Policy brief

Marine fuel transition

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Aligning global shipping climate policies with life cycle perspective

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The IMO Net-Zero Framework promotes adoption of low climate impact marine fuel through combination of pricing mechanism and fuel standard; however, fuel choice depends on competition for clean energy across sectors. Policies must consider life cycle perspective to avoid shifting impacts to the fuel supply chain and address wider environmental impacts, including land use and mineral resource depletion.

BASED ON Kanchiralla, F. M., Brynolf, S., Hansson, J. & Grahn, M. *Nat. Energy* https://doi.org/10.1038/s41560-026-02079-6 (2026).

The policy problem

Shipping-specific policies are important to meet the greenhouse gas (GHG) emission reduction targets set by International Maritime Organization (IMO). The proposed "IMO Net-Zero Framework" (NZF) approval was postponed in October 2025, and other policy designs are being discussed. The NZF includes two mechanisms: first, a greenhouse gas fuel intensity standard (GFI) that includes a life cycle perspective; and second, a pricing mechanism for GHG emissions.

Increased understanding of how different policy architectures, including the NZF, will drive the transition of the shipping sector, and whether these policy architectures create unintended risks such as shifting to fuels with high upstream emissions, is essential for effective regulation and ongoing policy discussions. The availability of low-climate-impact fuels is another key aspect. However, this is not determined by shipping policy alone but depends on the development of the wider energy system, including total demand and competition for renewable electricity and biomass across sectors.

The findings

Climate policies are needed to drive decarbonization of the shipping sector. Our assessment of different shipping policies confirms that it is critical to have a life cycle perspective on the GHG emissions to avoid shifting emissions upstream and to reduce net emissions from shipping. The cost-effective choice of marine fuel under different shipping policies is closely linked to competition from other sectors in the energy system such as biomass availability.

The NZF promotes biofuel adoption in shipping, but with cross-sector competition for biomass under climate targets, ammonia produced from renewable electricity and biomass might play an important role for several shipping segments, while electrification is preferred for vessels with daily bunkering possibilities (Fig. 1). However, this transition risks increasing other environmental impacts, including land use and mineral resource depletion. The implementation of policies with a standalone economic policy (for example, levies) without a life cycle perspective has a substantial risk of increasing life cycle climate impact from shipping.

The study

This study uses a global energy system optimization model to evaluate six different shipping policy scenarios. The model represents the entire global energy system to determine cost-effective pathways under different constraints and policies by optimizing supply of primary energy to final use. Selected shipping policies were represented inside the model and tested with and without a global climate constraint, allowing the study to identify the specific effect of shipping policy from broader decarbonization pressure from other sectors.

To consider other environmental impacts besides GHG, we integrated a prospective life cycle assessment into the model. This captures environmental impacts that conventional shipping policies overlook, including land use, mineral resource use, eutrophication and particulate matter. To test the robustness of findings, Monte Carlo simulations with 1,000 model runs and targeted sensitivity analyses are performed varying key parameters including biomass availability, carbon storage capacity, investment costs, and technology growth rates.

Messages for policy

- Shipping policies that adopt pricing only on exhaust emissions (for example, a tank-to-wake levy) without a life cycle perspective risk increasing life-cycle climate impact.
- The proposed IMO Net-Zero Framework is an important step for shipping decarbonization but stricter greenhouse gas fuel intensity levels are needed to meet the net-zero emission target.
- Policies should support the development of bioenergy with carbon capture and storage, as negative emissions influence future fuel choices in shipping.
- Stricter regulation on nitrogen oxides and nitrous oxide is crucial to avoid unintended environmental issues as ammonia emerges as a cost-effective fuel option in several cases.
- Shipping decarbonization should address wider environmental trade-offs, including land use and mineral resource depletion, to avoid unintended burden-shifting.

