

Navigating the Decarbonization Imperative: Regulatory Gaps, Financial Viability, and the Future of Zero-Carbon Fuel Governance in International Shipping

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Abstract: Global shipping stands at a pivotal moment in its effort to align with worldwide adopted climate goals. Being accountable for roughly 2.9-3% of whole anthropogenic greenhouse gases (GHG) emissions, the sector faces escalating burden to evolve towards a net-zero trajectory.¹ The IMO revised its GHG strategy in 2023, aiming net-zero emissions by or around 2050 while diagnosing contradictory nationwide settings. Yet, the existing plan remains disjointed and insufficient. Prevailing mechanisms such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) highlight incremental operative and technical developments that, by themselves, cannot deliver the transformative decarbonization required. Their focus on competence, absent vigorous fiscal instruments, exposes a grave policy void. The shift to alternate, zero-carbon fuels commands collective investment potentially exceeding USD 1.65 trillion by 2050, generally dedicated to fuel supply infrastructure.² This transition is economically hampered by the significantly higher Total Cost of Ownership (TCO) of clean fuels (increasing costs by 124% to 731%).³ Thus, the absence of a compulsory global Market-Based Mechanism (MBM), such as a substantial carbon levy, forms a critical legal deficit that fails to affect environmental externalities and bridges the competitive cost gap. Combining the issue of IMO's institutional flimsiness; inadequate administrative capacity, ambiguity over its directive to administer large financial instruments, and constant political divisions—mostly around the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), all these factors have shaped a governance inactivity and regional fragmentation, most visibly in the EU's unilateral initiatives under the Emissions Trading System (ETS) and FuelEU Maritime, which threaten the uniform regulatory framework sought by industry actors. Bridging these economical, legal, and institutional rifts through an obligatory binding global carbon-pricing policy with synchronized infrastructural investment is vital if global shipping is to align credibly with the Paris Agreement's temperature goals.

Keywords: Decarbonization, IMO, Carbon Tax, Alternative Fuels, Regulatory Fragmentation

1. Introduction: Highlighting the Loopholes and Policy Gaps

International shipping serves as the backbone of global trade, facilitating the movement of over 80 percent of world commerce by volume. Yet, its contribution to climate change remains substantial. Without decisive regulatory and technological interventions, total shipping-related GHG emissions are projected to rise by nearly 50 percent above 2018 levels by mid-century. In response, the International Maritime Organization (IMO) adopted a revised greenhouse gas strategy in 2023, setting a goal of achieving net-zero emissions by or around 2050.⁴ However, a closer examination of the regulatory architecture reveals significant deficiencies—loopholes, inconsistencies, and systemic gaps—that collectively threaten the attainment of this objective.

1.1 Policy Loopholes and Gaps in the Decarbonization Regime:

- a) **Loopholes in Operational Efficiency Metrics:** The IMO's current policy emphasis rests on technical and operational efficiency, primarily through instruments such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII). While these mechanisms represent important first steps, they are widely regarded as insufficient for achieving deep decarbonization.⁵ Compliance is often achieved through relatively simple adjustments—such as engine power limitation—rather than through the adoption of genuinely transformative propulsion technologies. As a result, these measures yield only marginal gains, failing to trigger the structural changes necessary for a zero-carbon future.⁶
- b) **The MBM and Economic Policy Gap:** There is broad consensus that technical and operational measures must be supported by **Market-Based Mechanisms (MBMs)** to create effective price signals for fuel switching. Despite

¹ Gray, N., O'Shea, R., Smyth, B., Lens, P.N. and Murphy, J.D., 2024. An assessment of decarbonisation pathways for intercontinental deep-sea shipping using power-to-X fuels. *Applied Energy*, 376, p.124163.

² Carlo, R., Marc, B.J., de la Fuente Santiago, S., Smith, T. and Søgaard, K., 2020. Aggregate investment for the decarbonisation of the shipping industry. *UMAS, London, UK*.

³ Möller, A.D. and Graeper, C.H.J., FUELING THE FUTURE.

⁴ MEPC, R., 2023. 2023 IMO strategy on reduction of GHG emissions from ships.

⁵ Bayraktar, M. and Yuksel, O., 2023. *Ocean Engineering*, 278, p.114295.

