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# Asian Journal of Law and Policy

Vol. 6 No. 1 (March 2026)

eISSN: 2785-8979

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## Decarbonization of Shipping: International Maritime Organization's Uncertain Pathway Towards Carbon Neutrality

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### ABSTRACT

The International Maritime Organization (IMO) finally has aligned its decarbonization target with the Paris agreement target of net-zero emissions by 2050 through adoption of the 2023 IMO GHG strategy revoking its previous 2018 GHG strategy. The IMO has been working towards decarbonization of shipping for nearly two decades now through implementing policies but unable to control the GHG emissions from shipping as global trade among countries has increased drastically. There is still a gap in fully understanding how carbon emissions are being reduced in international shipping, especially when it comes to the policies and actions in place making it harder to create solid, informed policies. Thus, the latest policy is being applauded by policymakers and business communities and simultaneously facing criticism from other stakeholders on being ambitious but unrealistic. Through a qualitative analysis approach, this study reveals why the IMO's ambitious policy goals are considered unrealistic. The results show that, the IMO, despite setting an ambitious target of net-zero emissions by 2050, due to issues like- technological barriers, high costs, limited market-based support and implication on regulatory enforcement, is still falling behind on its GHG emission reduction pathway. This paper also suggests some realistic solutions which could help immediate cut down of GHG emissions from shipping



© (2026) Asian Journal of Law and Policy, 6(1), 195–217

<https://doi.org/10.33093/ajlp.2026.8>

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Published by MMU Press. URL: <https://journals.mmupress.com/ajlp>



and attain the IMO's net-zero emission reduction target by 2050 and in the process attain 20% to 30% GHG near emission reduction target by 2030.

**Keywords:** Greenhouse gas; Decarbonization of shipping; MARPOL Annex VI; 2023 GHG Strategy; Net-zero

**Received:** 2 June 2025, **Accepted:** 20 February 2026, **Published:** 31 March 2026

## 1. Introduction

The United Nations has declared 2021-2030 the Decade of Ocean Science for Sustainable Development. As oceans cover about 70% of the earth and provide essential ecosystem services like climate management, food, energy, minerals, etc., preserving the ocean's health is currently vital (Bassan et al., 2025). However, the ocean's sustainability is at risk as greenhouse gas (GHG) emissions from shipping and the maritime industry have drastically increased (Munim et al., 2021). Ship emissions considerably impact port environments and coastal zones through their global warming effect, harming natural ecosystems and humans (Guild et al., 2024). The UNFCCC's Kyoto Protocol and Paris Agreement aim to reduce greenhouse gas (GHG) emissions and attain net zero emission by 2050. But the GHG emissions from shipping rose from 977 million tons in 2012 to 1076 million tons in 2018 (International Maritime Organization, 2023). Despite the UNFCCC's efforts to reduce GHG emissions and even 20 years after the adoption of MARPOL Annex VI, the International Maritime Organization (IMO) has yet to create a globally accepted GHG emission regulation for international shipping due to its dynamic nature and obstacles.

The IMO has implemented multiple legal frameworks to reduce greenhouse gas emissions from shipping. The IMO has also been conducting GHG studies on a periodic basis to determine the effectiveness of the policies. However, the results from the 4th IMO GHG Study 2020 show that the policy has failed in reducing GHG emissions; rather, the data show that GHG emission has increased during that period for which criticisms were mounting on IMO's approach on decarbonization of shipping. As a result, the IMO most recently, in 2023, replaced the previous 2018 Revised GHG Strategy with the 2023 IMO Strategy on Reduction of GHG Emissions from Ships. Another key reason for replacing the policy was that the IMO was working towards halving GHG emissions from shipping by 2050, while the mandate of the Paris Agreement was to decarbonize and attain net zero emissions by 2050. Stakeholder criticism forced the IMO to reintroduce a new policy approach aligned with the Paris Agreement target. However, the IMO still requires ships to comply with the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships, which was adopted at MEPC 62 (July 2011) through amendments to MARPOL Annex VI in 2011 and has been in effect since 2013 (Dan-Bunkering, 2024). While the IMO has established a "short-term measure" to reduce ship carbon intensity in 2021, it also has created the Carbon Intensity Indicator (CII) 2023 rating which is to be finalized by 2027. Moreover, from January 1, 2023, it was made mandatory for all ships to figure out their Energy Efficiency Existing Ship Index (EEXI) to

see how energy-efficient they are and gather information for their annual operational CII and CII rating reports. The implications of this rating system are significant for the future, as ships with a poor CII rating ('D' or 'E') for three consecutive years will be required to develop a plan of corrective action. By 2030, the IMO plans to reduce the carbon intensity of all ships by 40% compared to the 2008 baseline, which may impact shipping's GHG emissions by 2027. A crucial stage in the IMO's effort to decarbonize shipping is the implementation of the Energy Efficiency Existing Ship Index (EEXI) and the CII rating system, which are in line with the more general objectives of the 2023 IMO effort on the reduction of GHG emissions from ships. Enforcing these policies will be critical to overcoming obstacles in regulating GHG emissions from international shipping and reaching the targeted reduction by 2027 and beyond.

This study evaluates the 2023 IMO Strategy through a qualitative analysis of regulatory instruments, stakeholder positions, and global governance dynamics. It identifies key shortcomings in emission allocation, regulatory coherence, alternative fuel availability and environmental justice. Moreover, this study proposes realistic and inclusive approaches such as ecosystem-based governance, fuel sustainability standards, and equitable policy incentives that could bridge the gap between ambition and action. By exposing institutional, economic and political barriers, this study contributes to the broader discourse on climate governance in international shipping and offers a pragmatic roadmap toward maritime decarbonization.

## 2. IMO's Global Policy Framework of Shipping Decarbonization

The IMO has been working on regulating GHG emissions from shipping through an umbrella framework set forth in the International Convention for the Prevention of Pollution from Ships (MARPOL). The International Maritime Organization (IMO) established MARPOL as a key global convention to prevent marine pollution from ships.<sup>1</sup> Despite adopting and enforcing regulations for various types of ship pollution in 1973 and 1978, MARPOL failed to address air pollution from shipping due to a confluence of factors (International Maritime Organization, 2025). Primarily, the focus was on visible pollution like oil spills, which were a major concern at the time, particularly after several high-profile tanker accidents. This emphasis on oil, sewage and garbage pollution overshadowed the less understood impacts of air pollution from ships, such as sulfur and nitrogen oxide emissions. Furthermore, there was limited scientific awareness of the long-term environmental consequences of these emissions, coupled with political and industry resistance to the technological upgrades and fuel regulations that would have been necessary to address them. Many maritime nations prioritized economic growth and the shipping industry resisted the added costs. Additionally, there is an absence of established international standards for controlling ship emissions, making regulation difficult to implement and a

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<sup>1</sup> International Convention for the Prevention of Pollution from Ships (adopted 17 February 1973, entered into force 2 October 1983). [https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-\(MARPOL\).aspx](https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx).

lack of robust enforcement mechanisms for emissions control within the existing MARPOL framework. These combined factors meant that air pollution from shipping remained unaddressed until the adoption of Annex VI in 1997, which finally introduced regulations on SO<sub>x</sub> and NO<sub>x</sub> emissions, reflecting a growing understanding of the complex environmental challenges posed by shipping (Čampara et al., 2018).

