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Research Article

Decarbonization Strategy towards Net Zero Emission for International Shipping on International Shipping Routes in Indonesian Archipelago Sea Lanes

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Abstract: International Maritime Organization (IMO) has mandated measures to address greenhouse gas emissions from international shipping. Therefore, this study aims to develop a novel initiative for collaborative decarbonization strategies involving ship operators, regulators, and the broader maritime community, as part of Indonesian efforts to mitigate carbon emissions in the shipping sector. A case study was conducted focusing on international vessels transiting through Indonesian Archipelagic Sea Lanes (ALKI). The qualitative method supported by quantitative data analysis was applied and data were collected through direct interviews with relevant stakeholders, including business actors, ship crews (operators), maritime authorities (government representatives), and coastal communities. These findings estimated that carbon emissions from 12,189 ships passing through ALKI-II amount to approximately 3,110,023 tons of CO_2 annually, with additional emissions from ships in ALKI-I and ALKI-III. In light of the absence of a comprehensive decarbonization strategy for the Indonesian maritime sector, this study proposes a framework for reducing carbon emissions toward achieving net-zero emissions for the thousands of international ships transiting ALKI each year. This proposed strategy can be incorporated into the Indonesian Nationally Determined Contribution (NDC) report to the United Nations, potentially attracting funding through grants or global Environmental, Social, and Governance (ESG) funds. This funding would support the sustainable implementation of carbon management strategies, advancing the objective of net-zero emissions.

Keywords: CO_2 Emissions; Decarbonization strategy; Environment social government fund; Indonesian Nationally Determined Contribution (NDC); International shipping

1. Introduction

In response to the United Nations Convention on the Law of the Sea agreement reached during the International Maritime Organization (IMO) session in 1982 (United Nation,1982), Indonesia ratified the convention in 1985 through Indonesia Law No. 17 of 1985. This convention established its regulations in Law No. 6 of 1996 on Indonesian Waters, which among other provisions, governs the right of transit passage for international ships and aircraft through Indonesian territorial waters and archipelagic waters (Bakti et al., 2022). These international vessels will sail from their ports of

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origin in various countries, crossing the high seas and exclusive economic zones to enter Indonesian waters through Indonesian Archipelagic Sea Lanes (ALKI) (UNCTAD, 2023).

During the IMO Maritime Safety Committee session on May 19, 1998, Indonesia approved the proposal for 3 ALKI routes, which were later regulated with rights and obligations for ships and aircraft passing through these routes, as outlined in Indonesian Government Regulation No. 37 of 2002 (Hutagalung, 2017). The primary objective of this policy is to ensure that Indonesia upholds the rights of international nations whose vessels transit through ALKI, guaranteeing their passage is safe, efficient, and unobstructed. At the same time, these international nations, as ship owners, are responsible for navigating in a manner that minimizes risks and prevents harm to Indonesia (Hidayat et al., 2019).

To facilitate the smooth flow of international maritime traffic through ALKI, Indonesia has established regulations defining the precise geographical coordinates of latitude and longitude as reference points along the axis of the archipelagic sea lanes. These coordinates are used by ship crews to plan their voyages (Hadi 2024). ALKI-1 shipping route, approximately 25 nautical miles wide, is delineated to guide vessels traveling between the South China Sea, the Natuna Sea, the Karimata Strait, and the Indian Ocean, or vice versa. ALKI-1 branch IA provides additional direction for ships navigating from the Singapore Strait through the Natuna Sea, Karimata Strait, the Java Sea, and the Sunda Strait towards the Indian Ocean, or vice versa. Alternatively, this branch accommodates routes between the Natuna Sea to the South China Sea, or vice versa. Meanwhile, for ALKI-II, the geographical coordinates set the route from the Sulawesi Sea, passing through the Makassar Strait, the Flores Sea, and the Lombok Strait towards the Indian Ocean and vice versa. ALKI-III-A guides the Pacific Ocean through the Maluku Sea, Seram Sea, Banda Sea, Ombai Strait, and Sawu Sea to the Indian Ocean and vice versa. ALKI-III-B connects the Pacific Ocean through the Maluku Sea, Seram Sea, Banda Sea, and the Leti Strait to the Timor Sea and vice versa. Finally, ALKI-III-C guides ships from the Pacific Ocean through the Maluku Sea, Seram Sea, and Banda Sea to the Arafura Sea or vice versa (President of the Republic of Indonesia, 2002).

According to reports presented in 2023, approximately 12,189 vessels from various countries around the world navigated through Indonesian ALKI II, close to the Indonesian new capital in Nusantara, East Kalimantan. There are also thousands of other vessels passing through Indonesian ALKI-I and ALKI-III routes, which are located along internationally recognized maritime routes according to the 1982 United Nations Convention on the Law of the Sea. For more than 40 years, hundreds of large vessels, some exceeding 180 meters in length and carrying various goods and passengers on long-distance voyages across oceans and continents, have been allowed to transit through these sea lanes safely and efficiently at no cost (Alamsyah and Hadi, 2023). This is in contrast to the Suez and Panama Canals, which charge commercial fees for vessels using their routes. However, the fees are offset by the benefits they provide, including significant time and fuel savings, as well as reduced operational costs compared to navigating longer routes through open seas.

When navigating through Indonesian waters along ALKI routes, vessels typically take 3 to 5 days, depending on the speed set by each captain at around 12 knots, in line with their passage plan. They are not allowed to enter the waters outside the designated ALKI routes unless for emergency reasons or specific purposes, with prior coordination with the nearest Indonesian port authorities. The existence of ALKI routes serves the same function as the Suez and Panama Canals, providing economic benefits for international vessels, particularly in terms of time efficiency and reduced operational costs, specifically fuel consumption, for ships traveling from Asia to Australia, Europe, or vice versa (Hadi, 2024).

