Improving Environmental Management and Green Shipping: Innovation, Regulation, Awareness, Support

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Abstract. This research explores the role of technological innovation, regulation, public awareness, and financial support in enhancing environmental management in the shipping sector. Using a qualitative, descriptive-analytical approach, this study primarily utilizes a literature review to evaluate the effectiveness of green technology and policies. The data was taken from reports by the International Maritime Organization (IMO), scientific articles, and government policy documents. Data triangulation ensures validity by comparing various sources, while content and thematic analysis identify patterns and themes. Striking examples include wind-assisted propulsion technology, such as rotor sails, which can reduce fuel consumption by up to 10 percent and decrease CO2 emissions by 20–25 percent. Regulatory measures such as the IMO Global Sulfur Limit have significantly reduced sulfur emissions and improved air quality. Public awareness and corporate social responsibility (CSR) initiatives are crucial in promoting environmentally friendly technologies, as seen in companies like Norsepower. Financial mechanisms, including green bonds, support the transition to sustainable practices. This study emphasizes that technological innovation, regulation, public awareness, and financial support collectively drive significant improvements in environmental management in the shipping industry.

Keywords: Green Shipping Technology, Environmental Regulation, Public Awareness, Technological Innovation, Financial Support

1 Introduction

Climate change and environmental degradation are becoming increasingly urgent issues that need to be addressed globally. The shipping industry is one of the main contributors to greenhouse gas (GHG) emissions. According to the International Maritime Organization (IMO), international shipping accounts for about 2.2% of total global anthropo-genic CO2 emissions. This shipping sector is expected to grow by 50 to 250 percent by 2050 due to the growth of global maritime trade.

[1] In this regard, the new role of Indonesian seaports in reducing emissions from this source indicates that maritime shipping contributes ap-proximately 2.89% of the total global anthropogenic CO2 emissions, with international shipping accounting for 2.4% and domestic shipping contributing around 0.49%. [2]. Although this portion is

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lower com-pared to other transportation sectors, the global scale of the shipping industry and its long-term environmental impact remain a major concern, especially with projections of increased shipping activity in the coming decades. In 2023, Tanjung Priok Port recorded 53,000 ship vis-its, an increase of 2.47% compared to 2022. [3], Every year, large ships operating in the oceans release carbon dioxide (CO2), methane (CH4), and nitrogen oxides (NOx) into the atmosphere, accelerating global warming. In addition, air pollution from sulfur dioxide (SO2) and fine particulate matter (PM) also has detrimental effects on human health and the environment. To address this challenge, a comprehensive approach is needed that includes technological innovation, strict regulations, public awareness, and financial support. The Indonesian government has issued various regulations to reduce greenhouse gas (GHG) emissions in the shipping industry.

One example is the MEPC 80 meeting, which discussed emission re-duction strategies, including the use of low-sulfur and non-carbon fuels. [4]. This research aims to explore how the four factors—technological innovation, regulation, public awareness, and financial support—can contribute to enhancing environmental management and promoting green shipping. The main focus of this study is on technological innovation in the shipping industry, the role of regulation in driving change, as well as the public support and policies needed to accelerate the adoption of green technologies.

2 Literarure Review

2.1 Technological Innovations in Green Shipping

Technological innovation has become a key pillar in efforts to reduce the environmental impact of the shipping industry. The use of fuels such as LNG (Liquefied Natural Gas) has been identified as one of the main solutions. LNG can reduce greenhouse gas emissions by up to 23% compared to conventional fossil fuels. [5]. In Indonesia, PGN (Pe-rusahaan Gas Negara) continues to develop LNG bunkering services, one of which is at the Bontang LNG terminal in East Kalimantan, located on a strategic route between Australia and East Asian countries such as Japan, Korea, and China. [6]. This terminal is expected to begin operations serving LNG-fueled ships with a capacity of 1,000 to 15,000 cubic meters in 2026. [7]. The use of LNG not only reduces carbon emissions but also decreases air pollution from sulfur dioxide (SO_2) and nitrogen oxides (NOx), which are known to be harmful to human health and the environment. In this regard, Perusahaan Gas Negara (PGN) is committed to implementing the company's core values to ensure the safety and health of workers, environmental sustainability, and to provide world-class service to consumers. The use of LNG as a fuel for ships is considered more environmentally friendly compared to other ship fuels. [8] In addition to LNG, Indonesia is also adopting bio-diesel with a 40% content (B40) as a step towards green shipping. The Indonesian National Shipowners' Association (INSA) emphasizes that the use of B40 in the shipping industry will increasingly rise in line with the commitment to the development of renewable energy. [9]. In addition to alternative fuels, the development of environmentally friendly propulsion systems, such