⁶ Serra, P. and Fancello, G., 2020. *Sustainability*, 12(8), p.3220.

long-standing debate and industry pressure, the IMO regulatory mix **lacks any implemented economic instruments**. This failure leaves untaxed Heavy Fuel Oil (HFO) economically preferable and allows the substantial cost disparity of alternative fuels (TCO increases 124% to 731%) to persist, stalling massive investment in infrastructure and technology development.⁷

c) **Governance and Consistency Gap:** The IMO's governance framework suffers from both political and institutional inertia. Traditionally oriented toward regulating mature technologies, the organization has struggled to pivot toward overseeing multiple emergent, zero-carbon solutions simultaneously. This inertia is compounded by member states' reluctance to empower the IMO with the legal authority to implement complex financial or innovation-based mechanisms, such as a global R&D fund.⁸ Consequently, the regime remains fragmented, lacking both the coherence and administrative capacity necessary to coordinate a global energy transition in shipping.

d) **Technological Accountability Loopholes:** The introduction of new fuels raises unique environmental

uncertainties that current regulations fail to capture comprehensively. Ammonia, for instance, while promising as a carbon-free fuel, risks emitting significant quantities of nitrous oxide (N₂O)—a greenhouse gas nearly 300 times more potent than CO₂—if not tightly controlled. Similarly, the true carbon footprint of e-methanol depends heavily on carbon-source accounting practices; if the CO₂ feedstock originates from non-renewable sources, its lifecycle emissions can be drastically understated. These gaps reveal the need for robust lifecycle governance capable of addressing secondary emissions and ensuring that nominally “green” fuels deliver verifiable climate benefits.⁹

1.2 Highlighting Each Issue and Linking it to the Legal Gap Existent

The fundamental policy objective of decarbonization is severely hampered by major, interconnected challenges, each corresponding to a specific legal or regulatory deficit at the global level.

Issue	Description of Challenge	Corresponding Legal/Regulatory Gap
I. Financial and Investment Lock-In	The aggregate investment required to achieve decarbonization by 2050 is estimated at up to USD 1.9\$ trillion. The greatest share 85% to 90% is needed for fuel supply infrastructure. Shipowners face a massive economic disincentive, as electrofuels (like e-methanol) increase the vessel's TCO by hundreds of percent compared to conventional fuel. ¹⁰ Vessels may only be profitable for retrofitting if offset by substantial carbon taxes and high charter rates.	The legal deficit lies in the failure to establish a global MBM . A levy of at least is needed to incentivize fuel switching. The IMO's abandonment of MBM discussions due to internal divisions leaves a vacuum where environmental externalities are not internalized, thereby sustaining the fossil fuel's competitive advantage.
II. Political and Institutional Inertia	The IMO, despite being the global regulator, is a small technical body (fewer than 100 technical staff) that lacks the financial and human capacity to oversee complex financial/innovation mechanisms necessary for a transition. Decision-making is slow and consensus-driven, often leading to gridlock.	This constitutes a legal/institutional capacity gap . Member states frequently express uncertainty over whether the IMO has the legal authority or organizational capacity to administer sophisticated financial schemes, such as an R and D fund or a global levy. This hesitation is compounded by political obstruction and conflicts over the application of the CBDR-RC principle.
III. Technical Viability and GHG Accounting	Promising fuels like green hydrogen, FAME biodiesel, and bio-methanol offer high decarbonization potential 74-94% reduction compared to HFO. However, widespread adoption is stalled by infrastructure gaps. Furthermore, leading candidates like Ammonia introduce significant non-CO ₂ risks: its combustion byproducts NO, 297 times more potent than CO ₂ are a highly sensitive parameter that could negate climate benefits. ¹¹	The legal response to these risks is delayed. Safety and regulatory standards (e.g., in MARPOL/IGF Code) for these emerging fuels (Ammonia, Hydrogen) are still being developed, creating a regulatory void that hinders commercial deployment. Although the IMO adopted LCA Guidelines in 2023 integrating full Well-to-Wake accounting into mandatory regulation is a crucial pending legal measure required to accurately measure GHG performance across the fuel life cycle.
IV. Regulatory Fragmentation	IMO's failure to regulate GHG effectively and swiftly led to regional powers, notably the EU taking unilateral action. The EU's implemented the ETS (phased inclusion from 2023) and the FuelEU Maritime regulation.	A key legal vulnerability emerges from the growing risk of fragmented jurisdiction and the potential for carbon leakage across regulatory boundaries. While the European Union's initiatives have undeniably accelerated momentum toward maritime decarbonization, they have also disrupted the uniform competitive conditions that the global shipping industry depends upon. In response, the IMO's revised strategy seeks to reassert coherence by advancing universally applicable standards. Yet, despite these efforts, the underlying tension between region-specific climate action and the pursuit of a globally harmonized regime remains unresolved.