International vessels transiting through Indonesian waters are granted the right to peaceful passage. However, they are also obligated to avoid engaging in any illegal activities that could harm, damage, or disrupt the environment and marine ecosystem, including pollution caused by ship emissions (Winebrake, 2007). Carbon emissions a significant byproduct of fuel combustion by ships, are particularly concerning for Indonesia. These emissions not only contribute to environmental degradation but are also a major source of pollutants driving global warming and extreme climate change, an issue that has drawn serious attention from IMO member countries (Seithe et al., 2020), in line with global commitments outlined in the 2015 Paris Agreement. However, to date, this issue has not been addressed seriously by stakeholders in Indonesia (operators, regulators, and the public). According to a 2020 IMO study on greenhouse gases, emissions from the shipping sector increased by 9.6% to 1,076 million tons of CO2, compared to 977 million tons in 2019. This represents an increase from 2.76% to 2.89% of total global carbon emissions (IMO, 2020). The findings should be a serious concern for IMO member countries, including Indonesia, which signed the 2015 Paris Agreement and is expected to contribute to global efforts to reduce global warming. This is particularly relevant in light of findings by the United Nations Framework Convention on Climate Change (UNFCCC) in 2023, which showed that the global temperature has increased significantly in the last decade, by 1.1°C. This trend is expected to exceed 1.5°C and could reach up to 2°C if global climate action is not taken seriously, including in the shipping sector

To support the global goal of reducing greenhouse gas emissions, specifically in the shipping sector, IMO has developed a decarbonization strategy that is regularly reviewed and updated. On July 7, 2023, IMO issued guidelines for achieving emission reduction targets under MARPOL Annex VI regulations (IMO,1991) and during the 80th meeting of the Marine Environment Protection Committee (MEPC). These efforts are primarily focused on improving energy efficiency for ships built after 2015, to achieve a 40% reduction in carbon emissions by 2030 compared to 2008 levels. Additionally, the transition towards zero-emission shipping is prioritized through support for alternative technologies, fuels, and energy sources, targeting a 5% to 10% reduction by 2030. Long-term strategies are aligned with achieving zero-emission shipping by 2050, including intermediate greenhouse gas reduction goals of 30% by 2030 and 70% to 80% by 2040.

In 2020, the Institute of Environmental Management and Assessment (IEMA) presented a study on the Hierarchy of Carbon and Greenhouse Gas Management, which is highly relevant to IMO strategy for achieving low-emission and zero-emission shipping through sustainable practices. The carbon and greenhouse gas management hierarchy can be explained through four stages (IEMA, 2020).

Efforts to address carbon and greenhouse gas emissions in the shipping sector can be categorized into four key strategies such as elimination, reduction, substitution, and compensation. Subsequently, elimination involves transitioning to measures that avoid emissions altogether, such as using an Onshore Power Supply (OPS) at ports to prevent fuel consumption while ships are docked (Nevers, 2000). Reduction focuses on minimizing emissions through operational excellence, technical enhancements on vessels, and adopting advanced technologies and digital solutions to improve energy efficiency, leading to lower fuel consumption or utilizing emission-filtering and capture/storage technologies (Taptich, 2015). Substitution emphasizes the use of low-emission energy sources, including non-fossil fuels such as LNG, biodiesel, hydrogen, and ammonia, as alternatives to traditional fossil fuels (IEMA, 2020). Compensation addresses residual emissions through carbon offset mechanisms, the development of carbon markets, or the implementation of carbon taxes to balance and mitigate environmental impacts (Aisyah *et al.,* 2020).

IMO as the leading organization for maritime shipping has provided guidance and frameworks to be implemented by all countries worldwide to reduce greenhouse gas emissions, specifically, carbon emissions from ships, with targets to reduce them by 40% by 2030 and 50% by 2050, based on the 2018 level of 1,076 million tons of CO2, which accounted for 2.96% of global greenhouse gas emissions (Budiyanto et al., 2022). IMO and IEMA carbon management guidelines offer valuable references for Indonesia, as an IMO member, to select appropriate strategies to manage and control carbon emissions from international vessels passing through Indonesian waters, particularly along ALKI routes.

Indonesia, as an IMO member and signatory to the 2015 Paris Agreement, is expected to undertake various initiatives to support climate change mitigation efforts in line with global

Sustainable Development Goals (SDGs). However, the current issue is that initiatives have been limited to studies and adaptation efforts for land-based pollution sources, not maritime sources. There has been no comprehensive study on the maritime sector, particularly on the international shipping traffic in Indonesian waters. Therefore, this study aims to comprehensively examine strategies that could serve as collaborative initiatives among Indonesian stakeholders to reduce carbon emissions (decarbonization) towards net zero emissions for international vessels passing through ALKI.

These findings address the critical issue of a lack of comprehensive studies on efforts and strategies for achieving decarbonization and net zero emissions from the thousands of internationally flagged vessels transiting through ALKI. Based on the gap, this study aims to elaborate a novel initiative for collaborative decarbonization strategies among ship operators, regulators, and the maritime community as part of Indonesian broader carbon management efforts in the shipping sector. In 2023, these vessels generated a potential carbon emission of 3,110,023 tons of CO_2, equivalent to 0.2% of global greenhouse gas emissions, which could serve as one of the Indonesian Nationally Determined Contribution (NDC) in addressing climate change caused by ship emissions.

2. Methods

This study is conducted using a qualitative method supported by quantitative data analysis. Qualitative data is obtained by gathering information through direct interviews with relevant informants who align with the topic, including business actors, ship crews (ship operators), maritime authorities as government representatives (regulators), and coastal communities. The structured method in this study is shown in Figure 1.

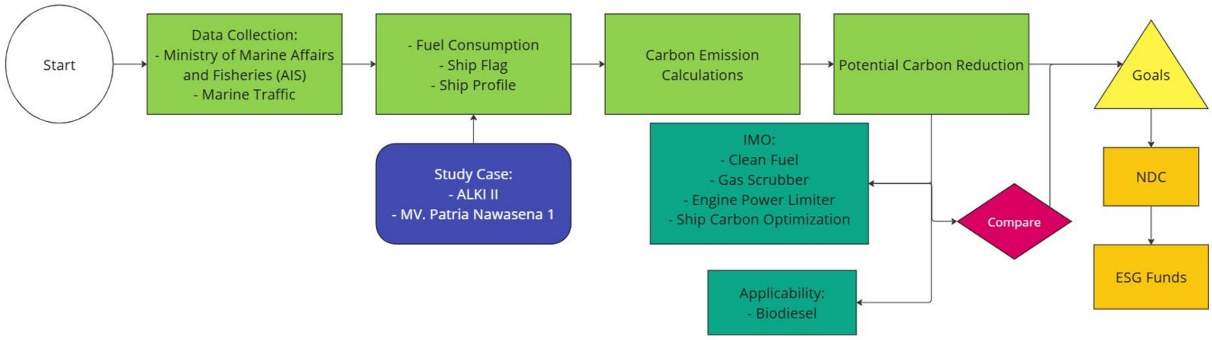

Figure 1 Flow Diagram Study Method.