However, major developing countries like China, Brazil, Chile, Kuwait, Saudi Arabia, India (all these countries have ratified MARPOL Annex VI as it stands today) etc. were still against the no more favour treatment (NMFT)<sup>2</sup> policy of the IMO. This reveals the IMO's struggle to bring all the stakeholders under the same umbrella which deferred it from implementing stricter policy framework initially. At last, MARPOL Annex VI came into force in 2005 through subsequent amendments in 2011 and most recently amended in 2023, which brought significant changes from the previous ones (Tichavska & Tovar, 2015). Though MARPOL Annex VI is the only global regulation addressing ship air emissions, despite some opposition, 100 countries have ratified MARPOL Annex VI, covering 96.65% of world merchant shipping tonnage which regulates limits on SO<sub>x</sub>, NO<sub>x</sub> and prohibits deliberate emissions of ozone-depleting substances (Gillie and Kent, 2024; Shi & Gullett, 2018).<sup>3</sup> In regulating those, the IMO has introduced the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for existing ships, along with a mandatory Data Collection System (DCS). The EEDI requirements were made mandatory for all the new ships through amendments to MARPOL Annex VI at MEPC 62 (July 2011) (International Maritime Organization, n.d.-c). In 2013, the EEDI came into force, requiring all new ships greater than 400 gross tons (GT) built after January 1, 2013 to meet a certain level of efficiency in CO<sub>2</sub> emissions compared to the base level of 2008 (IMO). According to the International Council on Clean Transportation, the EEDI requires new ships to improve efficiency in three phases: 10% more efficient in 2015, 20% more efficient by 2020 and 30% more efficient by 2025 (International Council on Clean Transportation, 2011). The MEPC 74th session of March 2019 approved amendments to the early start of Phase 3 in 2022 and created a new, more stringent "Phase 4" EEDI standard for 2025 (Song, 2020). The Ship Energy Efficiency Management Plan (SEEMP) functions as a cost-effective operational tool for enhancing a ship's energy efficiency (International Maritime Organization, n.d.-c).

The SEEMP emphasizes reducing greenhouse gas emissions from ships by providing methods for reducing fuel consumption and using alternative fuels that produce fewer GHG emissions (Narula, 2018). The SEEMP is not a set rule of operation, but rather a roadmap to try to achieve better fuel efficiency through its guidance regulations. Both the EEDI and SEEMP have been criticized for being less ambitious, non-mandatory goal setting and lacking public disclosure requirements (Tanaka, 2016).

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<sup>2</sup> No more favour treatment—a principle where all the countries should contribute equally to pollution prevention regardless of their actual contribution in terms of pollution.

<sup>3</sup> Marine Environment Protection Committee Resolution 304(72) (13 April 2018) Document MEPC.304(72). [https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304\(72\).pdf](https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf).

The IMO had adopted the Initial Strategy on Reduction of Greenhouse Gas Emissions from Ships in 2018, and has been working to achieve its vision through these energy efficiency management plans (International Maritime Organization, n.d.-b). The initial GHG strategy of the IMO includes a “to reduce the carbon intensity of international shipping (to reduce CO<sub>2</sub> emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008); and that total annual GHG emissions from international shipping should be reduced by at least 50% by 2050 compared to 2008” (International Maritime Organization, n.d.-b).

To meet this target, the strategy suggests an indicative framework of measures to be implemented in the short-term (2018–2023), medium-term (2023–2030) and long-term (after 2030) (International Maritime Organization, 2023). As part of the strategy, in 2021, the IMO adopted the “short-term measure” to reduce ship carbon intensity (Serra & Fancello, 2020). The IMO bases its strategies on data collected from studies on ship emission factors, engine performance and fuel types (Olmer et al., 2017). The Data Collection System (DCS) was adopted through resolution MEPC.278(70) on Amendments to MARPOL Annex VI and is intended to equip the IMO with concrete data on fuel oil consumption to assist Member States in decision-making on enhanced energy efficiency measurements and addressing greenhouse gas emissions from international shipping (International Maritime Organization, n.d.-a). The DCS, which entered into force on March 1, 2018, is a mandatory requirement for ships with 5000 gross tonnage (GT) and above and requires ship operators to record and report their fuel oil consumption data, as well as other, more specific data, including proxies to transport work (International Maritime Organization, n.d.-a). This was done in order to come up with more concrete data on ship fuel oil consumption so that the IMO could finalize its Initial Strategy on Reduction of Greenhouse Gas Emissions from Ships in 2023. Surprisingly, the IMO did not come up with any medium and long-term measures, but rather revoked the Initial Strategy and adopted a new 2023 IMO Strategy on the Reduction of GHG Emissions from Ships.

### **3. 2023 IMO Strategy on Reduction of GHG Emissions from Ships**

The International Maritime Organization (IMO) has recently updated its greenhouse gas (GHG) strategy to align with the Paris Agreement’s goal of net-zero emissions by 2050. The 2023 IMO GHG Strategy supersedes the 2018 Initial GHG Strategy, setting forth a revised ambition to achieve net-zero GHG emissions from international shipping by or around 2050 (International Maritime Organization, n.d.-b). This strategy includes commitments to adopt alternative zero and near-zero GHG fuels by 2030 and sets indicative checkpoints for 2030 and 2040 (Louizou, 2024).

However, the new strategy has faced criticism for being unrealistic and lack of lacking specific policy directives to support the Paris Agreement. The obscurity of the strategy could be seen as a deliberate effort to appease conflicting stakeholders within the maritime industry, reflecting the broader challenges of establishing enforceable measures within the IMO’s political framework. Researchers argue that the 2023 plan is unrealistic and fails to

commit to a just and equitable transition (Kristiansen & Valeur, 2023). Additionally, the policy has been scrutinized for focusing primarily on CO<sub>2</sub> emissions while neglecting other GHGs, which undermines the IMO's broader goal of achieving net-zero emissions. The focus on CO<sub>2</sub> emissions in the IMO's 2023 strategy, despite criticism, can be attributed to several factors, including the complexity of balancing diverse stakeholder interests and the challenges inherent in the maritime industry's regulatory framework (Takebayashi & Yamaguchi, 2024). The strategy's perceived vagueness and emphasis on CO<sub>2</sub> may serve to appease conflicting interests within the industry, reflecting broader issues in establishing enforceable measures within the IMO's political framework. This focus persists due to institutional path dependencies and power dynamics that prioritize economic and competitive interests over comprehensive environmental goals. The maritime industry's regulatory framework is deeply entrenched in historical practices that prioritize CO<sub>2</sub> due to its significant contribution to global emissions, making it a primary target for reduction efforts (Sahin, 2024). The ecological modernization discourse, which emphasizes incremental changes and technology neutrality, creates lock-ins that hinder broader decarbonization efforts, including addressing other GHGs (von Malmberg, 2024). Additionally, economic interests of powerful stakeholders, such as shipping companies and certain states, are served by focusing on CO<sub>2</sub>, as it allows for maintaining competitiveness while meeting moderate emission reduction targets (Li et al., 2024). The strategy's vagueness may be a deliberate effort to navigate conflicting interests, allowing stakeholders to interpret policies in ways that align with their economic goals. The IMO's strategy also faces challenges in aligning international regulations, which often results in fragmented and insufficiently aligned policies that focus on CO<sub>2</sub> due to its quantifiable nature and the existence of measurement frameworks. Furthermore, the lack of comprehensive policy frameworks and incentives to address other GHGs further entrenches the focus on CO<sub>2</sub> emissions (Ibokette et al., 2024). While the focus on CO<sub>2</sub> emissions serves certain economic and competitive interests, it undermines the broader goal of achieving net-zero emissions by neglecting other GHGs. This approach reflects the challenges of balancing diverse stakeholder interests and the limitations of the current regulatory framework, which may require a shift towards more inclusive and comprehensive strategies to ensure a just and equitable transition (Li & Hu, 2024).