as solar-powered and electric ships, has be-come a major focus of the shipping industry in Indonesia. This innovation not only extends the lifespan of ships but also reduces the negative impact on marine ecosystems. [10], Indonesia can learn from countries like Denmark and New Zealand, which have been pioneers in the adoption of green technology. Denmark has become one of the most advanced countries in the development of electric ships. They have developed various types of electric vessels, including passenger ships and cargo ships, which use lithium-ion batteries as their primary power source. [11], New Zealand has also developed maritime technology innovations by launching several electric vessels focused on reducing greenhouse gas emissions. This ship uses a large-capacity battery and has been operating on domestic routes, providing a real example of how environmentally friendly technology can be integrated into the shipping sector. [12]. In addition to the use of alternative fuels and electric power, emission reduction technologies such as scrubbers are also an important solution. A scrubber aims to reduce sulfur dioxide (SO_2) emissions from the internal combustion engines of ships that use oil-based fuels such as diesel or bunker fuel. This technology helps meet international regulations that set a threshold of 0.5% sulfur content in exhaust gas emissions. [13]. Although effective, scrubber technology increases operational costs due to the need for intensive maintenance, including regular filter replacements. [14].

2.2 Regulations and Policies

The International Maritime Organization (IMO) has played a central role in establishing global regulations that promote the decarbonization of the shipping sector. One of its biggest steps is the Greenhouse Gas (GHG) Reduction Strategy adopted in 2018, with a target of reducing GHG emissions by 50% by 2050 compared to 2008 emission levels. This strategy aims to mitigate the environmental impact of shipping activities. [15]. In addition, the IMO has implemented the Global Sulfur Regulation 2020, which requires ships to use fuel with a sulfur content of less than 0.5%, well below the previous limit of 3.5%. [16]. This regulation has reduced sulfur oxide emissions by 77% since it was implemented on January 1, 2020. [17]. This regulation is implemented through the amendment of Annex VI of the MARPOL Convention. International ships are required to use fuel with a maximum sulfur con-tent of 0.5% m/m, and for ships operating in Emission Control Areas (ECA), the sulfur content in the fuel must not exceed 0.1% m/m. [18]. Thus, the IMO has played a central role in establishing global regulations that promote the decarbonization of the shipping sector through strategies for reducing GHG emissions and global sulfur regulations. Developing countries face various challenges in the implementation of green shipping regulations set by the International Maritime Organization. (IMO). The investment costs for adopting green technologies such as LNG fuel, scrubbers, or wind-assisted propulsion systems are very high. This makes it difficult for developing countries to finance the transition to environmentally friendly technology. Developing countries also face challenges in terms of regulatory and supervisory capacity. The implementation of IMO standards requires a solid policy frame-work, strong oversight capacity, and strict law enforcement. However, many cases indicate that developing countries lack human resources and technology to

monitor compliance with international regulations. [19] Developing countries also face challenges in terms of regulatory and supervisory capacity. The implementation of IMO standards re-quires a solid policy framework, strong oversight capacity, and strict law enforcement. However, many cases indicate that developing countries lack the human resources and technology to monitor compliance with international regulations, which plays an important role in steering the shipping industry towards best practices.