This study explored possible initiatives and decarbonization strategies that can be implemented for international vessels to reduce carbon emissions resulting from the combustion of fuel, as outlined in IMO guidelines. The initiatives are based on extensive literature reviews, particularly focusing on IMO decarbonization strategy guidelines, with a focus on carbon management towards achieving zero emissions.

The informants selected include maritime industry professionals with expertise in ship design and construction, ship operation, and fuel management. The information gathered and data will be strengthened by conducting an emic study/field observation directly in the Lombok Strait on the ALKI II route in February and March 2024, as well as in-depth interviews with the crew of Indonesian-flagged bulk carrier MV Patria Nawasena 1. The vessel operating on ALKI II has similar specifications to those of international ships passing through ALKI.

To support the interviews and analysis, the quantitative data gathered was processed. This data was obtained from ship traffic crossing ALKI II in 2022, collected through satellite tracking using the Marine Traffic (2022) application and other sources from the Directorate of Navigation at the Directorate General of Sea Transportation, Ministry of Transportation of Indonesia, 2023, as the authority responsible for regulating vessel navigation in Indonesian waters. Vessel specification data analyzed includes vessel type, size, fuel consumption data, and daily consumption standards according to shipyard references. Using the carbon emissions calculation formula from previous studies, the potential carbon emissions produced by international vessels passing through ALKI can be calculated.

3. Results and Discussion

3.1. Carbon Emissions

Using Trozzi and Vaccaro (2002) carbon emissions calculation formula, data from December 31, 2023, indicate that 35 foreign-flagged vessels passing through ALKI II emitted 2,976 tons of CO_2/day. Over the course of 2023, a total of 12,189 vessels passing through ALKI II resulted in approximately 3,110,023 tons of CO_2 emissions. This figure accounts for 0.2% of global greenhouse gas emissions and highlights a critical target for reducing the adverse effects of global temperature rise and extreme climate change, which are partly driven by carbon emissions from ship exhaust (Chatzinikolaou and Ventikos, 2015). Similar reduction strategies can also be applied to the thousands of foreign vessels passing through ALKI I and ALKI III, contributing to millions of tons of CO_2 emissions, as shown in Table 1, Table 2, and Figure 2.

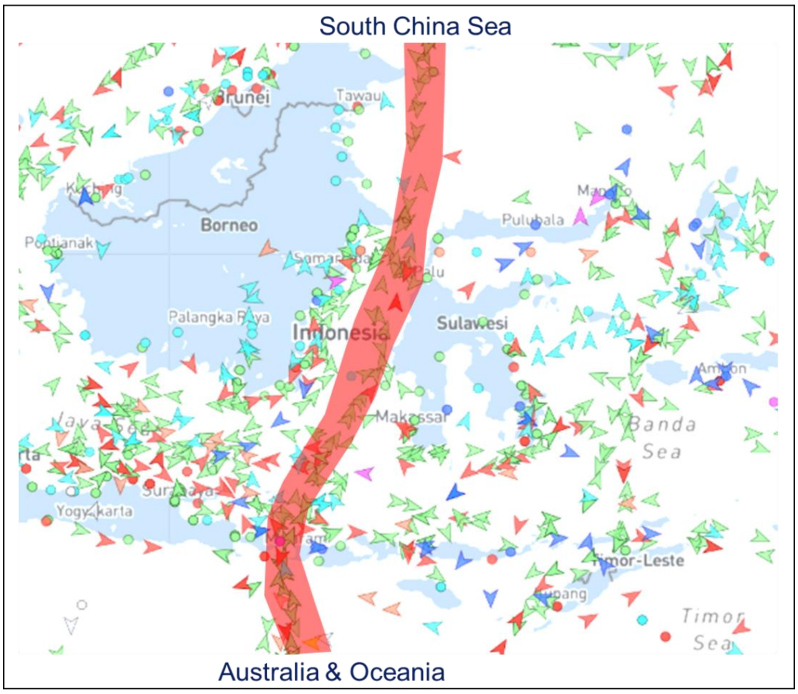

Figure 2 ALKI II Maritime Line

Figure 2 shows the traffic density along ALKI II, an important international maritime route connecting the South China Sea to Australia and Oceania. ALKI II traverses the Makassar Strait and the Lombok Strait, acting as a critical pathway for international vessels, including bulk carriers, tankers, and containers. This high-traffic corridor is important for global trade, with thousands of ships annually utilizing the route to bypass congested areas such as the Strait of Malacca. The red-highlighted pathway represents the designated ALKI II route, emphasizing its strategic importance in accommodating international maritime traffic while ensuring safe navigation through Indonesian waters. Considering this heavy traffic volume, ALKI II presents significant opportunities and challenges for implementing decarbonization strategies to mitigate the carbon emissions produced by vessels transiting the route. Vessel traffic data in this study was obtained on December 31, 2023, as shown in Table 1 below.

Table 1 International Ships in ALKI II on December 31, 2023

No	Time	Vessel	Vessel: Type, LoA	Vessel: Flag	Fuel Cons (K1/d)	Position
1	31.12.23 00:14:52	HENG LONG	Bulk Carrier (BC), 300M	Hong Kong	31	Passing TSS
2	31.12.23 01:06:40	GO AUSTRALIS	SUPPLY VSL, 83M	Panama	3	Passing TSS
3	31.12.23 01:11:20	ORE DALIAN	BC, 300M	Hong Kong	31	Passing TSS
4	31.12.23 01:23:27	GOLIATH	BC, 300M	Liberia	31	Passing TSS
5	31.12.23 02:21:08	BULK SANTOS	BC, 299M	Liberia	31	Passing TSS
6	31.12.23 02:42:28	ALPHA UNITY	BC, 292M	Liberia	31	Passing TSS
7	31.12.23 02:59:10	HUI ZHENG HAL	BC, 300M	Hong Kong	31	Passing TSS
8	31.12.23 03:12:15	NORA	BC, 291M	Malta	31	Passing TSS
9	31.12.23 03:42:05	SEASTAR HAWK	BC, 182M	Panama	19	Passing TSS
10	31.12.23 03:51:57	NORWEGIAN JEWEL	Passenger Ship, 294M	Bahamas	31	Passing TSS
11	31.12.23 04:11:08	NAUTICA	Passenger Ship, 181M	Marshalles	18	Passing TSS
12	31.12.23 05:39:38	SHAKESPEARE BAY	BC, 175M	Hong Kong	18	Passing TSS
13	31.12.23 05:52:58	MARAN VIRTUE	BC, 292M	Greece	31	Passing TSS
14	31.12.23 08:32:25	AASHNA	BC, 292A	Panama	31	Passing TSS
15	31.12.23 08:38:51	MINERAL HIROSHIGE	BC, 292M	Liberia	31	Passing TSS
16	31.12.23 11:53:32	JABAL AR RAWDAH	BC, 292M	Marshalles	25	Passing TSS
17	31.12.23 11:46:27	RMC RIGEL	BC, 292M	Singapore	34	Passing TSS
18	31.12.23 11:53:32	VL RENAISSANCE	Tanker, 333M	Liberia	34	Passing TSS
19	31.12.23 11:55:24	MEI HUA HAI	BC, 254M	China	28	Passing TSS
20	31.12.23 11:57:59	XIN FU HAI	BC, 292M	Hong Kong	31	Passing TSS
21	31.12.23 15:06:18	MOUNT AMELIOR	BC,329	Liberia	34	Passing TSS
22	31.12.23 15:17:34	PROTI	BC, 254M	Malta	31	Passing TSS
23	31.12.23 16:13:46	GOLDEN SUE	BC, 292M	Marshalles	31	Passing TSS
24	31.12.23 17:52:36	HBIS	BC, 329M	Liberia	34	Passing TSS
25	31.12.23 17:54:56	MINERAL CHARLIE	BC, 299M	Hong Kong	31	Passing TSS