A contentious issue within the strategy is the use of the Carbon Intensity Indicator (CII) rating to control ship emissions (Austin, 2023). While the IMO intends to use CII data to finalize its strategy by 2027, this plan is subject to review in 2026, adding complexity and unpredictability to the organization's future (Zhang et al., 2024). The rejection of a CO<sub>2</sub> levy on ships, despite demands from nations like Denmark<sup>4</sup> and France<sup>5</sup> which are actively engaged in green shipping initiatives, further highlights the difficulties in implementing cohesive policies. The rejection was attributed to concerns that such a tax may conflict with

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<sup>4</sup> Denmark is one of the leading countries in developing and implementing green technologies.

<sup>5</sup> France is a major market for green shipping technologies and one of the top investors in offshore wind and green fuels.

national tax legislation and fall outside the scope of the Marine Environment Protection Committee (MEPC) (Dikos & McCoy, 2024).

Even in light of recent developments, the IMO faces criticism for lacking specific policies that support the Paris Agreement. According to researchers, the 2023 plan is unrealistic and does not commit to a just and equitable transition (Krigslund, 2023). In addition, the policy has come under scrutiny for ignoring other GHGs and concentrating just on CO<sub>2</sub> emissions, which runs counter to the IMO's larger goals of achieving net-zero emissions. Another topic of disagreement is the use of the controversial Carbon Intensity Indicator (CII) rating to control ship emissions (Ibokette et al., 2024). The IMO intends to use CII data to finish its 2023 strategy in 2027; however, this plan is subject to review in 2026, which will increase the complexity and unpredictability of the organization's future. In addition, the IMO rejected a CO<sub>2</sub> levy on ships despite demands from nations such as Denmark and France. The lack of adoption is attributed to concerns that such a tax may conflict with national tax legislations and fall outside the scope of the Marine Environment Protection Committee (MEPC). Experts suggest that by 2025, the IMO should develop incentives for the green transition, including a technical standard for maritime fuels to reduce fossil content and an economic incentive through a maritime CO<sub>2</sub> emissions pricing mechanism, potentially paving the way for a tax on fossil fuels. The same principle as in FuelEU Maritime (Kristiansen, 2023).

Absolute well-to-wake GHG emissions trajectories under each scenario vs business as usual scenario (Carvalho & Comer, 2024)



The table above shows IMO's 2050 GHG emissions target in different trajectories, as well as the business-as-usual GHG emissions scenario. While the IMO is aiming for net-zero emissions by 2050, the business-as-usual growth would result in a further increase in GHG emissions from shipping in 2050.

Overall, skepticism surrounds the effectiveness and comprehensiveness of the IMO's updated GHG strategy in addressing the multifaceted challenges of maritime emissions, even though it represents progress towards the Paris Agreement targets.

### **3.1 Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII)**

The IMO, since January 2023, has introduced two crucial regulatory measures that carry significant importance in shipping decarbonization and meet the newly set IMO target of achieving net zero emissions by 2050 in line with the Paris Agreement.

The IMO introduced the Energy Efficiency Existing Ship Index (EEXI) as a regulatory instrument to assess the energy efficiency of existing ships and reduce their greenhouse gas (GHG) emissions. It requires ships to calculate their acquired energy efficiency and compare it to a requisite level, indicated by a reduction factor in connection to the baseline of the Energy Efficiency Design Index (EEDI) for new ships.

The EEXI is part of the IMO's exclusive strategy to combat climate change by developing the shipping industry's environmental performance. This aligns with the Carbon Intensity Indicator (CII), which rates ships based on their operational carbon intensity, connecting the distance traveled and the cargo carried with GHG emissions. The CII encourages ship owners to optimize their operational practices to reduce emissions further. Together, the EEXI and CII represent a dual regulatory approach aimed at achieving the IMO's decarbonization targets. By 2030, the IMO seeks to reduce vessel carbon emissions per transport work by at least 40%, with a more ambitious goal of a 70% reduction by 2050. This is in line with the overall reduction of GHG emissions by 50% across the sector, moving towards net-zero GHG emissions by around 2050 (Laffineur et al., 2023).

The Carbon Intensity Indicator (CII) of the IMO under MARPOL Annex VI, serves as a pivotal metric for gauging a vessel's energy efficiency. It quantifies CO<sub>2</sub> emissions per cargo capacity and nautical mile, with the inaugural verification slated for 2024, reflecting the 2023 operational year. This progressive rating system, ranging from A (optimal) to E, necessitates increasingly stringent benchmarks up to 2030, compelling ship-owners to enhance their fleet's energy efficiency (Rauca & Batrinca, 2023).

The accuracy of the CII comes from the Annual Efficiency Ratio (AER), which takes into account things like the amount of fuel used, the amount of CO<sub>2</sub> emissions, the distance traveled and the deadweight of the vessel. Ships exceeding 5,000 GT must comply with these regulations, including submitting an augmented SEEMP to the IMO. This plan outlines the anticipated operational CII for the next three years, as well as strategies for calculation, reporting and continuous development. The IMO's practice of tightening CII criteria on a yearly basis intends to stimulate perpetual optimization while also encouraging recognition of companies operating ships with high CII scores (Gianni et al., 2022). The EEXI and CII regulations are crucial steps in ensuring that the maritime industry aligns with global efforts to mitigate the impact of climate change.

However, the Carbon Intensity Indicator Cluster also has several drawbacks. Although the CII policy aims to lower emissions, it could inadvertently lead to slower steaming, potentially disrupting the supply chain. Its annual reporting focus may stymie real-time emission reduction initiatives. Furthermore, the CII's absence of lifecycle emissions, such as vessel construction and fuel generation, constrains its environmental effect assessment. The

universal application to all ships disregards operational variety and may disadvantage some vessels (Trakakis et al., 2023). Additionally, compliance charges for any upgrades may disproportionately hit smaller firms, affecting market dynamics. The above-mentioned limitations are required to be adjusted with refined policies to execute more effective and developed maritime industrial development and suitability.

#### **4. Challenges in Regulating International Shipping and Possible Solutions**

##### **4.1 Allocating Emissions**

The most critical step in regulating greenhouse gas (GHG) emissions from international shipping is determining how to allocate these emissions to contributing states. A ship can be constructed, owned and operated by different entities across multiple jurisdictions, further complicated by the open registry system that allows registration in any country (Selin & Cowing, 2018). Additionally, ships carry cargo from various sources and traverse international waters, making emissions attribution complex. Consequently, the Kyoto Protocol excluded shipping emissions from its targets and mandated the IMO to measure and record these emissions independently (Kopela, 2016).

There are multiple methods for allocating carbon dioxide emissions, such as by the origin or destination of cargo, the flag state, or the location where fuel is sold (Rauca & Batrinca, 2023). Each approach assigns emissions responsibility differently, creating challenges for consensus-building among states. Research suggests that adopting the “polluter pays” principle and establishing an international emissions trading system could incentivize emission reductions (Kerr, 2024). However, the proposals discussed during the ISWG 18 session of the IMO regarding the GHG Fuel Standard (GFS) revealed that route-based exemptions and the exclusion of smaller vessels could undermine emission reduction efforts. Exemptions for developing countries routes could exclude 34% of emissions (330 MtCO<sub>2</sub>) and vessels under 5000 GT could account for 15% of total emissions. These exemptions could allow nearly 50% of shipping emissions to remain unregulated, threatening the effectiveness of the GFS (Kristiansen & Valeur, 2023). While the IMO is ambitious with its target and applauds its progress with statistical data, it must also consider these factors before representing its progress towards the target reduction of GHG emissions.