2.3 Public Awareness and Financial Support

Public awareness of the environmental impact of the shipping industry continues to grow, driven by educational campaigns and environmental advocacy initiated by the media and non-governmental organizations (NGOs). The media and NGOs have played an active role in raising public awareness about the environmental effects of the shipping industry. They conducted an educational campaign focused on the importance of reducing greenhouse gas (GHG) emissions and improving the operational efficiency of ships by using green technology. [20]. The educational campaign has contributed to changes in consumer behavior. The community is increasingly aware of the importance of reducing greenhouse gas emissions and improving the operational efficiency of ships by using green technologies such as scrubbers, wind-assisted propulsion, and alternative fuels like LNG and biofuels. [21] The government has also issued regulations and policies that govern the prevention of marine environmental pollution. The International Maritime Organization (IMO) has developed a new legally binding instrument to ensure that the ship recycling process is safe and environ-mentally sound. [22]. Thus, public awareness of the environmental im-pact of the shipping industry continues to grow, driven by educational campaigns, environmental advocacy, and changes in consumer behavior influenced by green technology and government regulations.

3 Methodology

This research employs a qualitative approach with a descriptive-analytical method that focuses on a literature review to explore the contributions of technological innovation, regulation, public awareness, and financial support to the improvement of environmental management in the shipping sector. Data collection was carried out by accessing various sources of literature, such as reports from the International Maritime Organization (IMO), scientific articles, and government poli-cy documents related to green technology innovations and regulations in the shipping industry. To ensure the validity of the data, this research employs data triangulation by comparing various sources of literature to ensure the consistency of information [23]. This research applies content analysis to identify patterns and themes found in the literature by conducting a systematic examination of the text's content to un-cover recurring themes and patterns. Additionally, thematic analysis is used to identify the main themes and the relationships between factors influencing the adoption of green technology. This method is carried out systematically to ensure that the main research areas can be clearly defined and

understood [24]. As a concrete example from the literature used, technological innovations such as wind-assisted sailing technology harness wind power to enhance energy efficiency and reduce exhaust emissions. One example is the use of rotor sails on ships, which can save fuel by up to 10% during the journey. Norsepower, a company that has successfully developed and installed rotor sails on several commercial ships, demonstrates significant fuel savings and a reduction in CO2 emissions [25]. In terms of regulation, the IMO implement-ed the Global Sulphur Cap rule on January 1, 2020, which reduced the sulfur content in ship fuel from 3.5% to 0.5%. This policy successfully decreased SOx emissions and improved air quality around ports and coastal areas, with a reduction in SOx emissions of up to 77%, equivalent to a decrease of 8.5 million tons of CO2 per year [23].

Public awareness also plays an important role in the adoption of green technology in the shipping industry. Corporate Social Responsibility (CSR) initiatives that focus on environmental sustainability, such as reducing emissions and improving energy efficiency, are very important. Several companies, such as Norsepower, are involved in CSR activities that promote sustainable practices and educate the public about the importance of green technology [25]. From the perspective of financial support, green bonds have become one of the global financing mechanisms that support sustainable projects. For example, DNV developed green bonds to fund projects aimed at reducing emissions and improving energy efficiency in the shipping industry [25]. The methodology employed in this study ensures a comprehensive under-standing of the challenges and opportunities in implementing green technology in the shipping sector. By integrating content and thematic analysis, the study identifies patterns, main themes, and relationships between various factors influencing the adoption of green technology. The results provide a deep understanding of how technological innovation, regulation, public awareness, and financial support contribute to environmental management improvements in the shipping sector. The methodology used in this research provides a comprehensive under-standing of the challenges and opportunities in the implementation of green technology in the shipping sector. By combining content and thematic analysis, this study successfully identifies patterns, key themes, and the relationships among factors influencing the adoption of green technology. The results offer deep insights into how technological innovation, regulations, public awareness, and financial support contribute to improved environmental management in the shipping sector.

4 Discussion and results

Wind-assisted shipping technology utilizes wind power to enhance energy efficiency and reduce exhaust emissions in the shipping industry. One of its implementations is the use of fans or rotor sails on ships, which can help save up to 10% of fuel during the journey. A concrete example of the application of this technology is Norsepower, a company that has successfully developed and installed rotor sails on several commercial vessels [26].

Fig. 1. Rotor sail. Source: https://www.youtube.com/watch?v=iDQvNBuS-2A&t=17s

The rotor sail, developed by Norsepower, functions as a vertical cylinder mounted on a ship. This sail harnesses wind power to provide additional propulsion. When the wind strikes the rotor sail, it spins the vertical cylinder, which then generates significant thrust. This process uses a small amount of electricity from the ship to operate the rotor sails, thereby saving fuel and reducing CO2 emissions. The Norsepower Rotor Sail™ installation has shown several significant results, including:

Fuel Consumption Reduction: The rotor screen has successfully saved fuel with varying percentages, such as 4-5% on M/V Berlin and M/V Copenhagen up to 13.5 tons per week on SC Connector.

