

Ship Decarbonization Strategies Based on MARPOL Annex VI Regulations

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Abstract: Decarbonizing maritime shipping in Indonesia presents both challenges and opportunities for achieving sustainable development goals aligned with the "Golden Indonesia 2045" vision. Goods transport is a vital sector of the Indonesian economy, yet it currently relies heavily on fossil-fuel-based systems that contribute significantly to carbon dioxide (CO₂) emissions. This study aims to identify the challenges of establishing a low-carbon maritime freight transport system and the opportunities arising from implementing decarbonization measures within this sector. Through interviews and direct observations of vessels docked at Tanjung Priok Port, the study assesses current vessel conditions and carbon emission levels, while also outlining potential opportunities by examining global trends in freight transport decarbonization. Key data regarding fuel consumption and the implementation of zero-emission practices were collected. The most cost-effective shipping decarbonization measures depend on factors such as fuel type, trade routes, and operational profiles. Achieving a successful transition to a more environmentally friendly shipping sector requires a combination of new technologies, operational strategies—such as route optimization and "slow steaming"—and regulatory measures.

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INTRODUCTION

In press release number 287.Pers/04/SJI/2024, the Ministry of Energy and Mineral Resources (ESDM) identified the transportation sector as the largest contributor to greenhouse gas (GHG) emissions in 2024. Globally, the transportation sector accounts for one-third of total emissions, with road transport alone responsible for one-sixth. In Indonesia, transportation accounts for one-third of final energy consumption, a significant portion of which is attributed to freight transport. Freight transport in Indonesia utilizes various modes—including trucks, trains, aircraft, and ships—to facilitate the movement of goods across the archipelago. These modes remain heavily reliant on fossil fuels; trucks, in particular, emit over 50 million tons of CO₂ (Ministry of Energy and Mineral Resources, 2024). This has environmental consequences, as poor air quality directly impacts public health. GHG emissions are a contributing factor to the decline in air quality—an issue that has been a matter of concern since 2014. Six major Indonesian cities Palembang, South Tangerang, Bandung, Cileungsi, Jakarta, and Surabaya—have recorded unhealthy air quality indices (IQAir, 2023). In response to this situation, the Indonesian government issued Government Regulation No. 79 of 2014 concerning the national energy policy, which serves as the framework for the energy transition (CNBC Indonesia, 2022).

The maritime transport industry accounts for 2–3% of global greenhouse gas (GHG) emissions annually (Schnurr and Walker, 2019; Walker et al., 2019; Walker, 2019). The shipping industry is projected to grow at an average annual rate of 2.1% over the next four years (UNCTAD, 2023) and

faces significant pressure from stakeholders and the International Maritime Organization (IMO) to reduce GHG emissions in alignment with the Paris Agreement. Regulations and policies are also driving the net-zero agenda for the shipping and port sectors. To meet the ambitious climate goals set out in the Paris Agreement, urgent action is required from the shipping sector to reduce carbon dioxide (CO₂) emissions (Traut et al., 2018). In line with this objective, the maritime transport sector aims to achieve significant reductions in CO₂ emissions; however, further measures are urgently needed to meet these ambitious targets (Halim et al., 2018).

The IMO has implemented various regulations to combat air pollution based on the mandate received through the Kyoto Protocol (Dong et al., 2022). The IMO's strategy to reduce greenhouse gas emissions from international shipping aims for a 20% reduction by 2030 and a 70% reduction by 2040 compared to 2008 levels, with a goal of reaching 100% reduction by 2050 (Alamouch et al., 2023). Consequently, decarbonization of the maritime industry is essential, particularly regarding emission reductions and the transition to cleaner energy sources (Prados, 2024). The concept of net-zero emissions has become increasingly important as the industry strives to minimize its carbon footprint, eliminate greenhouse gas emissions, and combat climate change. Ports can play a pivotal role in decarbonizing the maritime transport supply chain by adopting alternative marine fuels (low-carbon or zero-carbon) and developing modern, energy-efficient infrastructure to support these initiatives (Schnurr and Walker, 2019; De Manuel-López et al., 2024). While the industry possesses numerous implementable solutions and opportunities to achieve net-zero, the decarbonization process faces significant challenges and is unlikely to proceed without obstacles (Walker, 2019; Walker et al., 2019).