##### **4.2 Issue of Ocean Governance**

The structure and function of oceans are unique compared to those of terrestrial realms. Covering 71% of the earth’s surface, with the Pacific Ocean alone capable of containing all continents, the application of terrestrial regulatory paradigms to the maritime environment is often ineffective (Zacharias & Ardrion, 2019). The International Maritime Organization (IMO) faces significant challenges in implementing its decarbonization policies, particularly

as regional approaches, such as the European Union (EU), set divergent baselines for the carbon emissions reduction baseline of 1990 whereas the IMO has set 2008 as its baseline.

Furthermore, regulatory discrepancies between domestic and international requirements create additional challenges. For example, the United States bases domestic maritime regulations on engine power, whereas IMO standards often use gross tonnage (Clapp, 2014). This requires ship designers and operators to navigate multiple regulatory frameworks. The need to synchronize market forces, performance-based policies and regulatory mandates at both national and international levels (Corbett & Winebrake, 2010). Data reliability is another obstacle. Inconsistent emission measurement methods lead to discrepancies in the reported data, impairing regulatory enforcement (Trimmer & Godar, 2019). Variability in ship engines, hull conditions, fuel consumption and sea states further complicates data accuracy (Miola et al., 2010). Without robust data collection systems, enforcing emission reduction policies remains challenging. Accountability mechanisms are also underdeveloped. Existing regulatory instruments do not clearly define the obligations of shipping corporations to reduce GHG emissions (Rahim et al., 2016). Additionally, the IMO's policies often favor shipowners and corporate interests, reflecting broader trends in international environmental governance, where powerful industry stakeholders exert influence over regulatory processes (Chircop et al., 2018). The life cycle of ships further complicates decarbonization efforts. Ships typically operate for 20 to 25 years, and fleet replacement rates remain low at 1.5% annually (Horvath et al., 2018). Even if all new ships adopted low-emission technologies, older vessels would likely remain operational beyond 2050 (Martinić, Radica & Barbir, 2018). Liquefied Natural Gas (LNG), often viewed as a transitional fuel, reduces SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub> emissions but poses concerns due to methane leakage, a potent greenhouse gas (Ekemezie & Digitemie, 2024).

These regulatory challenges necessitate both immediate and long-term solutions to mitigate GHG emissions from the shipping industry. Short-term measures include slow steaming and route optimization, which can reduce fuel consumption by 27% when the speed is decreased by 12% (Silva & Moreira, 2024). Incremental design improvements, such as hull optimization and waste heat recovery, can reduce emissions by up to 5% per vessel (Huy et al., 2024).

The IMO must incorporate these measures immediately as the International Court of Justice (ICJ), in July 2024, issued Advisory Opinion No. 187 about the Obligations of States over Climate Change. In the initial submission of this research, it provides significant interpretative insights that may affect the IMO's regulatory trajectory (Nguyen & Nguyen, 2025). In paragraphs 271-315, the ICJ highlighted that under customary international law, governments are obligated to implement appropriate measures both individually and collectively to avert substantial environmental harm, including those resulting from greenhouse gas emissions. The Court underscored that such obligations extend extraterritorially when a state's actions or those under its jurisdiction or control, contribute to climate damage outside its borders (Prieur et al., 2024).

Paragraphs 336-368 further analyzed requirements under the United Nations Convention on the Law of the Sea (UNCLOS), confirming that governments are required to safeguard and maintain the marine ecosystem against the effects of climate change, including ocean warming, acidity and rising sea levels (Browne et al., 2024). The ICJ notably associated these obligations with the necessity for vigorous enforcement of additional environmental treaties, such as the UNFCCC and the Paris Agreement (De Spiegeleir, 2025).

For the IMO, these interpretations might substantially bolster the legal argument for aligning maritime decarbonization measures with the aims of the Paris Agreement as well as with binding customary and treaty-based duties under UNCLOS. This may warrant the implementation of more stringent measures such as compulsory lifecycle GHG accounting, absolute emissions limits and market-based strategies on the grounds that inaction would violate established international legal obligations. Furthermore, the opinion's acknowledgment of shared but differentiated obligations may necessitate the IMO to adjust its policies to guarantee equal treatment of poorer nations, while concurrently upholding the overarching goal of achieving net-zero emissions by 2050. In summary, the ICJ's advisory judgment emphasizes that the IMO's decarbonization plans constitute legal duties for its member states under customary international law and maritime law, rather than just policy options.

### **4.3 Alternative Fuel Option**

Non availability of alternative fuel or green fuel is another key challenge for shipping to achieve carbon neutrality. Fuel switching can be considered an option in this regard. Fuel switching to low-sulfur fuels can significantly reduce emissions, although methane slip from LNG-powered ships poses climate risks (Herdzik & Lesnau, 2024).

Innovative low-emission fuels offer potential solutions for decarbonizing the maritime sector. Ammonia, a zero-emission fuel, presents a promising pathway (Mashruk et al., 2024). But its widespread adoption requires substantial investment in new production facilities, storage, and distribution infrastructure (Raza et al., 2024). Significant retrofitting of existing vessels and engine designs is also necessary. Furthermore, safety concerns surrounding ammonia's toxicity and corrosiveness must be addressed through robust handling protocols and crew training. Biofuels, derived from sustainable biomass, combined with carbon capture and sequestration (CCS) technologies, could achieve a net-negative carbon footprint, effectively removing CO<sub>2</sub> from the atmosphere (Chavando et al., 2024). However, scaling up sustainable biofuel production to meet global shipping demand remains challenging. Shore power infrastructure at ports, allowing vessels to connect to the electrical grid while docked, can eliminate emissions during port stays, significantly improving local air quality and reducing noise pollution in coastal communities (Zhao, 2024). This requires investment in port-side electrical connections and vessel compatibility.

However, these technological solutions must be assessed alongside ethical and economic considerations. Shipping decarbonization involves trade-offs between

environmental objectives, economic costs and global trade stability (Motlagh et al., 2023). Developing countries could struggle with compliance costs, raising concerns about equitable policy implementation. The proposed remedial unit (RU) prices for non-compliance under the GFS range from \$802 to \$1,048 per tonne of CO<sub>2</sub>, which could disproportionately impact smaller firms and developing nations (Longva et al., 2024). Institutional dynamics within the IMO reveal systemic biases favoring developed nations and corporate interests, consistent with patterns in international environmental governance (Hörteborn & Hassellöv, 2023). Industry lobbying and consensus-driven decision-making often dilute ambitious policies (Corbett & Winebrake, 2010). Addressing these disparities requires strengthening accountability, increasing transparency and enhancing the participation of developing countries and non-state actors (Mavrakos et al., 2024).

The IMO's Global Fuel Standard (GFS) risks incentivizing the use of harmful biofuels, such as those derived from palm and soy oil. These fuels, while technically reducing direct emissions, are associated with indirect land use change (ILUC) emissions, which can actually worsen the climate impact compared to traditional heavy fuel oil (Roux et al., 2024). The demand for biofuels could lead to deforestation and the conversion of agricultural land, requiring an estimated 35 million hectares (the size of Germany) to meet the shipping industry's biofuel needs by 2030. This not only exacerbates emissions but also raises food security concerns (Escobar et al., 2024).

A potential solution from the provided text is for the IMO to establish clear sustainability criteria for biofuels under the GFS, similar to the approach taken by the EU's FuelEU Maritime and RefuelEU regulations, which exclude feed and food-based biofuels like palm and soy. Implementing such criteria would ensure that only biofuels with verifiable low ILUC risks, such as waste-based biofuels (e.g., used cooking oil, animal fats), are permitted. Additionally, the IMO could prioritize the development and scaling of green e-fuels, such as green hydrogen or ammonia, through financial and political incentives to reduce reliance on biofuels altogether (Yacout et al., 2024).