Table 1 International Ships in ALKI II on December 31, 2023 (Cont.)

No	Time	Vessel	Vessel: Type, LoA	Vessel: Flag	Fuel Cons (K1/d)	Position
26	31.12.23 17:56:59	SARAH OLDENDORFF	BC, 245M	Madeira	26	Passing TSS
27	31.12.23 18:38:29	HAI CHANG	BC, 178M	Hong Kong	19	Passing TSS
28	31.12.23 18:56:44	SILVER NAVIGATOR	BC, 228M	Marshalles	23	Passing TSS
29	31.12.23 19:40:41	HL HARMONY	BC, 292M	Panama	31	Passing TSS
30	31.12.23 20:40:32	AQUAMARINE	TUG BOAT	Cyprus	3	Passing TSS
31	31.12.23 20:49:11	BLUE LHOTSE	BC, 292M	Panama	31	Passing TSS
32	31.12.23 21:00:48	QRE SHENZEN	BC, 351,9M	Hong Kong	34	Passing TSS
33	31.12.23 21:38:17	HE HUA HAI	BC, 254M	China	26	Passing TSS
34	31.12.23 22:17:34	XIN LI HAI	BC, 292M	Hong Kong	31	Passing TSS
35	31.12.23 22:56:32	BERGE MERU	BC, 285 M	United Kingdom	29	Passing TSS

Table 2 Recapitulation of International Ship Traffic at ALKI II on December 31, 2023

NO	Ship Type/Ship Length	Number of ships	Estimated Daily Consumption	Ship Flag (Registered ship)
1	Bulk Carrier/150m-350 m)	30	27-31 KL	• English • Panama • Liberia • Malta • Bahama • Marshall • Hong Kong • Greece • Spanish • Cyprus • China • Singapore
2	Liquid cargo ship/tanker	1	27-31 KL	
3	Passenger ship	2	27-31 KL	
4	Special vessels (offshore vessels)	2		
	TOTAL	35 Ships	Min: 945 KL/day	

The amount of exhaust emissions was explored in interviews to identify initiatives that can be implemented to reduce carbon (decarbonization), as guided by IMO. These initiatives can also serve as targets for Indonesian contribution to lowering global temperature increases through decarbonization efforts aimed at zero emissions for international ships, which are significant sources of pollutants in Indonesian waters.

Table 3 Potential Carbon Emissions of International Ships in ALKI II US of December 31, 2023.

Ship Fuel Consumption Details	Consumption (Tons @27 Kl / Day)	Emission Factor (Tons Co2 / Ton)	CO_2 Emissions (Tons)
Ship Daily Consumption (35 Ships/Day)	945	3.15	**2.976**
Consumption While Crossing Alki Ii(Three-Day Voyage)	2,835	3.15	**8.930**
Consumption Of 12,189 Ships In 2023 For 3 Shipping Days In Alki	**987,309**	**3.15**	**3,110,023**

3.2. Decarbonization Strategies Aboard Ships by Ship Owners and Operators

The formulation of strategies and frameworks for carbon emission reduction (decarbonization) from foreign vessels passing through ALKI in this study is a collaborative effort. It involves stakeholders in Indonesia, including business actors (shipowners and operators), the Indonesian government, and IMO, as well as coastal communities along ALKI. These strategies are based on IMO carbon management guidelines and greenhouse gas reduction framework, published in 2018 and updated in 2020.

Since ships are moving sources of pollution, the primary focus of emission reduction (decarbonization) efforts and strategies is the ship itself. As previously mentioned, carbon emissions from ships result from the combustion of fuel oil used to generate energy onboard. Marine Fuel Oil (MFO) powers both the main and auxiliary engines of ships, producing carbon emissions that are released into the atmosphere, contributing to environmental pollution. The initiative phases for decarbonization strategies implemented by ship operators are shown in Figure 2.

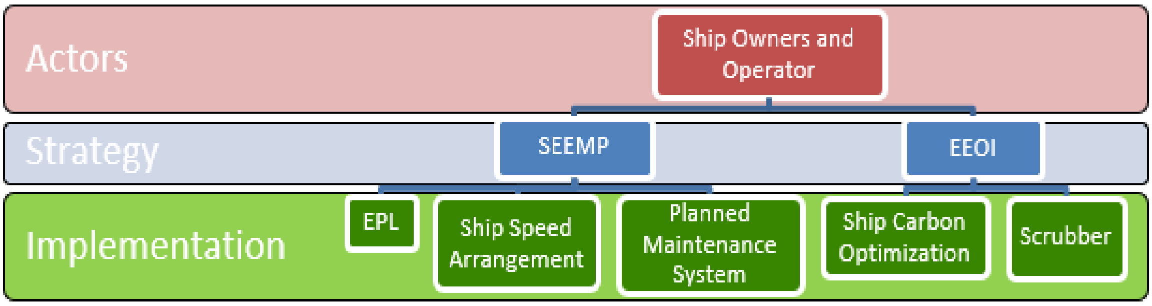

Figure 3 Strategies for decarbonization implemented by ship owners and operator.

