declines, the government must enforce strict regulations on ship calls in the affected port area. This will lead to a decrease in shipping activities, which consequently results in an economic decline. Secondly, the decline in EQI will likely affect the sea or river that is part of the ship's trajectory, which will disrupt the loading and unloading process so that many ships will avoid the impacted port. Lastly, when the EQI drops, the port's reputation will also decline, thus it will reduce the number of visiting ships. Policy instruments for port management can contribute to better safety for ships. Therefore, a policy instrument for port management is needed to contribute to better ship safety. To achieve this safety without sacrificing development, these instruments must be designed carefully. This makes sure that environmental standards don't get in the way of future port growth and executive authority (Praharsi et al., 2023).

Basically, these statistical findings in the model used is to offer the preliminary evidence only for spatial distribution of 25 ports to be more geographically described, and only proves the directions but not necessarily lead to the significant influence of EQI and Ship calls. The future step is needed to quantify the more empirical evidence into operational strategies by deeply investigating the port management and regulation. Qualitative insight is also important to ensure statistical finding is more effective and relevant. As well as its policy to regulate vessel pollution and elevating EQI to a binding Key KPI to ensure environmental standards based on the sustainable green port concept but still do not hinder competitiveness.

4. Conclusions

In response to the core research question on whether there is a causal dynamic between Ship calls and EQI, the statistical analysis confirmed this relationship. Though the causal link is less significant at the 5% and 10% levels in several of Indonesia's strategic port areas, and is not uniformly distributed. The research found a bilateral causality, where Ship calls are predicted to cause EQI and vice versa, was found in the ports of Ambon and Bitung. Meanwhile, unidirectional causality from Ship calls to EQI was observed in the ports of Banten, Aceh, and Lampung, and from EQI to Ship calls was found in Riau and Sorong. The overall statistical results indicate that 14 port areas still fall into the category of independent causality, while seven areas are predicted to have a significant causal link between the EQI and ship calls volume. Although a potential bidirectional causal link exists in certain ports, the majority (14 areas) demonstrate no significant connection, which means that in general, the volume of ship activity does not affect the environment, and conversely, environmental quality does not influence ship traffic. This evidence suggests that Ship calls tend to have a clearer predictive impact on environmental quality than the reverse scenario.

This research provides an empirical basis for a differentiated policy approach, suggesting that port operators consider green port standards (Haris, 2017). Although the Environmental Quality Index (EQI) is not always explicitly listed as a singular KPI in current Indonesian models (Praharsi et al., 2025), its role as a critical indicator for 'Environment' remains significant. Integrating EQI into port monitoring could offer preliminary support for IMO (2023) mandates on emission reduction. For ports where statistical tests were insignificant, these findings can still encourage a precautionary approach, using the EQI as a baseline to monitor potential environmental degradation from future ship traffic.

This paper serves as preliminary evidence regarding the environmental impacts of maritime activity in Indonesia through shipping activity. The authors also acknowledged several limitations of this study, including those related to the empirical statistical data and the research methodology. Firstly, the findings serve only for initial justification and should be verified with future in-depth primary surveys to support the results. Secondly, this research uses a simple methodology and was only designed to test the predictive causality between ship calls and EQI using secondary data provided by government institutions. Therefore, for more comprehensive insight, future studies should consider incorporating other statistical methods for comparison, as well as investigating the policy implications in more detail regarding the trend of maritime transportation's effect on the environment.

This includes an in-depth study on the integration of the EQI into the performance metrics of sustainable port operations. This is in line with the global mandates from IMO concerning total decarbonization and supports the national effort toward achieving sustainable port development. Further research plans may include strengthening these findings by conducting research in other types of ports (e.g., tankers, passenger ships, etc.).

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Author Contribution
The authors contributed to the data acquisition, analysis, and interpretation in this study. Conceptualization: N.H.D; Methodology: N.H.D, A.B.S; Data Curation: N.H.D; Writing – Original Draft Preparation: N.H.D; Review, Supervision: A.B.S. All authors have read and agreed to the published version of the manuscript.

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