#### **4.4 Addressing Regulatory Gaps and Advancing Ecosystem-Based Shipping Governance**

Another key challenge global shipping industry is facing today is the regulatory gaps that fail to comprehensively address the environmental impacts of shipping on biodiversity and the climate. While the International Maritime Organization's (IMO) 2023 Greenhouse Gas (GHG) strategy targets net-zero emissions by 2050, several critical environmental pressures associated with shipping such as underwater noise pollution, ship strikes on marine species, ballast water discharge, waste management and chemical pollution from scrubbers remain underregulated or inconsistently enforced (Santos & Serra, 2024). The shipping sector operates across jurisdictions, often resulting in fragmented governance and a lack of cohesive environmental safeguards. This regulatory fragmentation exacerbates threats to marine biodiversity, ecosystem services and coastal communities, particularly as shipping expands into sensitive and less regulated areas like the Arctic and remote high seas.

To bridge the regulatory gaps and promote a globally sustainable shipping industry, an Ecosystem-Based Approach to Shipping Governance should be prioritized. This approach seeks to integrate biodiversity conservation, pollution reduction, and climate action into maritime governance and operational practice. By aligning shipping activities with the health of marine ecosystems, the industry can reduce its environmental footprint while advancing towards its decarbonization goals. A key element of this approach is the mainstreaming of Ecosystem-Based Management (EBM) into shipping governance (Akhtar et al., 2024). EBM emphasizes a holistic perspective that considers the cumulative impact of shipping activities on marine ecosystems. To achieve this, ecosystem-based considerations should be embedded into shipping-related regulations, policies and planning processes at international, regional and national levels (Li et al., 2024). Additionally, area-based management tools such as Particularly Sensitive Sea Areas (PSSAs), Emission Control Areas (ECAs) and Marine Protected Areas (MPAs) should be expanded and strengthened to comprehensively address shipping pressures in environmentally vulnerable regions (Alshiqi et al., 2024).

Strengthening international and regional cooperation is another crucial step towards ecosystem-based governance. Effective protection of marine biodiversity requires harmonized action across jurisdictions. Therefore, enhanced coordination between the IMO, the Convention on Biological Diversity (CBD), the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement and regional seas conventions is essential to ensure that biodiversity, pollution and climate objectives are fully integrated into shipping governance (Wang & Zhang, 2024). IMO Member States should be encouraged to advance mandatory measures, particularly in areas such as reducing underwater radiated noise (URN) and phasing out environmentally harmful practices like open-loop scrubbers (BIMCO, 2024). Developing overall monitoring and data systems is fundamental to supporting evidence-based governance and ensuring compliance. Real-time monitoring systems utilizing satellite data, remote sensing and vessel tracking technologies should be implemented to assess the environmental impact of shipping activities (Chen et al., 2024). Furthermore, global and regional data-sharing platforms should be established to promote transparency and enable stakeholders to make informed decisions (Vidar et al., 2023). The shipping industry itself can play a leading role in driving environmental stewardship through voluntary measures and innovation. Shipowners, ports and insurers can be incentivized to adopt practices that exceed existing environmental standards, such as slow steaming, just-in-time port arrival and the use of noise-reducing vessel designs. Simultaneously, the development and adoption of low impact alternative fuels and nature-positive shipping technologies should be encouraged to reduce the sector's ecological footprint.

Finally, inclusive decision making and capacity building are vital to ensure that shipping governance reflects the diverse interests of those affected by maritime activities. Participatory governance processes should actively involve Indigenous Peoples, local coastal communities and scientific experts in the development and implementation of policies. Investment in capacity-building initiatives across the maritime sector is necessary to equip

stakeholders with the knowledge and skills needed to support the transition to ecosystem-based shipping governance.

Adopting a globally integrated ecosystem-based approach will enhance the resilience of marine ecosystems, mitigate biodiversity loss and reduce pollution, while simultaneously facilitating the shipping industry's transition to decarbonization (Onwubiko & Worlanyo, 2024). This approach aligns with international commitments such as the Kunming-Montreal Global Biodiversity Framework (GBF) and the broader Sustainable Development Goals (SDGs). It positions the shipping sector as a proactive partner in safeguarding planetary health and ensuring that maritime activities contribute to a sustainable future for the oceans (Kudyakov, 2024).

A theoretical framework grounded in global environmental governance theories, such as the regime complex approach and principal-agent theory, could help analyze the interactions between states, corporations and regulatory institutions (Rodriguez Luna & Martínez Marín, 2024). A methodological approach employing qualitative content analysis of IMO negotiations and stakeholder interviews would enable a more robust examination of power dynamics and policy formation (Kenney-Lazar et al., 2023).

Lastly to say, while technological innovations and policy instruments are essential for decarbonizing international shipping, addressing underlying governance challenges is equally crucial (Adanma & Ogunbiyi, 2024). Equitable and transparent policymaking, coupled with robust enforcement mechanisms, is vital to ensure that the shipping sector contributes effectively to global climate goals.

## **5. Conclusion**

The IMO adopted its decarbonization policy, 'MARPOL Annex VI', in 1997, which came into force in 2005. Nearly two decades have passed and IMO is yet to finalize the policy and come up with a complete regulation to regulate GHG emissions from shipping. Until the adoption of the most recent 2023 IMO GHG Strategy, the IMO was working towards the finalization of 'IMO Initial GHG Strategy 2018' in 2023. But it failed to do so and adopted a completely new strategy, revoking the initial GHG Strategy. While the changes brought by the IMO in alignment with its target with the Paris Agreement goal of net-zero emissions are praiseworthy, the process of achieving the target is still unclear. Moreover, the IMO is still walking on its old path of regulating GHG only instead of GHGs, despite major push from stakeholders. Another concern is the alternative fuel IMO is pushing for, as LNG is responsible for 20% more methane leakage and the World Bank was against the use of LNG due to its global warming effect (Lehtoranta et al., 2023). Recent policy, though, was praised by ship-owners and corporate parties but criticized by researchers, NGOs and civic society, which shows that the IMO's 2023 Strategy is still far away from achieving its target.

To sum up, the main purpose of this write-up was to present an analysis of IMO's newly adopted decarbonization policy and show that the recent policy, even though applauded, lacks many of the key aspects and would simply further delay the process of a

concrete policy as before. Despite all the recent amendments to MARPOL Annex VI by the IMO, shipping decarbonization will not be possible as long as the gap between the planned reduction and the effort required is aligned. Hence, instead of implementing a new policy to regulate GHG emissions from shipping, a realistic pathway towards decarbonization is dubious. Since the IMO has finally aligned its target with the Paris Agreement target, it must finalize the pathway to achieve it as soon as possible. The sooner IMO considers the key challenges discussed above and takes into consideration the solutions accordingly, the faster it would be on its track to meet the newly adopted target of net-zero emissions by 2050.

### **Acknowledgement**

This paper is a follow-up of the Masters thesis paper of the Corresponding author, which was written during the LLM in Maritime Law at the University of Oslo. Gratitude to Mr. Viktor Weber, PhD, for his motivated in completion of the paper. Also, special thanks to the Scandinavian Institute of Maritime Law for data collection support.

### **Funding Statement**

No funding was received.

### **Authors' Contributions**

Imran: Conceptualization, methodology, investigation, formal analysis, and writing - original draft.

Wahi: Validation, investigation, formal analysis, and writing - review & editing.

### **Conflict of Interest Declaration**

The authors declare no conflict of interest.

### **Ethics Approval**

This study did not involve human or animal subjects or personal data and therefore did not require ethical approval.

### **AI Usage Declaration**

No Artificial Intelligence (AI) tools were used in the research or writing of the manuscript.

### **References**

Adanma, U. M., & Ogunbiyi, E. O. (2024). Evaluating the effectiveness of global governance mechanisms in promoting environmental sustainability and international relations.