This study aims to determine the extent to which the shipping industry contributes to carbon emission reduction within the territory of the Republic of Indonesia. While many existing studies focus on the legal frameworks applied in Indonesia, there is limited research regarding carbon emissions—specifically CO₂ from ship engine exhaust—and the associated mitigation measures. Therefore, this study seeks to assess the condition of vessels docking at Tanjung Priok Port and examine how they comply with IMO regulations concerning ship engine exhaust emissions.

RESEARCH METHOD

This study was conducted at Tanjung Priok Port, focusing on vessels docked at the facility. The research involved collecting key data regarding the vessels' fuel consumption systems and the implementation of zero-emission practices. Data collection involved observation to determine the vessel's fuel consumption levels; this technique aimed to gather data directly at the site where the issue occurred. Additionally, an interview method was employed, in which the author directly consulted the Chief Officer and the Captain regarding strategies to optimize fuel usage. CO₂ emission load calculations were performed using the 2019 IPCC Tier 1 method.

The initial step involved determining fuel consumption based on the vessel's Gross Tonnage (GT). Subsequently, the fuel consumption derived from the previous calculation was converted into energy units—specifically, terajoules (TJ).

Energy Consumption (TJ) = Fuel Consumption (kg) × Calorific Value (TJ/Gg). Then, the fuel consumption value is multiplied by the emission factor to determine the amount of CO₂ produced. Emissions = Energy Consumption (TJ) × Emission Factor (kg/TJ).

RESULTS AND DISCUSSION

Pressure to address decarbonization challenges is mounting, driven by a variety of factors. Companies with clear decarbonization strategies can effectively tackle both practical and reputational challenges while achieving higher total shareholder returns. This success is driven by revenue growth, cost reductions, and expanded valuation multiples. In the discussion part, the author should explain the meaning, context, and implications of the results in an analytical and critical manner. Link the findings to relevant theories and previous studies—both supporting and contrasting—to demonstrate the study's academic contribution and its position within the existing body of literature. Describe how the findings answer the research questions or achieve the study's objectives, while highlighting the research's novelty and contributions to theoretical development and practical advancement in engineering.

Throughout 2025, a total of 14,169 ships docked at Tanjung Priok Port, generating approximately 3,110,023 tons of CO₂ emissions. This figure accounts for 0.2% of global greenhouse gas emissions and underscores the critical need to mitigate the adverse effects of rising global temperatures and extreme climate change—impacts partly driven by carbon emissions from ship exhaust (Chatzinikolaou & Ventikos, 2015). Given the high volume of vessel activity at Tanjung Priok Port, researchers collected data on ships docking there during May and June 2026 to determine the amount of CO₂ emitted by each individual vessel; these findings are presented in Table 1.

Table 1. Vessels Docking at Tanjung Priok

No	Time to Lean On	Ship Name	Vessel Type	LoA (m)	Ship's Flag	Fuel Cons (KI/d)
1	6/28/2026 2:00	GELBRAY EXPRESS. MV	Livestock Carrier	135.0	Madeira	26
2	6/24/2026 9:00	MERATUS KARIMUN	Container	124.4	Indonesia	22
3	6/18/2026 2:00	TANTO SEHATI	Container	120.05	Indonesia	23
4	5/31/2026 8:00	OCEAN GOLD	BC	228.99	Singapore	31
5	5/30/2026 22:00	STARSHIP JUPITER	Container	196.16	Liberia	23
6	5/21/2026 14:00	MERATUS LEMBATA	Container	123.6	Indonesia	23
7	5/12/2026 4:00	MERATUS KUMAI	Container	124.4	Niue	24
8	5/11/2026 18:00	MSC CAPETOWN III	Container	222.16	Portugal	26
9	5/10/2026 17:00	MERATUS GORONTALO	Container	161.85	Indonesia	31
10	5/10/2026 8:00	OCEAN PERKASA	BC	228.99	Singapore	29
11	5/5/2026 1:00	GLOUCESTER EXPRESS	Livestock Carrier	134.8	Portugal	26
12	5/1/2026 18:30	BANGKOK HIGHWAY	Vehicles Carrier	179.99	Japan	31
13	4/29/2026 12:00	OCEAN SUKSES	BC	199.99	Singapore	31
14	4/26/2026 20:00	MSC BAY IV	Container	260.05	Liberia	24

Interviews conducted with vessels docked at Tanjung Priok Port yielded the results presented in Table 1. Exhaust emission levels were assessed through these interviews to identify implementable initiatives for carbon reduction (decarbonization), in accordance with IMO directives. These initiatives could also serve as targets for Indonesia's contribution to curbing the rise in global temperatures through decarbonization efforts aimed at achieving zero emissions for vessels—which are significant sources of pollution in Indonesian waters.