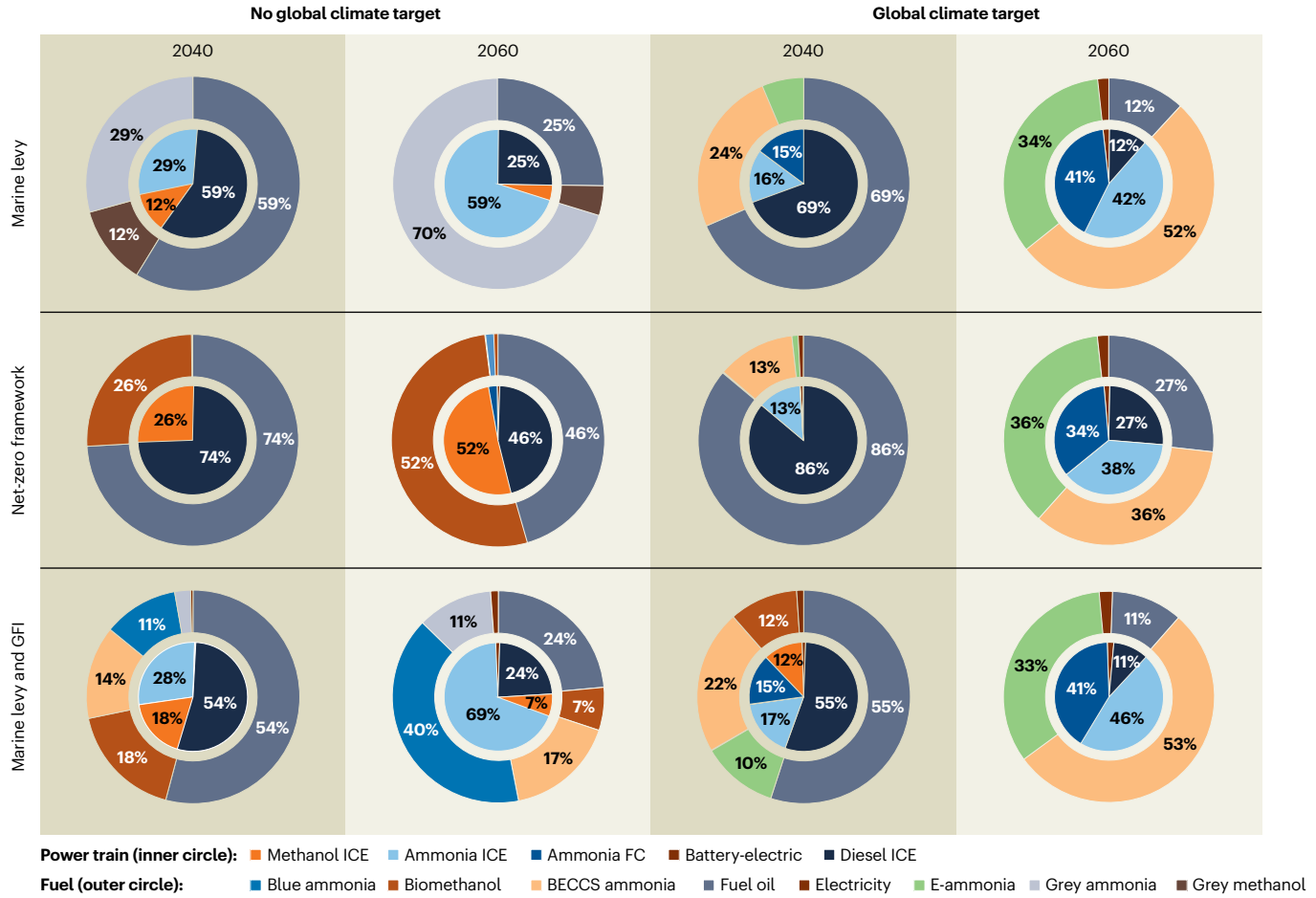

Fig. 1 | Cost-effective fuel and technology choices for global shipping under different policies and climate targets. Each panel shows the share of energy from different fuels (outer circle) and powertrain (inner circle) for global shipping for the years 2040 and 2060 under three policy scenarios with and without a global 2 °C climate target. Under a scenario without a global climate target, a marine levy on tank-to-wake emissions without a life cycle perspective favours grey ammonia that has a high climate impact in fuel production. Under the IMO Net-Zero Framework, without a global climate target, biomethanol becomes cost-effective whereas ammonia is found to be a cost-effective choice in most cases; the ammonia production pathway depends on both shipping policy and climate target. Figure adapted from Kanchiralla, F. M., Brynolf, S., Hansson, J. & Grahn, M. *Nat. Energy* https://doi.org/10.1038/s41560-026-02079-6 (2026).

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Further reading

1. Kanchiralla, F. M., Brynolf, S. & Mjelde, A. Role of biofuels, electro-fuels, and blue fuels for shipping: environmental and economic life cycle considerations. *Energy Environ. Sci.* **17**, 6393–6418 (2024).
This study provides the foundational lifecycle environmental and economic data for different fuels from different production routes including biofuels, e-fuels, and blue fuels, that underpin the LCA integration used in the present analysis.
2. Müller-Casseres, E. et al. International shipping in a world below 2 °C. *Nat. Clim. Change* **14**, 600–607 (2024).
This multi-model study demonstrates that international shipping is unlikely to meet 2 °C-compatible targets supporting the finding that cross-sectoral climate ambition is essential for deep shipping decarbonization.
3. Speizer, S. et al. Integrated assessment modeling of a zero-emissions global transportation sector. *Nat. Commun.* **15**, 4439 (2024).
This integrated assessment of zero-emission transport shows how transport decarbonizing interacts with land use, energy system costs, and resource competition globally, providing important context for the cross-sectoral dynamics explored in this study.
4. Kanchiralla, F. M. et al. How do variations in ship operation impact the techno-economic feasibility and environmental performance of fossil-free fuels? A life cycle study. *Appl. Energy* **350**, 121773 (2023).

This life cycle study of how ship segments and operational patterns affect fuel feasibility and environmental performance provides key vessel-level insights that inform the fleet-wide modelling assumptions used in the present work.

5. Bullock, S., Mason, J. & Larkin, A. Are the IMO's new targets for international shipping compatible with the Paris Climate Agreement?. *Clim. Policy* **24**, 963–968 (2023).
This study evaluates whether the IMO's revised 2023 GHG targets are sufficient to meet Paris Agreement goals, directly motivating the need for the stronger policy combinations assessed in the present work.

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Competing interests
The authors declare no competing interests.