Effective Implementation of Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Indicator (EEOI) on all foreign ships passing through ALKI. SEEMP aims to guide shipping companies and operators of vessels exceeding 5,000 gross tonnage (GT) in planning, implementing, and monitoring energy efficiency measures. This initiative specifically targets vessels transiting through ALKI (Archipelagic Sea Lanes of Indonesia) to optimize fuel consumption and directly reduce carbon emissions compared to operations conducted without SEEMP protocols. Similar to environmental protection regulations for maritime pollution (Marine Pollution/MARPOL Annex VI), which were discussed in MEPC Resolution 62 (Marine Environment Protection Committee) in 2011 and later improved in MEPC Resolution 78 in 2022 concerning SEEMP development guidelines, SEEMP should ensure efficient energy consumption onboard ships. This includes the following:

3.2.1. Activation of Engine Power Limit (EPL) on All Vessels Passing Through ALKI.

Recognizing that the ship engine is the primary component generating power and is closely related to fuel consumption. Technical analysis has been conducted and detailed regulations have been set by engine manufacturers regarding the power limits of ship engines, specifically the installation of the Engine Power Limitation (EPL) system. This system utilizes mechanical devices integrated into the ship's engine governor to optimize engine control. However, it may impose certain limitations on the speed (Korean Register, 2020). In practice, the engine speed and ship speed when passing through ALKI over three days cannot be increased once the EPL limit is reached. This ensures better control and efficiency of fuel consumption, except during emergencies or specific conditions where the EPL may be deactivated, either manually or remotely.

The effect of this system is that engine power capacity, engine RPM (revolutions per minute), and ship speed can be increased, leading to higher fuel consumption and carbon emissions. However, given that ALKI has been designated by Indonesia as a safe, smooth, and disruption-free international shipping lane, there is no longer an urgent need to increase ship speed. Therefore, the EPL system should be activated on all foreign vessels over 400 GT passing through Indonesian waters in ALKI.

The correlation between EPL and energy efficiency targets is essential for achieving operational energy efficiency. It ensures that ship energy consumption does not surpass the efficiency standard established at the time of its construction, as documented in the International Energy Efficiency Certificate (IEE Certificate). Compliance with the SEEMP and energy efficiency indices, such as the Energy Efficiency Design Index (EEDI) or Energy Efficiency Existing Index (EEXI), ensures that vessels adhere to these standards without exceeding the established standards.

The Energy Efficiency Index (EEI) of the ship is a correlation between the amount of carbon emissions produced in grams per ton (g/ton) of cargo carried over one nautical mile (Polakis et al., 2019). This monitoring is essential for ships passing through ALKI under MEPC Resolution 62. Therefore, all ships passing through ALKI over 400 GT must have an analysis comparing the actual energy efficiency index with the prescribed energy efficiency index. Ships constructed after January 1, 2013, or completed by January 1, 2015, are required to have the EEDI. By January 1, 2023, all international vessels exceeding 400 GT passing through ALKI must comply with this requirement. For ships built prior to this period, the EEXI serves as the reference for assessing energy efficiency efforts on board.

If the operational ship EEDI and EEXI exceed the reference values, one of the measures is to activate the EPL system. Additional actions may include installing energy-saving devices and switching to low-carbon emission fuels. These measures should be anticipated by stakeholders along ALKI.

Performance testing of ship operational efficiency, including engine RPM data, specifically when EPL is activated, can be seen in the data collection of the Indonesian-flagged bulk carrier, MV Patria Nawasena 1, which operates on the Indonesia-Japan route through ALKI II. This vessel has the same specifications and fuel consumption as foreign ships passing through ALKI. The vessel has a size of 31,236 gross tonnages, a deadweight capacity of 56,047 tons (including cargo, fuel, and freshwater), a length of 189.9 meters, and a main engine capacity of 12,000 horsepower, with a maximum engine speed of 127 RPM.

Figure 4 Marine vessel used in this research

In the collection of ship data carried out, several results were reported, as shown in Table 4 below:

Table 4 Experimental Data on the MV Patria Nawasena Ship 1

NO	Engine Power Rotation (Rpm)	Ship Speed (Know)	Fuel Consumption (liters/day)	Cruise Duration on ALKI-II (986nm)	Estimate CO_2 emissions (tons), Emission factor = 3.15
1	105	12.28	24,144 people	80.29 hours or 3,245 days	246,793.91
2	**110 (Engine Power Limit)**	**12.68**	**26,924 people**	**76.67 hours or 3,194 days**	**270,885.05**
3	115	12.71	28,331 people	77.57 hours or 3,232 days	288,432.24
4	120	12.82	29,224 people	76,911 hours or 3,204 days	294,956,142 people
5	125	12.88	30,985	76,552 hours or 3,189 days	311,255.17
6	127 (max)	13.10	32,288	75.26 hours or 3,136 days	318,953.77

Data collected during vessel operation in Indonesian waters reveals a noticeable difference in ship operational performance under varying engine conditions. When EPL is activated, the engine RPM is locked at an optimal point of 110 RPM, which is approximately 85-86% of the engine's maximum capacity of 127 RPM. Under these conditions, ship speed reaches 12.68 knots, with fuel consumption amounting to 26,924 KL and carbon emissions totaling 270,885.05 tons of CO_2. This calculation is in line with the approach used for estimating exhaust emissions, as outlined in the study by Trozi (2002), using the following equation.

$$E = S\ x\ F \tag{1}$$

E: Total emissions of pollutants (kg/ton)
S: Fuel consumption (tons)
F: Pollutant emission factor from the engine (3.15 for MFO)

When EPL is activated, the engine's rotational speed (RPM) cannot exceed a certain limit. This will trigger an alarm if the maximum EPL point is reached. This enables ship operators and company management to choose a lower, more fuel-efficient speed (around 110 RPM) while still maintaining standard service for customers. This approach can significantly reduce fuel consumption compared to maintaining higher RPMs. However, if the EPL is not activated, the engine RPM can increase up to 127 RPM, leading to a substantial increase in fuel consumption from 26.9 KL/day to 32.28 KL/day. Despite this significant fuel consumption increase, the increase in vessel speed is relatively minor, from 12.68 to 13.10 knots. Therefore, activating the EPL is a strategic decision that can effectively reduce fuel consumption and carbon emissions without significantly impacting vessel speed or cargo capacity. This strategy can be considered a new standard or policy for international vessels traversing the ALKI Strait, supporting the IMO's global targets for reducing ship emissions. The successful application of the EPL on MV Patria Nawasena can be adopted as a decarbonization strategy for other international vessels with similar specifications. This approach can accelerate decarbonization efforts, making them measurable and reportable, aligning with the NDC initiative.