- Finance & Accounting Research Journal*, 6(5), 763–791.  
<https://doi.org/10.51594/farj.v6i5.1151>
- Akhtar, M. Z., Zaman, K., & Khan, M. A. (2024). Unveiling the role of ecosystem-based fisheries management in mitigating biodiversity loss: A panel study of Asian countries. *International Journal of Rural Management*, 21(1), 66–79.  
<https://doi.org/10.1177/09730052241292924>
- Alshiqi, S., Bekteshi, X., Jóźwik, B., Altin, F. G., Dogan, M., & Petrossyants, T. (2024). *The impact of shipping connectivity on environmental quality, financial development, and economic growth in RCEP countries*. Preprints.org.  
<https://doi.org/10.20944/preprints202410.2559.v1>
- Austin, N. (2023, October 13). *CII—Change in the air?* Lexology.  
<https://www.lexology.com/library/detail.aspx?g=f2f3000e-18db-4051-a3e5-e3982f799ef5>
- Bassan, N., Flamand, A., & Clausen, A. (2025). Developing the ambition for action in the Ocean Decade to 2030. *ICES Journal of Marine Science*, 82(1), fsae195.  
<https://doi.org/10.1093/icesjms/fsae195>
- BIMCO. (2024, February 7). Ships must cut underwater noise or face mandatory regulation. *International Shipping News*. <https://www.hellenicshippingnews.com/ships-must-cut-underwater-noise-or-face-mandatory-regulation/>
- Browne, G., Natano, K., & Whipps, S., Jr. (2024, May 21). *Request for an advisory opinion submitted by the Commission of Small Island States on Climate Change and International Law*. International Tribunal for the Law of the Sea.  
[https://www.itlos.org/fileadmin/itlos/documents/cases/31/Advisory\\_Opinion/C31\\_Adv\\_Op\\_21.05.2024\\_orig.pdf](https://www.itlos.org/fileadmin/itlos/documents/cases/31/Advisory_Opinion/C31_Adv_Op_21.05.2024_orig.pdf)
- Čampara, L., Hasanspahić, N., & Vujičić, S. (2018). Overview of MARPOL Annex VI regulations for prevention of air pollution from marine diesel engines. *SHS Web of Conferences*, 58, 01004. <https://doi.org/10.1051/shsconf/20185801004>
- Carvalho, F., & Comer, B. (2024, January 26). *Aligning the IMO's greenhouse gas fuel standard with its GHG strategy and the Paris Agreement*. International Council on Clean Transportation. <https://theicct.org/aligning-the-imos-greenhouse-gas-fuel-standard-with-its-ghg-strategy-and-the-paris-agreement-jan24/>
- Chavando, A., Silva, V., Cardoso, J., & Eusebio, D. (2024). Advancements and challenges of ammonia as a sustainable fuel for the maritime industry. *Energies*, 17(13), 3183.  
<https://doi.org/10.3390/en17133183>
- Chen, L., He, Y., & He, Y. (2024). Factors influencing marine ecological environment governance toward sustainability: A case study of Zhejiang Province. *Frontiers in Marine Science*, 11, 1359879. <https://doi.org/10.3389/fmars.2024.1359879>

- Chircop, A., Doelle, M., & Gauvin, R. (2018). The challenge of regulating GHG emissions from international shipping. In *Shipping and climate change: International law and policy considerations* (pp. 27–55). Centre for International Governance Innovation. <http://www.jstor.org/stable/resrep24972.8>
- Corbett, J. J., & Winebrake, J. J. (2010). The role of international policy in mitigating global shipping emissions. *Brown Journal of World Affairs*, 16(2), 143–154. <http://www.jstor.org/stable/24590915>
- Dan-Bunkering. (2024, October 14). *Key requirements in MARPOL Annex VI*. <https://dan-bunkering.com/maritime-insights-and-knowledge-hub/key-requirements-in-marpol-annex-vi/>
- De Spiegeleir, M. A. T. B. (2025, July 28). *The ICJ's advisory opinion on climate change: An introduction*. Climate Law Blog. <https://blogs.law.columbia.edu/climatechange/2025/07/24/the-icjs-advisory-opinion-on-climate-change-an-introduction/>
- Dikos, D., & McCoy, T. J. (2024). Interactive attained and predicted CII grade calculator tool. In *SNAME Maritime Convention*. SNAME. <https://doi.org/10.5957/smc-2024-079>
- Ekemezie, I. O., & Digitemie, W. N. (2024). Assessing the role of LNG in global carbon neutrality efforts: A project management review. *GSC Advanced Research and Reviews*, 18(3), 91–100. <https://doi.org/10.30574/gscarr.2024.18.3.0095>
- Escobar, N., Seber, G., Skalsky, R., Wögerer, M., Jung, M., & Malina, R. (2024). Spatially-explicit land use change emissions and carbon payback times of biofuels under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSA). *Science of The Total Environment*, 948, 174635. <https://doi.org/10.1016/j.scitotenv.2024.174635>
- Gianni, M., Pietra, A., Coraddu, A., & Taccani, R. (2022). Impact of SOFC power generation plant on Carbon Intensity Index (CII) calculation for cruise ships. *Journal of Marine Science and Engineering*, 10(10), 1478. <https://doi.org/10.3390/jmse10101478>
- Gillie, M., & Kent, G. (2024). Expert review of AI-generated responses to the top ten patient complaints in primary care. *Academia Medicine*, 1(4). <https://doi.org/10.20935/acadmed7388>
- Guild, R., Wang, X., & Quijón, P. A. (2024). Climate change impacts on coastal ecosystems. *Environmental Research: Climate*, 3(4), 042006. <https://doi.org/10.1088/2752-5295/ad9f90>
- Herdzik, J., & Lesnau, A. (2024). Decarbonization in shipping—The hopes and doubts on the way to hydrogen use. *Energies*, 17(18), 4668. <https://doi.org/10.3390/en17184668>
- Hörteborn, A., & Hassellöv, I.-M. (2023). Economic incentives and technological limitations govern environmental impact of LNG feeder vessels. *Journal of Cleaner Production*, 429, 139461. <https://doi.org/10.1016/j.jclepro.2023.139461>

- Horvath, S., Fasihi, M., & Breyer, C. (2018). Techno-economic analysis of a decarbonized shipping sector: Technology suggestions for a fleet in 2030 and 2040. *Energy Conversion and Management*, 164, 230–241. <https://doi.org/10.1016/j.enconman.2018.02.098>
- Huy, N. Q., Duong, P. A., Nam, T. T., Ha, T. T. T., Ryu, B. R., & Kang, H. (2024). A novel proposal for a marine fuel cell system utilizes LNG as a sustainable and green fuel for the future of shipping. *Journal of Advanced Marine Engineering and Technology*, 48(2), 46–54. <https://doi.org/10.5916/jamet.2024.48.2.46>
- Ibokette, A. I., Ogundare, T. O., Akindele, J. S., Anyebe, A. P., & Okeke, R. O. (2024). Decarbonization strategies in the U.S. maritime industry with a focus on overcoming regulatory and operational challenges in implementing zero-emission vessel technologies. *International Journal of Innovative Science and Research Technology*, 9(11), 131–162. <https://doi.org/10.38124/ijisrt/ijisrt24nov829>
- International Council on Clean Transportation. (2011). *The energy efficiency design index (EEDI) for new ships* (ICCT Policy Update No. 15). [https://theicct.org/wp-content/uploads/2021/06/ICCTpolicyupdate15\\_EEDI\\_final.pdf](https://theicct.org/wp-content/uploads/2021/06/ICCTpolicyupdate15_EEDI_final.pdf)
- International Maritime Organization. (2023). *2023 IMO strategy on reduction of GHG emissions from ships*. <https://www.imo.org/en/ourwork/environment/pages/2023-imo-strategy-on-reduction-of-ghg-emissions-from-ships.aspx>
- International Maritime Organization. (2025, April 11). *Draft regulations will set mandatory marine fuel standard and GHG emissions pricing for shipping to address climate change*. <https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-approves-netzero-regulations.aspx>
- International Maritime Organization. (n.d.-a). *IMO data collection system (DCS)*. <https://www.imo.org/en/ourwork/environment/pages/data-collection-system.aspx>
- International Maritime Organization. (n.d.-b). *IMO's work to cut GHG emissions from ships*. <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx>
- International Maritime Organization. (n.d.-c). *Improving the energy efficiency of ships*. <https://www.imo.org/en/OurWork/Environment/Pages/Improving%20the%20energy%20efficiency%20of%20ships.aspx>
- Kenney-Lazar, M., Johnson, A., Sultana, F., Himley, M., Bebbington, A. J., Havice, E., Rice, J., & Osborne, T. (2023). Relational environmental governance: A critical framework for praxis with the material world. *Journal of Political Ecology*, 30(1), 677–698. <https://doi.org/10.2458/jpe.5542>
- Kerr, B. (2024). Climate obligations for international shipping [Doctoral dissertation, Utrecht University]. <https://doi.org/10.33540/2406>
- Kopela, S. (2016, May 3). Shipping and climate change: The IMO is making progress - though worryingly slowly. *EJIL: Talk!: Blog of the European Journal of International Law*.