CO2 Emission Reduction: By using rotor screens, CO2 emissions can be reduced by 20-25% and even up to 70% under optimal conditions. Operational Experience: Norsepower has gathered over 250,000 hours of operational data from various vessels, including Scandlines, Sea-Cargo, Vale, CLdN, Bore, and Socatra [27]. Thus, the Norsepower Rotor Sail™ becomes an effective solution for reducing pollution and increasing energy efficiency in the shipping industry.

This innovation not only reduces fuel consumption but also significantly contributes to lowering carbon dioxide emissions, thereby supporting more environmentally friendly shipping.

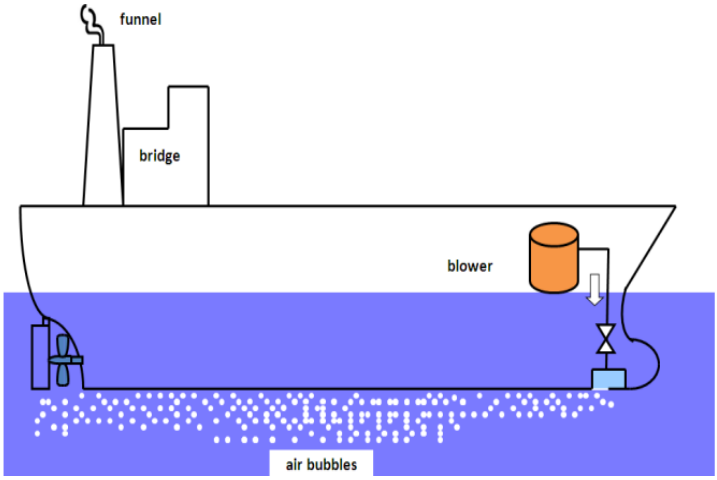

Fig. 2. Water Lubrication System Technology. Source: https://safety4sea.com/report-summarizes-air-lubrication-technology-for-shipping/

This image shows a ship that uses air lubrication system technology. The air lubrication technology works by generating air bubbles that cover the underside of the ship. This bubble reduces friction between the ship and the water, thereby saving energy and reducing emissions. [28]. By reducing water resistance, ships equipped with a water lubrication system can save up to 5% of fuel during their operations. [29]. The air lubrication system reduces friction by generating air bubbles between the ship's hull and the water, providing significant environmental benefits in several ways. First, fuel savings occur because this system creates air bubbles that reduce friction between the ship's hull and the water, thereby de-creasing resistance and saving the fuel needed to propel the ship. This fuel savings enhances the ship's energy efficiency, allowing it to operate longer without the need for frequent refueling, which in turn reduces the frequency of trips to the port for refueling. Secondly, the reduction of fuel directly impacts the decrease in CO2 emissions, as fuel is the primary source of greenhouse gas emissions. In addition to CO2, reducing friction also lowers emissions of other toxic gases such as NOx and SOx, which contribute to air pollution and environmental damage. Thirdly, by lowering fuel requirements, ships also reduce marine pollution caused by fuel residues and other waste. Lastly, the air lubrication system enhances the overall performance of the vessel, making it more stable and efficient in operation, which contributes to the safety and comfort of the journey. Thus, the reduction of friction produced by the air lubrication system provides significant environmental benefits through fuel savings, reduced emissions, and decreased marine pollution. One of the companies that has developed and implemented this technology is Silverstream Technologies. This company offers a water lubrication system that can be installed on various types of ships using Air Release Units (ARUs) to create a uniform layer of air bubbles beneath the hull of the ship. [30] The elements present in the image are: (a) funnel, the exhaust pipe of the ship's engine, which usually emits smoke or exhaust gases; (b) bridge, the structure where the ship's captain controls and monitors

navigation. (c) Blower, a machine or device that is responsible for generating air bubbles that are channeled under the hull of the ship; (d) Air Bubbles, bubbles blown under the ship that create an air layer between the ship and the water to reduce friction as the ship moves; (e) Pipe and valve system, which channels air from the blower to the bottom of the ship's hull.