3.2.2. Arrangement Ship Speed When Crossing ALKI

As outlined in SEEMP, the choice of ship speed plays a crucial role in determining fuel consumption and the level of carbon emissions produced. With the established shipping route in ALKI, as shown on the ship map and electronic chart, operating the vessel at an optimal speed with the selected RPM under active EPL conditions will significantly contribute to reducing carbon emissions. An interview with the crew of the Patria Nawasena revealed that the difference in speed from 12.6 knots to 13.1 knots has minimal impact on the duration of the voyage. However, it does result in a substantial increase in fuel consumption when the engine speed exceeds the EPL limit. Ship speed will be adjusted according to the voyage plan (passage plan) created by the captain and reviewed in collaboration with the ALKI supervisory authority. This ensures vessel follows a safer, shorter, and more efficient shipping route, ultimately making fuel consumption more economical. On the ALKI shipping route, ship speed will also be influenced by traffic density, particularly in the inter-island straits near ALKI, such as the Sunda Strait for ALKI I and the Lombok Strait for ALKI II. The implementation of the policy of regulating and separating ship traffic/Traffic Separate Scheme in the two straits will certainly have an impact on regulating ship speeds in ALKI, but the safety aspect in shipping is the main factor besides efforts to protect the environment from the risk of pollution caused by ship exhaust carbon emissions.

3.2.3. Optimization Ship Cargo and Ballast Water

One important consideration in measuring a ship's operational energy efficiency index is the load. Ensuring that the load does not exceed the load line limit (Plimsoll mark) and adheres to regulations on overload/overdraft is crucial, as exceeding these limits can significantly affect speed and fuel consumption efficiency. Optimal loading on the load line determined by the classification society and the authority of the country of origin of the ship will have a positive impact on the operational energy efficiency index of the ship. For the balance of the ship, the presence of ballast water is very necessary, but its capacity must also be regulated in order not to have an impact on increasing the resistance and fuel consumption of the ship. The presence of ballast water as part of the shipload is a key factor that must be optimized within the limits of the predetermined load line. This ensures that the operational or achieved EEDI or EEXI of the ship remains the same as, or does not exceed, the initial energy efficiency index (EEDI or EEXI) approved by the ship flag state authority. Therefore, ships transiting through ALKI must ensure they do not exceed the permitted load capacity or face overload/overdraft conditions. This will help maintain more efficient fuel consumption while navigating through ALKI. The loading report is mandatory and must be controlled by ALKI authority to ensure that vessels cross safely and securely, minimizing carbon emissions during their passage.

3.2.4. Optimization Implementation of Planned Maintenance System (PMS) on Ships

Ships that have been carried out in a planned manner in terms of daily, weekly, and monthly maintenance as well as repair activities at the dock accumulated in the Planned Ship Maintenance System will have a positive impact on the operational performance of the ship, specifically the use of fuel and the level of carbon emissions produced. International ships passing through ALKI with poorly maintained engines or hulls, or those affected by issues such as damage or the attachment of marine biota, will experience increased fuel consumption. This, in turn, leads to a higher ship energy efficiency index (EEDI or EEXI) during operation compared to the initial index when the ship was designed. Therefore, ships passing through ALKI must submit a maintenance report prior to crossing ALKI II. If required, the report should include inspection notes related to maintenance, as well as PMS (Planned Maintenance System) reports. This should also cover any issues or disturbances in the ship engine and hull that could lead to a decrease in speed and an increase in fuel consumption, thereby contributing to higher carbon emissions and associated waste. Physically, the amount of black smoke produced by international ships while crossing ALKI can be observed.

3.2.5. Utilization of Scrubber and Technology Carbon Capture and Storage on Ships

Ships passing through ALKI are required to implement SEEMP from January 1, 2023, meet energy efficiency certificates, and ensure their operation at the most optimal energy efficiency level, specifically with the activation of EPL and a series of other initiatives contained in SEEMP, carbon emissions will be reduced. Further efforts can be made to reduce its quantity before being discharged into the environment along ALKI. Subsequently, it is hoped that carbon emission capture and filtering technology that has been developed by countries around the world can be utilized as part of efforts to reduce carbon emissions produced when ships pass through ALKI. The remaining combustion that still contains carbon emissions will then be put into an installation known as a scrubber which includes a carbon filtering and neutralizing system. This installation will be able to reduce the intensity of carbon emissions through the application of carbon conversion technology into a liquid form or other minerals such as hydrogen thereby carbon is reduced and the carbon emission storage capacity can be more optimal because it is in liquid form or other minerals.

The technology of capturing, filtering, neutralizing, and storing carbon as a combustion residue that has been developed by various institutions such as Det Norske Veritas the Norwegian classification agency (DNV, 2024) in Europe, needs to be applied to all ships operating in ALKI. The amount of carbon that has been successfully reduced from the technological process above is then stored in certain containers and can then be unloaded from the ship to the port. Furthermore, the carbon can be managed and circulated to be utilized in other industrial sectors such as the oil and gas industry with the CCUS (Carbon Capture, Utilization and Storage) concept on the seabed to encourage increased oil production in various oil wells (IPCC, 2006), as has been running since October 2022 in wells oil PT. Pertamina in Jatibarang with CO2 huff and puff pilot test concept (Ministry of Energy and Mineral Resources, 2023). According to the findings, it is anticipated that the advanced strategic measures outlined in Stage 3, as illustrated in Table 4 below, will effectively reduce carbon emissions from ship fuel combustion. This reduction aims to maintain emissions at a level that can be offset through strategies such as vegetation-based carbon capture, which naturally sequesters carbon.

Table 5 Stages of Decarbonization Strategy by Ship Operator.

Decarbonization Strategy Stages on Ships at ALKI	Information
Application of *Ship Energy Efficiency Management Plan* and *Energy Efficiency Design Index/Existing Energy Efficiency Index:* 1) *Engine Power Limit* Activation /EPL 2) Economy Ship Speed Setting 3) Delivery Optimization Plan on ALKI Route 4) Optimization of load and *ballast water management* for ship stability 5) *Planned* Ship Maintenance System Optimization Application	Decarbonization Strategy
Installation of *Scrabber* on ship	Decarbonization Strategy
Utilization of *Carbon Capture and Storage Technology* on Ships	Decarbonization Strategy

3.3. Decarbonization Strategy Indonesian Government and IMO

As part of a collaborative effort to reduce carbon emissions (decarbonization) on ships passing through ALKI, the initiative of ship owners and ship operators in implementing the 3 decarbonization strategies above will be able to run optimally if supported by the participation of the government and coastal communities. Indonesian government as the authority responsible for the safety of ships passing through ALKI and ensuring environmental protection in Indonesia can make efforts to reduce carbon emissions by preparing the following work as shown in Figure 4.