⁷ Eide, T.M., 2020. *Regulatory Uncertainties of the Sustainability Transition A Qualitative Study of the Norwegian Shipping Industry's Response to Stricter Environmental Regulation* (Master's thesis, University of Stavanger (Norway)).

⁸ Aiken, D., 2023. Maritime governance: Contextual factors affecting implementation of IMO instruments.

⁹ Hayhurst, A.N. and Lawrence, A.D., 1992. Emissions of nitrous oxide from combustion sources. *Progress in energy and combustion science*, 18(6), pp.529-552.

¹⁰ Lim, Y., Alternative Fuels for Environmentally-Friendly Ships.

¹¹ Task, I.B., 2025. Lowering Hinders for Maritime Biofuels.

1.3 Legal Gaps with a Comparative Cross-Border Jurisdictional Analysis

he international legal regime governing the reduction of greenhouse-gas emissions from shipping is defined by a fundamental shortcoming on the part of its global regulator, the IMO. Its inability to enforce sufficiently rigorous standards has, in turn, prompted a wave of reactive measures at the regional and unilateral levels, as states and economic blocs seek to fill the resulting regulatory vacuum.

1) The Global Regime (IMO) and the Enforcement Gap

The IMO's regulatory framework, implemented chiefly through MARPOL Annex VI, relies on binding instruments that set out both technical and operational obligations for flag states. Among the most prominent of these are the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII).

- a) **Compliance Loophole in Efficiency Metrics:** Although compliance with the CII is compulsory, its focus on operational efficiency—measured in terms of CO₂ emitted per tonne-mile—can produce counterproductive outcomes. For instance, it may incentivize “slow steaming,” a practice that lowers emissions per voyage segment but extends overall travel time, thereby increasing cumulative emissions across the global fleet and reducing the efficiency of supply chains.¹² Similarly, compliance with the EEXI standard can often be achieved through relatively inexpensive measures such as permanently limiting engine power, allowing shipowners to meet regulatory requirements without committing to substantive technological innovation or investment in genuinely transformative propulsion systems.¹³
- b) **Transparency and Accountability Deficit:** The IMO's original Data Collection System (DCS) for monitoring fuel consumption has faced criticism for its limited transparency, as the collected data were anonymized and withheld from public access. This opacity in reporting undermines the accountability required to ensure genuine compliance and informed policy evaluation. Efforts to relax these access restrictions have progressed slowly, largely due to ongoing concerns regarding the protection of commercially sensitive information.
- c) **The MBM Legal Void:** The core legal gap remains the **absence of an agreed market mechanism**. This failure is directly attributed to the IMO's reliance on consensus among 175 member states, complicated by the opposition of major flag states (often invoking the CBDR-RC principle). This legal void prevents the establishment of a **global carbon price**, which is critical for incentivizing fuel switching and ensuring a truly level playing field.

2) The Regional Regime (European Union) and Jurisdictional Overreach

Frustration with the slow and insufficient pace of IMO action motivated the European Union EU to assert regional jurisdiction over maritime transport emissions.

- a) **EU Emissions Trading System (ETS):** The EU ETS phase-in for shipping began in 2024, requiring ships calling at EU ports to account for their GHG emissions. Notably, the ETS covers 100% of emissions on voyages between EU ports, and 50% of emissions on voyages between an EU port and a third-country port.
- b) **FuelEU Maritime Regulation:** Adopted in 2023, this regulation imposes increasingly stringent limits on the GHG intensity of energy used on board, mandating an 80% reduction by 2050 compared to the 2020 baseline. Critically, it incorporates a **Well-to-Wake (WtW) life cycle approach**, moving beyond the IMO's traditional reliance on Tank-to-Wake accounting.¹⁴
- c) **Cross-Border Tension (Jurisdictional Conflict):** The European Union's unilateral measures have contributed to growing regulatory fragmentation, a development widely criticized by global industry stakeholders for eroding the uniform standards essential to international shipping. The partial extension of the EU Emissions Trading System (ETS) to voyages that occur beyond EU territorial waters has been particularly contentious, frequently challenged with reference to Article 211 of UNCLOS.¹⁵ Although EU legislation includes review provisions intended to harmonize its framework with any forthcoming, more stringent IMO agreements, the existing approach still carries the risk of carbon leakage, as vessels may attempt to circumvent additional costs by rerouting operations through proximate non-EU ports.