The implementation of this technology provides innovative solutions for supporting more environmentally friendly shipping by reducing fuel consumption and carbon emissions. This aligns with international goals to reduce exhaust emissions from ships. [31]. The implementation of this technology provides innovative solutions for supporting more environmentally friendly shipping by reducing fuel consumption and carbon emissions. This aligns with international goals to reduce exhaust emissions from ships. The shipping industry is one of the significant sectors in environmental management, especially in the context of reducing greenhouse gas (GHG) emissions. The shipping industry is responsible for about 2.3% of global CO2 emissions, which is a substantial contribution to climate change. [32]. These emissions come from the burning of fossil fuels such as oil and coal, as well as maritime operations that release emissions. [33] Ships that burn heavy fuel, maritime operations that release emissions, ballast water dis-charge, and ship noise are some of the challenges faced by the shipping industry in reducing greenhouse gas emissions. [34] The green transition in the shipping industry involves the development and adoption of cleaner fuels, enhancing ship efficiency, and investing in innovative technologies to reduce greenhouse gas emissions. [35]. The reduction of greenhouse gas emissions can help mitigate the impacts of climate change, such as rising global temperatures, changing weather patterns, and the risk of natural disasters. [36] By using cleaner fuels and increasing the energy efficiency of ships, operational costs can be reduced and ship performance can be improved. The development of innovative technologies such as air bubble hull lubrication, hull points, advanced propellers and rudders, and sail systems can optimize ship operations and reduce greenhouse gas emissions. [37] This article aims to explain the importance of reducing greenhouse gas emissions in the shipping sector and to highlight the initiatives currently being undertaken to decarbonize the shipping industry. It includes an analysis of the contribution of greenhouse gas emissions from the shipping industry, the challenges faced, green transition strategies, and the initiatives being implemented by the government, shipping companies, and regulatory bodies to reduce greenhouse gas emissions. [38].

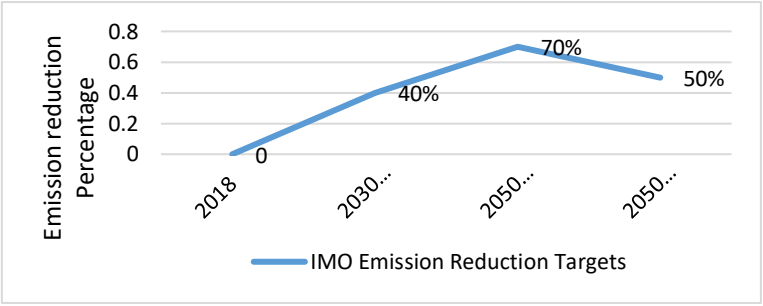

Fig. 3. Emission Reduction Targets (IMO GHG Strategy 2018)

The initial strategy of the IMO in 2018 set several targets for reducing green-house gas emissions from international ships. The main targets are to reduce the carbon intensity of international ships by 40% by 2030, with efforts to achieve 70% by 2050, compared to the year 2008. [39] The initial IMO strategy in 2018 also emphasized the importance of developing and using more environmentally friendly technologies and fuels to reduce greenhouse gas emissions. Some of the technologies and fuels that were promoted include using clean fuels such as hydrogen, ammonia, or biofuels to reduce greenhouse gas emissions and the development of more efficient propulsion technologies to decrease fuel consumption and greenhouse gas emissions. [40]

Green technology innovation has become one of the main factors in improving environmental management in the shipping sector. Technologies such as LNG fuel, scrubbers, and wind-assisted propulsion systems have been used to reduce greenhouse gas (GHG) emissions and air pollution.