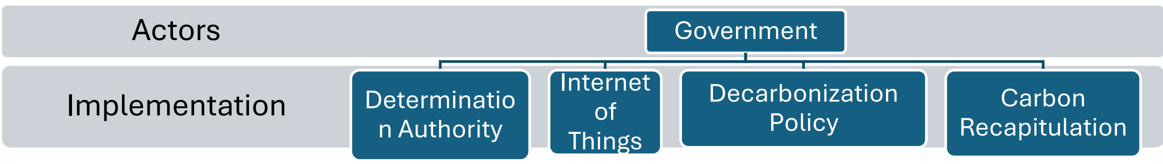

Figure 4 Actor and Implementation for carbon emission reduction.

3.3.1 <u>Determination Authority Driver Emission ALKI Special</u>

This specialized ALKI authority is a dedicated organization or task force responsible for safeguarding ALKI from environmental pollution risks, particularly those arising from ship exhaust emissions. This organization will communicate with the crew of ships entering and crossing ALKI in order to fulfill the rights and obligations of foreign ships while crossing. Considering that the ALKI route is near the Indonesian new capital in East Kalimantan, the ALKI monitoring office could be based there, with task forces stationed at each entry and exit point and along the route in Indonesian waters. This organization will then communicate and coordinate with various parties as needed to ensure the implementation of the rights and obligations of Indonesian and foreign ship operators while crossing ALKI.

3.3.2. <u>Utilization of Digital Technology (Internet of Things) in ALKI Supervision</u>

To facilitate monitoring of ALKI and the three strategies that will be implemented by ship operators in order to reduce carbon emissions on board ships, information technology, and digitalization support are very important. Subsequently, information and data alone are not enough to use data distribution through the Automatic Identification System (AIS), but it is necessary to add a special digital portal that optimally provides services to all foreign ships that will enter and pass through ALKI. On this portal, a declaration column can also be prepared for ships containing data and information related to efforts to ensure the implementation of energy efficiency on ships which determines the optimal implementation of ship decarbonization. Through this digital portal, not only is the movement of ships monitored to stay on the most economical route, but there are also ship declaration documents that can be accessed, analyzed, and responded to more quickly and effectively by officers from the ALKI supervisory authority. This digital portal is also a media for providing additional data and information from ships that are not included in AIS, namely as a data delivery system through Very High Frequency radio transmission which normally only contains data on the name and type of ship, ship call sign, ship nationality, maritime mobile services identities (MMSI), IMO number, ship gross tonnage, ship draft, ship length and width.

Through this portal, shipping companies will announce various reports including the implementation report of SEEMP and Energy Efficiency Operational Index (EEOI), Energy Efficiency Certificate, ship fuel usage records, ship oil filling analysis report, ship maintenance system plan (PMS) report, and other supporting documents.

3.3.3. Discussion Policy Decarbonization at ALKI at IMO Session

The Traffic Separation Scheme (TSS) was established to regulate and separate ship traffic at the intersections of the ALKI route with inter-island transportation routes in the Sunda and Lombok Straits. This was based on discussions and agreements during the IMO session. Specifically, IMO Circular Letter COLREG.2/Circ.74 addresses the challenges of the new TSS. Additionally, IMO Circular Letter SN.1/Circ.337, issued on June 14, 2019, provides further route regulation measures. These aim to reduce the risk of ship collisions in straits intersecting the ALKI route. To prevent environmental damage from ship exhaust carbon emissions, Indonesia, as an IMO member, must propose additional regulations. Enhanced supervision of ship traffic along ALKI should also be submitted at the IMO session. With the joint agreement in the circular letter at this international forum, efforts to reduce carbon emissions from international ship exhaust gases in accordance with the 2015 Paris Agreement and the 2018 and 2023 IMO directives in reducing greenhouse gases in the shipping sector can be implemented optimally and immediately with ALKI in Indonesia. The proposed implementation of an Emission Control Area (ECA) in the ALKI region could encourage global ship-owning countries to prioritize decarbonization efforts. This would raise awareness and drive initiatives to reduce emissions from fuel combustion while passing through Indonesian waters.

3.3.4. Carry Out Recapitulation Emission of the Final Carbon Resulting from the Implementation of a Nominal Carbon Tax Decarbonization Strategy

After the 3 stages of the decarbonization strategy have been implemented, with supervision by ALKI authorities through 3 main points, specifically at the entrance and exit of the ALKI route and at the recommended coordination center in the capital city of the country in the East Kalimantan archipelago, the carbon emissions generated by ships passing through ALKI will be recorded. This data will track the accumulation of residual carbon produced during their passage. The recorded carbon emissions will be used to determine the nominal carbon tax that shipping companies from various countries will pay. This aligns with the Indonesian carbon tax policy, as outlined in relevant national laws and regulations. These include Law Number 16 of 2016, ratifying the Paris Agreement, and Law Number 7 of 2021 concerning the Harmonization of Tax Regulations, along with Presidential Regulation Number 98 of 2021. The carbon tax will be levied based on a rate of IDR 30/kg of carbon dioxide equivalent (CO2e), effective from early 2025. This tax aims to support Indonesian efforts to reduce greenhouse gas emissions and achieve its climate goals under NDCs (Barus & Wijaya, 2022). The utilization of the economic value of carbon is for climate change control, such as the provision of various carbon control/management infrastructure in ALKI for foreign ships passing through it, providing social assistance for coastal communities along ALKI affected by carbon emissions, including compensation for community forests that can absorb carbon emissions.

Based on the potential emissions produced by foreign vessels on December 31, 2023, with the implementation of the phase 1 decarbonization strategy that activates EPL for average consumption of 27,000 liters of MFO/day on 35 vessels passing through, the estimated carbon tax that can be paid by foreign shipping companies is IDR 30/kg x 2,976,000 kg/day = IDR 89,280,000/day. If the same assumption is applied to 12,189 vessels from various countries passing through ALKI-II for 3 days with the potential carbon emissions produced of 3,110,023,000 kg CO_2, then the estimated carbon tax that can be paid by shipping companies is around IDR 93,300,690,000/year. With this figure of IDR 93 billion/year, it will be used effectively to support various sustainable decarbonization efforts towards net zero emissions for foreign vessels whose traffic is on ALKI II and the same efforts can also be performed on ALKI I and ALKI III (Table 6).