1.4 Policy and Legal Suggestions to the Same

Addressing the prevailing policy gaps, institutional stagnation, and jurisdictional fragmentation demands a coordinated and robust policy framework—one that integrates stringent regulation, well-designed economic incentives, and a significant strengthening of institutional capacity.

- 1) **Mandatory Global Carbon Pricing (Bridging the Economic Gap):**
 - a) **Legal Action:** The IMO must immediately finalize and implement a mandatory **GHG Levy (Carbon Tax)**. This measure should apply uniformly to all member states and be set at a price point demonstrably high enough (e.g., aiming for parity, requiring or greater) to financially compel investment in low- and zero-carbon fuels.
 - b) **Policy Function:** The substantial revenues generated must be utilized to create an **equitable transition** by funding R and D for new fuels, subsidizing essential fuel supply infrastructure globally, and providing

¹² Wei, J., 2021. Analytical review of countermeasures for the effective implementation of marine greenhouse gas regulations by the member states of IMO.

¹³ Psillas, A., 2022. Effective ways to reach EEXI limit for existing vessels and implications.

¹⁴ Miao, H., Feng, X. and Li, X., 2025. Economic viability of arctic shipping under IMO environmental regulations: a well-to-wake

assessment of different carbon tax scenarios. *Frontiers in Marine Science*, 12, p.1575551.

¹⁵ Murphy, H.C., The Extension of the EU ETS to Aviation and Shipping: Examining the Legality of Unilateral Environmental Measures under Public International Law and World Trade Organisation Law.

dedicated financial assistance/capacity building for vulnerable developing countries.

2) Institutional Reinforcement and Capacity Building:

- a) **Legal Action:** Member states must overcome political resistance regarding the IMO's mandate and capacity. Negotiations should confirm the IMO's legal authority to oversee and administer complex financial mechanisms (like the proposed International Maritime Research and Development Board, IMRB) to de-risk investment in long-term technologies.
 - b) **Policy Function:** Enhance the transparency of the IMO decision-making and reporting system, specifically by expanding access to (non-anonymized) vessel performance data DCS to ensure industry accountability and facilitate informed policy choices.
- ## 3) Integrate Life Cycle Accountability and Stricter Standards:
- a) **Legal Action:** The IMO should accelerate the incorporation of the 2023 Life Cycle Assessment (LCA) Guidelines into the MARPOL framework, making Well-to-Wake (WtW) emission accounting a mandatory standard. This integration is essential to generate accurate, comparative assessments of alternative marine fuels and ensure that emission evaluations reflect their full environmental impact.
 - b) **Policy Function:** It is equally crucial to establish strict low-emission performance standards for new WtW fuels, ensuring that engine technologies are specifically designed to minimize secondary greenhouse gas emissions.
- ## 4) Leveraging National Action Plans (NAPs) for Infrastructure Development
- a) **Legal Action:** The IMO should issue formal guidance encouraging member states to adopt National Action Plans (NAPs) as the primary domestic legal instrument for coordinating infrastructure investments—such as bunkering facilities and shore-power systems—and for implementing tailored national policy interventions.
 - b) **Policy Function:** These NAPs should focus on systematically dismantling domestic market barriers. For example, they could introduce tax exemptions or other fiscal incentives for low-carbon shore-side electricity, which currently faces a competitive disadvantage due to high taxation and operational costs.

1.5 Regulations in India and Strategies for Overcoming Challenges

Available information on India's domestic regulatory framework for controlling GHG emissions from shipping remains limited. The existing evidence indicates that national priorities continue to center on technological advancement and sectoral development rather than the imposition of binding emission reduction mandates.