The formulation of strategies and frameworks for reducing carbon emissions (decarbonization) from vessels operating and docking at Tanjung Priok Port in this study represents a collaborative effort. This initiative involves various stakeholders in Indonesia, including business entities (ship owners and operators), the Indonesian government, and the IMO. The strategies are based on the IMO's carbon management guidelines and greenhouse gas reduction framework, originally published in 2018 and updated in 2020. This study utilizes Gross Tonnage (GT) as the vessel size metric; GT represents the total volume of all enclosed spaces within a ship (rather than physical weight or cargo capacity). Statistically, there is a linear or proportional relationship between GT value and daily fuel consumption. Vessels with higher GT ratings consume more fuel to generate the same propulsive power or transport larger cargo loads, resulting in higher total carbon emissions. Furthermore, different types of marine fuel possess varying carbon contents and emission factors per ton of fuel consumed.

Table 2. Emission Mitigation from Ships Docked at Tanjung Priok Port

Ship Name	GT	Fuel Consumption (TJ/year)	Emission (Ton CO ₂)
GELBRAY EXPRESS. MV	10421	5237	16,287.07
MERATUS KARIMUN	7568	3952	12,290.72
TANTO SEHATI	6812	3785	11,771.35
OCEAN GOLD	48245	12289	38,218.79
STARSHIP JUPITER	27997	4789	14,893.79
MERATUS LEMBATA	8588	4329	13,463.19
MERATUS KUMAI	7568	3888	12,091.68
MSC CAPETOWN III	38900	13875	43,151.25
MERATUS GORONTALO	13444	5766	17,932.26
OCEAN PERKASA	48245	12396	38,551.56
GLOUCESTER EXPRESS	10421	5335	16,591.85
BANGKOK HIGHWAY	48936	11873	36,925.03
OCEAN SUKSES	34578	10652	33,127.72
MSC BAY IV	39491	11211	34,866.21
Total	351,214.000	109,377.000	340,162.47

Table 3. Total Average Emissions from Ships Docked at Tanjung Priok Port

SUMMARY METRICS	
Total Vessels	14
Total GT	351,214
Total Fuel Consumption (TJ/yr)	109,377.000
Total Emission (Ton CO ₂)	340,162.47
Average Emissions per Vessel	24,297.32

Based on the data in Table 2 above, the 14 ships sampled at Tanjung Priok Port in 2026 generated a total of 340,000 tons of CO₂ emissions. These 14 vessels illustrate the high level of carbon emissions produced, particularly considering that thousands of ships dock at Tanjung Priok Port. Consequently, it is necessary to assess the impact that decarbonization initiatives—scheduled for implementation by 2030—will have on the shipping industry. This national plan aims to significantly reduce CO₂ emissions from international shipping vessels by 2030 through the use of low-carbon and zero-carbon fuels, as well as innovative energy-efficiency technologies, thereby demonstrating the impact of decarbonization initiatives in Indonesia.

International shipping plays a crucial role in decarbonization efforts. Shipping companies are employing various strategies to achieve decarbonization; this is evident from interviews and data collection involving 14 vessels docked at the Port of Tanjung Priok. Air pollution resulting from maritime trade contributes to climate change and has adverse effects on health. While clean air is essential, pollutant levels remain high—particularly in coastal areas—due to ship emissions. Through policies such as MARPOL Annex VI, the International Maritime Organization (IMO) plays a vital role in establishing international guidelines for controlling ship emissions and mitigating health risks. The IMO has implemented strict regulations regarding emission reductions under MARPOL Annex VI.

Captains and chief officers implement various measures to achieve decarbonization; one such measure is Engine Power Limitation (EPL)—a concept discussed several years ago as a method to limit engine power output by using a fuel index limiter. This concept originated from the "slow steaming" technique that emerged after 2008. EPL enables CO₂ emission reductions by limiting the main engine's Maximum Continuous Rating (MCR) during voyages. A study on CO₂ intensity in international shipping reported that operating at low loads can reduce CO₂ emissions by 30% (Rissman et al., 2020). Energy Saving Devices (ESDs) have been classified into categories A, B, and C based on MEPC guidelines (IMO, 2021c); Category A relates to propulsion power or vessel speed, taking into account rudder resistance and propeller design. The Propeller Boss Cap Fin (PBCF) is an example of a technology designed to enhance propulsion efficiency. Category B relates to reducing propulsion power without involving electricity generation. An air lubrication system is a technology that injects air bubbles beneath the ship's hull to reduce propulsion resistance. Category C encompasses technologies for generating electricity through waste heat recovery processes.