Table 6 Estimated Calculation of Carbon Tax on Ship Exhaust Emissions at ALKI.

NO	Coverage	Potential Emissions CO_2 equivalent	Carbon Tax Potential (@IDR 30/kg CO_2 equevalent)
1	Daily Carbon Emissions (35 Ships)	2,976,000 kg	Rp. 82,280,000/day
2	Annual Carbon Emissions (12,189 Ships)	3,110,023,000 kg	Rp 93,300,690,000/year

ALKI special supervisory body can summarize the results of implementing the three stages of the decarbonization strategy for thousands of foreign-flagged vessels from various countries that pass through ALKI I, ALKI II, and ALKI III each year into a report for Indonesian NDC. This initiative serves as a strategic proposal for Indonesia to secure grant funds and assistance from global stakeholders under the ESG fund scheme, as established during the COP 26 meeting of the United Nations Framework Convention on Climate Change (UNFCCC) in 2021.

3.4 Decarbonization Strategies by Coastal Communities along ALKI

Coastal communities along ALKI can contribute to reducing carbon emissions by referring to carbon management strategies and IMO framework for reducing greenhouse gases, namely through:

1. Follow as well as supervision of foreign vessels in ALKI in order to prevent air pollution due to ship exhaust emissions. With the help of digital portals and applications, the public can monitor foreign vessel traffic along ALKI. The public can provide information on monitoring results and enter it into the digital portal/application which can be followed up by the IKN authorities in the nation's capital and at the ALKI entrance/exit.
2. Guard sustainability plants in tropical forests and aquatic plants along the ALKI coast to offset the carbon emissions produced by ships passing through ALKI.

Based on the calculation results of the potential carbon emissions produced by ship traffic each year in ALKI-II, which is 3.1 million tons of CO_2, It is essential to preserve forests with diverse plant species capable of naturally absorbing carbon. An inventory of tropical forest capacity, which can be conserved to offset remaining carbon emissions after decarbonization efforts targeting ship exhaust, is presented in Table 7 below.

Table 7 Tropical Forest Plant Requirements for Potential Carbon Absorption of Ship Exhaust Emissions Remaining from Decarbonization at ALKI II

NO	Types of Plants on ALKI Beach	Emission Absorption Capacity (kg/year)	Estimate Need Trees/kgC/year against 3,110,023,000 kg of CO_2 Ship Exhaust Emissions.
1	Rain Tree/Samanea Saman	28,488	109,169.5 trees
2	Cassia flower/Cassia sp	5,295 people	587,350.89 trees
3	Ylang ylang/Canangium odoratum	756.59	4,110,524 trees
4	Pingku/Dysoxilum Excelsum	720.49	4,316,538.7 trees
5	Banyan/Ficus Benjamina	535.90	5,803,364 trees

Coastal plants such as mangroves and seagrass can absorb carbon emissions. Mangrove forests can absorb up to 937 tons of carbon/ha/year (Alongi, 2012). To offset the total carbon emissions produced by ships passing through ALKI Strait, approximately 3,319.12 ha of mangrove forest would be required annually. Seagrass, on the other hand, can absorb 6,590 kg of carbon/ha/year (Dirhamsyah, 2018). To offset the residual carbon emissions after implementing decarbonization strategy 1, a seagrass area of 471,930 ha would be needed along the coast of ALKI II. To determine the availability of these coastal ecosystems, local governments and communities along ALKI II and the islands between the Makassar Strait and the Lombok Strait will need to conduct an inventory of existing mangrove and seagrass forests. If these natural resources are insufficient, additional carbon sequestration can be achieved through the planting of appropriate tropical forest vegetation as shown in Table 6. To support these efforts, Indonesia can leverage ESG funds obtained through the NDC initiative. These funds can be allocated to the maintenance and preservation of tropical forests and aquatic plants with proven carbon sequestration capabilities.

4. Conclusions

In conclusion, this study utilized a qualitative method supported by quantitative data analysis. Qualitative data were collected through direct interviews with key stakeholders, including business actors, ship crews (operators), maritime authorities (government representatives), and coastal communities. As part of the case study, data were gathered from ALKI and MV Patria Nawasena 1. The carbon emissions from international vessels traversing ALKI were calculated, yielding significant insights. The results indicated that implementing a decarbonization strategy could reduce potential carbon emissions from ships in ALKI by nearly 1% of global greenhouse gas emissions, equating to over 3 million tons of CO2 in ALKI II alone and a potential 5 million tons in ALKI I and ALKI III combined. This initiative is in line with global efforts to reduce carbon emissions from international shipping, as targeted by IMO: a 40% reduction by 2030 and a 50% reduction by 2050 from the 2018 baseline of 1,076 million tons of carbon emissions. One of NDC to the United Nations Framework Convention on Climate Change is an initiative to implement a decarbonization strategy for international ship exhaust gases passing through the Indonesian Archipelago Sea (ALKI), a significant international shipping lane. The decarbonization strategy is a collaborative effort involving international shipping businesses, the Indonesian government, IMO, and coastal communities along ALKI. The goal is to gradually transition ALKI towards a carbon-neutral future by 2050, in line with global commitments and IMO guidelines. By implementing this decarbonization strategy, Indonesia aims to ensure that international shipping actors operating in ALKI fulfill their obligation to minimize environmental damage caused by ship exhaust emissions. This obligation is balanced with the rights of Indonesia, which has provided security and convenience to international shipping for over 40 years since the ratification of the 1982 UN

Convention on the Law of the Sea. To effectively and sustainably implement this decarbonization strategy, a unified commitment from all IMO member countries is crucial. Ensuring that all nations whose ships traverse ALKI comply with these standards will accelerate the reduction of greenhouse gas emissions, particularly from ship exhaust, achieving the goal ahead of the 2050 target.

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Author Contributions

Hadi, I. served as the Lead Research coordinator, overseeing the conceptualization and execution of the study. Hadi, I. wrote the manuscript with support from Muzhaffar, M.H. and Hanifa, A.S. and Yola, L contributed as Data Contributors, providing essential data and supporting its validation. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Conflict of Interest

The authors declare no conflict of interest. The authors are required to disclose and acknowledge any personal circumstances or interests that might be considered inappropriate to influence the representation or interpretation of the study results.

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