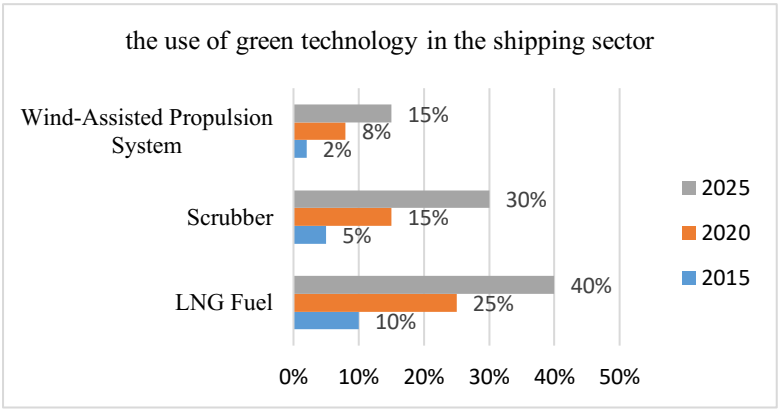

Fig. 4. Increase in the Use of Green Technology in the Shipping Sector from 2015 to 2025.

The use of LNG fuel in the shipping sector has seen a significant increase, from 10% in 2015 to 25% in 2020, and it is projected to reach 40% by 2025 [41]. This trend shows that LNG fuel is increasingly being accepted as a primary solution for reducing emissions compared to traditional fuels. This increase reflects technological advancements and the successful adoption of cleaner fuels. In addition, the use of scrubbers increased from 5% in 2015 [42]. It reached 15% in 2020 and is projected to reach 30% by 2025, also reflecting the industry's response to stricter regulations and environmental demands, as scrubbers are effective in reducing sulfur oxide emissions. [43]. On the other hand, wind-assisted propulsion systems, which started at 2% in 2015 and increased to 8% in 2020, are expected to reach 15% by 2025. Although still in the development stage, this system shows significant potential in reducing emissions and may become a more common technology in the future. Regulations from the International Maritime Organization (IMO) play a crucial role in the push for the adoption of green technology. Adoption of greenhouse gas (GHG) reduction strategies

in 2018, targeting a 50% reduction in GHG emissions by 2050 compared to 2008 emission levels. [44], encouraging the shipping industry to adopt green technology. This regulation encourages the shipping sector to invest in cleaner and more efficient technologies. Overall, the data shows that the shipping sector is increasingly committed to adopting green technology, with LNG fuel, scrubbers, and wind-assisted propulsion systems becoming key focuses. IMO regulations also play a crucial role in accelerating the transition towards better environmental management in this industry.

Effective public awareness often utilizes social media to disseminate information about the importance of reducing greenhouse gas emissions and adopting green technology. For example, international organizations like the International Science Council use social media platforms to raise awareness about climate jus-tice and the decarbonization of shipping. [36] Community participation in public campaigns can enhance awareness and behavioral change. For example, campaigns that involve sailors and local communities can be more effective in raising awareness about the importance of green technology in the shipping sector. [44], Collaboration with non-governmental organizations (NGOs) can enhance the effectiveness of public campaigns. For example, NGOs focused on the environment can help disseminate information and raise public awareness about the im-portance of reducing greenhouse gas emissions, as well as provide education and consultation on green technologies and ways to reduce these emissions. For in-stance, they can organize seminars and workshops for sailors and shipping companies on innovations in green technology. NGOs also play a role in advocacy and lobbying to influence government policies and regulations that support the reduction of greenhouse gas emissions. For example, they can participate in international meetings to promote more environmentally friendly policies. Collabo-ration with non-governmental organizations (NGOs) can enhance the effective-ness of public campaigns. For example, NGOs focused on the environment can help disseminate information and raise public awareness about the importance of reducing greenhouse gas emissions, as well as provide education and consultation on green technologies and ways to reduce these emissions. For instance, they can organize seminars and workshops for sailors and shipping companies on innovations in green technology. NGOs also play a role in advocacy and lobbying to influence government policies and regulations that support the reduction of greenhouse gas emissions. For example, they can participate in international meetings to promote more environmentally friendly policies. [44]. Financial sup-port in the form of subsidies and incentives plays a crucial role in encouraging the adoption of green technology in the shipping sector. For example, the Indonesian government has provided subsidies in the form of exemptions from Value Added Tax (VAT) and Motor Vehicle Fuel Tax on the purchase of fuel for the national shipping industry.