The selection of eco-friendly technologies for a shipping fleet should be based on Marginal Abatement Cost (MAC). MAC represents the cost of reducing one ton of greenhouse gases, encompassing both operational expenses and the necessary equipment. If a technology's average MAC value is negative—indicating economic viability—it is considered promising for "green ships." Selected

technologies include main engine upgrades, air lubrication systems, and propeller enhancements. Furthermore, even if the average MAC value is positive, alternative marine fuels remain worth considering to achieve the goal of green shipping (Oliveira et al., 2022).

Maritime fuel regulations are constantly evolving, creating uncertainty regarding fuel standards and potential carbon taxes, which makes companies hesitant to invest in eco-friendly technologies. Low-carbon fuels can have a high carbon footprint during their production process; for instance, producing hydrogen fuel via steam methane reforming or electrolysis powered by fossil fuels is carbon-intensive. When considering only combustion-stage emissions, LNG ranks among the top options for carbon reduction potential, theoretically capable of lowering carbon emissions by 25% and 10%, respectively, compared to conventional fuel oil. However, this reduction potential diminishes significantly when methane leakage and upstream emissions are factored in. Therefore, to achieve carbon-neutral shipping while accounting for full lifecycle emissions, the adoption of carbon-free or carbon-neutral synthetic fuels and biofuels has become an inevitable trend.

Biofuels are fuels produced from organic matter, such as plant materials and animal waste. Advanced biofuels are produced by extracting fuel from materials like wood, cultivated crops, and waste. Biofuels can exist in solid, gaseous, or liquid forms. Advanced biofuels hold significant potential for reducing CO₂ emissions; depending on the quality, type, and processing method of the feedstock, they are estimated to reduce CO₂ emissions by 25% to 100% for high-quality varieties. Furthermore, the use of biofuels results in very low sulfur emissions. However, biofuel supplies may be insufficient to power the entire shipping fleet. Current biofuel supplies—comprising biodiesel and bioethanol—can meet only about 15% of total demand (IEA, 2017). Consequently, biofuels can serve as an energy source for only a small fraction of the global shipping fleet. Through the implementation of mandates and fuel standards, governments can generate stable demand, thereby ensuring biofuel uptake while also influencing its availability.

Instead of using alternative fuels or replacing ship propulsion systems, the shipping industry can turn to voyage optimization (VO), which offers vital theoretical and technical insights for efficient voyage operations. VO regarding fuel consumption and greenhouse gas (GHG) emissions involves route determination—specifically, managing the vessel's trajectory and engine power across varying weather conditions. In this context, VO is treated as a multi-objective function to be minimized, while vessel movement and the Estimated Time of Arrival (ETA) serve as constraint variables. Vessel movement is typically represented by latitude and longitude coordinates, time, speed, and heading. These movement parameters, combined with environmental conditions—such as wind, waves, currents, sea water temperature, and air temperature—can influence navigation and potentially render specific routes impassable during periods of adverse conditions.

Reducing a ship's average speed can lower fuel consumption; however, this results in longer transit times. Longer transit times necessitate more vessels or additional cargo capacity, which ultimately diminishes the fuel savings achieved. Slow steaming has become a widely adopted practice for reducing vessel fuel costs. There are numerous emission-reduction techniques available (such as the kite sails discussed in the previous section), and slow steaming offers shipping companies a way to help mitigate the environmental impact of their business activities. The benefits of slow steaming depend on the vessel's type, size, route, and operational role. As previously noted, slow steaming increases transit times; however, a 10% reduction in speed can yield an average total emissions reduction of 19%, and the method is applicable to vessels of all types and sizes.

CONCLUSION

This study found that ships docking at Tanjung Priok Port have yet to fully implement measures to minimize carbon emissions, particularly regarding engine exhaust. This is largely because current ship engine technology is not yet fully optimized for carbon emission reduction. Most vessels continue to rely on conventional fuels, as hybrid engines remain costly. Consequently, shipping companies are adopting various cost-effective decarbonization strategies tailored to specific factors such as fuel type, trade routes, and operational profiles. New technologies, operational measures (such as route optimization and "slow steaming"), and regulatory actions are essential for a successful transition toward a more environmentally friendly future for the shipping sector.

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