<https://www.ejiltalk.org/shipping-and-climate-change-the-imo-is-making-progress-though-worryingly-slowly/>

- Krigslund, N. (2023, June 29). IMO hit with scathing criticism ahead of crucial meeting. *ShippingWatch*. <https://shippingwatch.com/regulation/article16214021.ece>
- Kristiansen, T. (2023, July 13). Researchers: New skills are needed at IMO to reach climate goals. *ShippingWatch*. <https://shippingwatch.com/regulation/article16287045.ece>
- Kristiansen, T., & Valeur, I. T. (2023, July 7). Shipping companies praise climate deal: ‘An important milestone’. *ShippingWatch*. <https://shippingwatch.com/regulation/article16276653.ece>
- Kudyakov, A. K. (2024). Применение экосистемного подхода к ликвидации и возмещению накопленного вреда окружающей среде [Application of the ecosystem approach to liquidation and compensation of accumulated damage to the environment]. *Economy and Law*, (10), 95–108. <https://doi.org/10.18572/0134-2398-2024-10-95-108>
- Laffineur, L., Spiegelenberg, F., Sidenvall Jegou, I., Smith, T., & Bonello, J.-M. (2023, December 1). *The implications of the IMO revised GHG strategy for shipping*. Global Maritime Forum. <https://globalmaritimeforum.org/insight/the-implications-of-the-imo-revised-ghg-strategy-for-shipping/>
- Lehtoranta, K., Kuittinen, N., Vesala, H., & Koponen, P. (2023). Methane emissions from a state-of-the-art LNG-powered vessel. *Atmosphere*, 14(5), 825. <https://doi.org/10.3390/atmos14050825>
- Li, H., Xing, W., Jiao, H., Yang, Z., & Li, Y. (2024). Deep bi-directional information-empowered ship trajectory prediction for maritime autonomous surface ships. *Transportation Research Part E: Logistics and Transportation Review*, 181, 103367. <https://doi.org/10.1016/j.tre.2023.103367>
- Li, W., & Hu, Z. (2024). Pathways in the governance of shipping decarbonization from perspective of balancing the conflicting interests. *Frontiers in Marine Science*, 11, 1479528. <https://doi.org/10.3389/fmars.2024.1479528>
- Longva, T., Eide, M. S., Endresen, Ø., Sekkesæter, Ø., Helgesen, H., & Rivedal, N. H. (2024). Marginal abatement cost curves for CO2 emission reduction from shipping to 2050. *Maritime Transport Research*, 6, 100112. <https://doi.org/10.1016/j.martra.2024.100112>
- Louizou, D. (2024). *Shipping in energy transition pathways to meet IMO 2050 greenhouse gas reduction targets* [Master’s thesis, University of Piraeus]. [https://doi.org/10.26267/unipi\\_dione/4704](https://doi.org/10.26267/unipi_dione/4704)
- Mashruk, S., Shi, H., Mazzotta, L., Ustun, C. E., Aravind, B., Meloni, R., Alnasif, A., Boulet, E., Jankowski, R., Yu, C., Alnajideen, M., Paykani, A., Maas, U., Slefarski, R., Borello, D., & Valera-Medina, A. (2024). Perspectives on NOX emissions and impacts from ammonia

- combustion processes. *Energy & Fuels*, 38(20), 19253–19292. <https://doi.org/10.1021/acs.energyfuels.4c03381>
- Mavrakos, A. S., Tsaousis, T., Faggioni, N., Caviglia, A., & Manzo, E. (2024). A digital twin approach for selection and deployment of decarbonization solutions for the maritime sector. In B. Karakostas & T. Katsoulakos (Eds.), *State-of-the-art digital twin applications for shipping sector decarbonization* (pp. 26–52). IGI Global Scientific Publishing. <https://doi.org/10.4018/978-1-6684-9848-4.ch002>
- Miola, A., Ciuffo, B., Marra, M., & Giovine, E. (2010). *Analytical framework to regulate air emissions from maritime transport*. Publications Office of the European Union. <https://doi.org/10.2788/78254>
- Motlagh, H. R. S., Zadeh, S. B. I., & Garay-Rondero, C. L. (2023). Towards International Maritime Organization carbon targets: A multi-criteria decision-making analysis for sustainable container shipping. *Sustainability*, 15(24), 16834. <https://doi.org/10.3390/su152416834>
- Munim, Z. H., Saha, R., Schøyen, H., Ng, A. K. Y., & Notteboom, T. E. (2021). Autonomous ships for container shipping in the Arctic routes. *Journal of Marine Science and Technology*, 27(1), 320–334. <https://doi.org/10.1007/s00773-021-00836-8>
- Narula, K. (2018). Lowering emissions from the shipping sector. In K. Narula, *The maritime dimension of sustainable energy security* (Vol. 68, pp. 187–209). Springer Singapore. [https://doi.org/10.1007/978-981-13-1589-3\\_9](https://doi.org/10.1007/978-981-13-1589-3_9)
- Nguyen, P. D., & Nguyen, Y. T. H. (2025). Assessing the role of international judicial advisory opinions in the evolution of international environmental law in response to climate change. *University of Bologna Law Review*, 10(1), 1–34. <https://doi.org/10.6092/ISSN.2531-6133/22335>
- Olmer, N., Comer, B., Roy, B., Mao, X., & Rutherford, D. (2017). *Greenhouse gas emissions from global shipping, 2013–2015*. International Council on Clean Transportation. [https://theicct.org/sites/default/files/publications/Global-shipping-GHG-emissions-2013-2015\\_ICCT-Report\\_17102017\\_vF.pdf](https://theicct.org/sites/default/files/publications/Global-shipping-GHG-emissions-2013-2015_ICCT-Report_17102017_vF.pdf)
- Onwubiko, C., & Worlanyo, D. (2024). *A review: Nature-based solutions*. Preprints.org. <https://doi.org/10.20944/preprints202409.1583.v1>
- Prieur, M., Torre-Schaub, M., Duarte Júnior, D., Gaillard, É., Le Bris, C., Mekouar, M. A., Michelot, A., Mercure, P.-F., Piette, J., Juste Ruiz, J., Robert-Cuendet, S., Simou, S., Sozzo, C. G., & Tietzmann e Silva, J. A. (2024). *Exposé écrit à la Cour internationale de Justice fondé sur la résolution 77/276 du 29 mars 2022 de l'Assemblée générale des Nations Unies, par laquelle un avis consultatif a été demandé à la Cour sur les obligations des États à l'égard des changements climatiques: Amicus curiae du Centre international de droit comparé de l'environnement* [Written statement to the International Court of Justice based on United Nations General Assembly resolution 77/276 of 29 March 2022, by which an advisory