[45]. This support can significantly enhance the shipping company's ability to adopt green technology. In addition, investments and credit from financial institutions also play a crucial role in supporting the development and implementation of green technology by shipping companies. For example, the significant investment required to achieve net zero emissions by or before 2060 in Indonesia can be facilitated with international financial support. [46]. Tax programs and incentives offered by the government, such as carbon cost reductions for companies that use green fuels [44],

should motivate more shipping companies to adopt environmentally friendly technology. Thus, public awareness and financial support are important factors in enhancing the effective-ness of campaigns and the adoption of green technology in the ship-ping sector.

Fig. 5. Trends and technologies in environmentally friendly shipping

An infographic depicting trends and technologies in environmentally friendly shipping, including wind-assisted propulsion systems, air lubrication systems, and greenhouse gas emission reduction targets for 2030 and 2050. The colors blue and green reflect environmental sustainability.

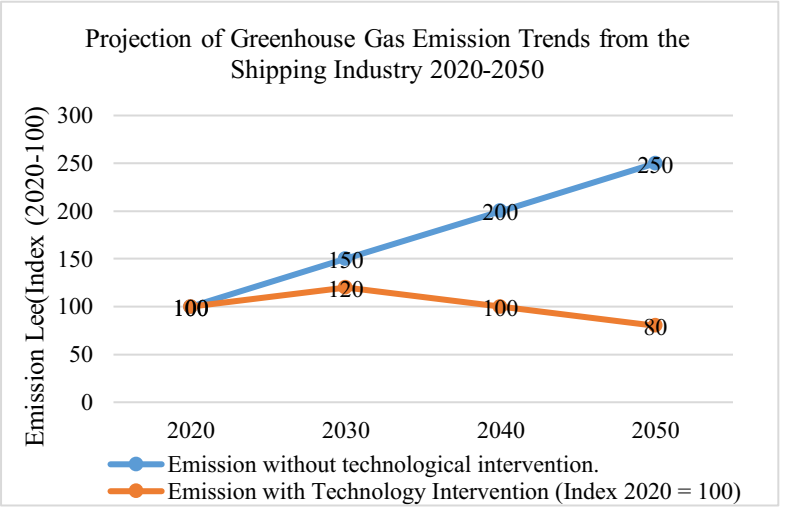

Fig. 6. Projections of greenhouse gas emissions from the shipping industry between 2020 and 2050.

The greenhouse gas emissions project from the shipping industry shows a significant difference between scenarios with and without the implementation of green technology.

Without technological intervention, CO2 emissions and other greenhouse gases are expected to increase significantly, reflecting industrial growth that is not matched by effective mitigation measures. This projection shows that without changes, global emissions from the shipping sector could continue to rise, exacerbating the impacts of climate change.

However, with the implementation of green technologies such as LNG (liquefied natural gas) and biodiesel, the impact on emissions becomes much more positive. This technology offers a significant solution to re-duce the carbon footprint of the shipping industry. For example, the use of LNG and biodiesel can reduce CO2 emissions by up to 80% from 2020 levels by the year 2050. The use of this green technology not only reduces CO2 emissions but also decreases emissions of other toxic gases, such as NOx and SOx, which also contribute to air pollution and climate change.

With the implementation of green technology, emission projections show a significant downward trend, supporting global efforts in climate change mitigation and enhancing the sustainability of the shipping industry. This emphasizes the importance of adopting environmentally friendly technology as a key step in reducing the environmental impact of the shipping sector.

5 Conclusion

This research highlights the crucial impact of integrating technological innovation, regulatory frameworks, public awareness, and financial support in advancing environmental management in the shipping sector. Technological advancements, such as wind-assisted propulsion and air lubrication systems, provide significant reductions in fuel consumption and greenhouse gas emissions, contributing to more sustainable shipping practices. Regulatory measures, such as the sulfur content reduction mandate from the IMO, have effectively reduced harmful emissions and improved environmental conditions around ports. Public aware-ness and CSR activities enhance the adoption of green technology, with initiatives from companies like Norsepower demonstrating tangible benefits. Financial sup-port through mechanisms such as green bonds facilitates the implementation of this technology, making it more accessible to shipping companies. Overall, this study reveals that a diverse approach involving technological, regulatory, social, and financial strategies is crucial for achieving significant progress in reducing the environmental impact of the shipping industry.

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