1) Status of Regulations and Legal Context

- a) **Global Position (CBDR-RC):** India has consistently upheld the principle of *Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC)* in IMO deliberations. This stance has been used to resist the introduction of more stringent global regulatory

mechanisms—particularly Market-Based Mechanisms (MBMs) such as a uniform GHG levy—on the grounds that such measures could perpetuate historical inequities and disproportionately burden developing nations. India has therefore emphasized the need for financial assistance, technology transfer, and capacity-building support from developed countries to meet its energy efficiency and decarbonization goals.

- b) **Domestic Policy Direction (Hydrogen):** Although India's maritime sector has yet to receive focused regulatory attention for decarbonization, the government has articulated ambitious plans to integrate green hydrogen into its broader transportation strategy, with potential applications in shipping. This emerging policy orientation underscores India's intent to transition toward cleaner fuel sources, even as regulatory frameworks are still evolving.
- c) **Implementation and Institutional Capacity:** India has been identified as one of the pilot participants under the IMO's *Global Maritime Energy Efficiency Partnerships (GloMEEP) Project*, which seeks to assist developing nations in adopting energy-efficient maritime practices and advancing corresponding legal and policy reforms. This collaboration marks an important step toward building institutional capacity and aligning national efforts with international decarbonization goals.

2) Legal Gaps and Policy Challenges

India faces a major challenge in closing the “green energy gap,” as domestic resources and funding frequently aren't enough to support the infrastructure and technology needed for a shift to alternative fuels. At the same time, a political focus mainly on external financial commitments often slows down domestic legal and market reforms, delaying the adoption of forward-looking policies.

3) Suggestions to Overcome Challenges

To align India's significant maritime presence with global decarbonization objectives, several policy and domestic measures are recommended:

- a) **Integrate Green Hydrogen Strategy at Home:** India should weave its ambitious Green Hydrogen initiatives into a unified National Action Plan for shipping. This plan should coordinate investments in port-side bunkering and distribution networks for hydrogen and ammonia, with a focus on streamlining logistics and enhancing port efficiency to cut fuel demand right away.
- b) **Promote Equity While Supporting Global Mechanisms:** While upholding the principles of CBDR-RC for receiving climate funds, India could adopt a more proactive stance in endorsing a global GHG levy. This approach not only signals commitment to international carbon pricing but also ensures India can secure revenues from the levy for climate adaptation, infrastructure development, and capacity-building efforts.
- c) **Strengthen Port-State Enforcement:** Domestic enforcement of MARPOL Annex VI should be reinforced, complemented by incentives for leading ships at Indian ports. Tailored schemes—such as port fee rebates or priority docking—can reward vessels that cut emissions beyond regulatory requirements, positioning India's ports as hubs for green shipping corridors.

2. Conclusion

The shift of international shipping toward net-zero emissions is ultimately a governance challenge, complicated by immense technical and economic hurdles and a lagging global regulatory framework. This analysis highlights significant gaps in the IMO's current approach: it leans heavily on incremental efficiency measures, such as the EEXI and CII, which leave operational loopholes, while failing to implement the crucial Market-Based Mechanism necessary to level the playing field for zero-carbon fuels and drive the trillions of dollars needed for infrastructure investment. Much of this inertia stems from institutional constraints, including limited capacity and unclear mandates, as well as political deadlock, where the principle of CBDR-RC is frequently cited to delay decisive global action.

The rise of regional and national measures—like the EU ETS and initiatives such as shore power promotion in the UK—underscores both the fragility of global coordination and the real risk of fragmentation. Technical challenges are further compounded by the need for robust regulation of emerging fuels, ensuring that potent non-CO₂ greenhouse gases are strictly controlled and that life-cycle assessments are applied accurately to avoid misleading carbon accounting.

Meeting the 2050 net-zero goal requires more than incremental adjustments. Legally, this calls for the immediate adoption of a unified global carbon pricing mechanism and the mandatory integration of rigorous Well-to-Wake life-cycle accountability into IMO rules. Policy measures should also strengthen the IMO's institutional capacity and push national governments—through National Action Plans—to remove domestic barriers to clean technology adoption. Only through a coordinated, multi-jurisdictional approach that is both economically rational and legally enforceable can the shipping industry accelerate its transition and mitigate the financial, technical, and environmental risks of continued inaction.