- opinion was requested from the Court on the obligations of States in respect of climate change: Amicus curiae of the International Centre of Comparative Environmental Law]. Centre international de droit comparé de l'environnement. [https://climatecasechart.com/wp-content/uploads/non-us-case-documents/2024/20240320\\_18913\\_na.pdf](https://climatecasechart.com/wp-content/uploads/non-us-case-documents/2024/20240320_18913_na.pdf)
- Rahim, M. M., Islam, Md. T., & Kuruppu, S. (2016). Regulating global shipping corporations' accountability for reducing greenhouse gas emissions in the seas. *Marine Policy*, 69, 159–170. <https://doi.org/10.1016/j.marpol.2016.04.018>
- Rauca, L., & Batrinca, G. (2023). Impact of carbon intensity indicator on the vessels' operation and analysis of onboard operational measures. *Sustainability*, 15(14), 11387. <https://doi.org/10.3390/su151411387>
- Raza, A., Hadia, M., Zunaira-Tu-Zehra, & Ali Khan, L. (2024). Perspective of NH<sub>3</sub> as a clean energy zero-carbon fuel. In J. J. Roa Rovira (Ed.), *Exergy—Theoretical background and case studies*. IntechOpen. <https://doi.org/10.5772/intechopen.1005666>
- Rodriguez Luna, Ó. D., & Martínez Marín, J. E. (2024). Climate governance: Relationship between the port states, the coastal states, and the flag states through the Venn diagram. In *10th International Conference on Maritime Transport (Maritime Transport X)*. Universitat Politècnica de Catalunya, Iniciativa Digital Politècnica. <https://doi.org/10.5821/mt.13203>
- Roux, M., Ekvall, T., Schmidt, J., & Croxatto Vega, G. (2024). Which rules to follow? How differences in renewable fuel standards obscure the potential climate impact of transportation fuels. *Frontiers in Energy Research*, 12, 1490137. <https://doi.org/10.3389/fenrg.2024.1490137>
- Sahin, A. U. (2024). IMO 2023 Revised Emission Reduction Strategy and Regulatory Challenges of Maritime Decarbonization. *European Journal of Commercial Contract Law*, 16(1), 25–33. <https://doi.org/10.7590/187714624x17132716463900>
- Santos, M. M., & Serra, E. G. (2024). Legislação e regulamentação sobre a emissão de gases de efeito estufa na navegação: Estado, evolução e impactos no Brasil [Legislation and regulation on the emission of greenhouse gases in shipping: State, evolution and impacts in Brazil]. *Revista fisio&terapia*, 28(140), 41–42. <https://doi.org/10.69849/revistaft/pa10202411102241>
- Selin, H., & Cowing, R. (2018, December 18). Cargo ships are emitting boatloads of carbon, and nobody wants to take the blame. *The Conversation*. <https://theconversation.com/cargo-ships-are-emitting-boatloads-of-carbon-and-nobody-wants-to-take-the-blame-108731>
- Serra, P., & Fancello, G. (2020). Towards the IMO's GHG goals: A critical overview of the perspectives and challenges of the main options for decarbonizing international shipping. *Sustainability*, 12(8), 3220. <https://doi.org/10.3390/su12083220>

- Shi, Y., & Gullett, W. (2018). International regulation on low-carbon shipping for climate change mitigation: Development, challenges, and prospects. *Ocean Development & International Law*, 49(2), 134–156. <https://doi.org/10.1080/00908320.2018.1442178>
- Silva, S. R. E., & Moreira, M. B. (2024). An optimisation-based approach to reduce fuel consumption and emissions from shipping navigation. In A. A. Kana (Ed.), *Proceedings of the 15th International Marine Design Conference: IMDC-2024*. TU Delft OPEN Books. <https://doi.org/10.59490/imdc.2024.832>
- Song, P. (2020). *Impact of GHG mitigation policy on China's shipping industry and suggestions* [Master's thesis, World Maritime University]. World Maritime University. [https://commons.wmu.se/cgi/viewcontent.cgi?article=1264&context=msem\\_dissertations](https://commons.wmu.se/cgi/viewcontent.cgi?article=1264&context=msem_dissertations)
- Takebayashi, M., & Yamaguchi, H. (2024). The net zero policy and its impact on the air transport network: Considering the modal competition between airlines and high-speed rail. *Transport Economics and Management*, 2, 122–129. <https://doi.org/10.1016/j.team.2024.06.002>
- Tanaka, Y. (2016). Regulation of greenhouse gas emissions from international shipping and jurisdiction of states. *Review of European, Comparative & International Environmental Law*, 25(3), 333–346. <https://doi.org/10.1111/reel.12181>
- Tichavska, M., & Tovar, B. (2015). Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port. *Transportation Research Part E: Logistics and Transportation Review*, 83, 126–140. <https://doi.org/10.1016/j.tre.2015.09.002>
- Trakakis, A., Daremas, N., Papatheodorou, M., Chatzinikolaou, S., Papadopoulos, C., & Kaiktsis, L. (2023, March 7–8). *CII compliance: Effects of operational and technological measures on current levels and time development of calculated CII* [Conference session]. SNAME 8th International Symposium on Ship Operations, Management and Economics, Athens, Greece. <https://doi.org/10.5957/some-2023-039>
- Trimmer, C., & Godar, J. (2019). *Calculating maritime shipping emissions per traded commodity* (SEI Brief). Stockholm Environment Institute. <https://www.sei.org/publications/shipping-emissions-per-commodity/>
- Vidar, A., Ella, E., & Göte, I. (2023). International environmental law and marine pollution in the Pacific Islands: Promoting sustainable ocean governance. *Law and Economy*, 2(11), 6–14. <https://doi.org/10.56397/le.2023.11.02>
- von Malmberg, F. (2024). At the controls: Politics and policy entrepreneurs in EU policy to decarbonize maritime transport. *Review of Policy Research*, 42(5), 1243–1276. <https://doi.org/10.1111/ropr.12609>
- Wang, J., & Zhang, Y. (2024). The area-based management tools coordination between IMO and BBNJ agreement regimes and its implications on vessel pollution control. *Frontiers in Marine Science*, 11, 1341222. <https://doi.org/10.3389/fmars.2024.1341222>

- Yacout, D. M. M., Tysklind, M., & Upadhyayula, V. K. K. (2024). Socio-economic implications of forest-based biofuels for marine transportation in the Arctic: Sweden as a case study. *Frontiers in Climate*, 6, 1414813. <https://doi.org/10.3389/fclim.2024.1414813>
- Zacharias, M., & Ardron, J. (2019). *Marine policy: An introduction to governance and international law of the oceans* (2nd ed.). Taylor & Francis. <https://doi.org/10.4324/9781351216227>
- Zhang, J., Zhang, Z., & Liu, D. (2024). Comparative study of different alternative fuel options for shipowners based on carbon intensity index model under the background of green shipping development. *Journal of Marine Science and Engineering*, 12(11), 2044. <https://doi.org/10.3390/jmse12112044>
- Zhao, H. (2024). Simulation research on ammonia-hydrogen mixed combustion engine. *Highlights in Science Engineering and Technology*, 88, 578. <https://doi.org/10.54097/3kbma921>

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