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From mitigation to adaptation: Problematizing climate change in the maritime transport industry

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Abstract

The literature on climate change in the maritime transport industry has grown rapidly in the last few years. Yet as the research agenda has progressed, scientific debates have become more isolated and fragmented, making it difficult to translate new findings into broader policy debates. This article draws on problematization methodology to help organize the scientific debate on maritime emissions and to identify analytical gaps and challenges. We argue that scholars investigate shipping's emission problem from four distinct analytical perspectives— (1) international laws and regulations, (2) markets and economics, (3) engineering and technology, and (4) authority and legitimacy. Each of these perspectives problematizes maritime emissions in specific ways, leading to different policies and strategies to address the problem. We call for better integrating these four literatures and highlight three crosscutting areas and problems for future research. First, developing institutions that facilitate market and engineering solutions; second, integrating climate mitigation and adaptation research; and third, focusing on justice concerns to ensure an equitable green transition in the maritime industry.

This article is categorized under:

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KEYWORDS

climate change, decarbonization, maritime shipping, mitigation, problematization

1 | INTRODUCTION

Shipping is a major emitter, contributing 1056 million tons of greenhouse gas (GHG) emissions annually, and reducing these emissions is vital to decarbonize supply chains and to reach international climate goals. Climate-related risks such as extreme weather events and higher waves, but also the handling of new dangerous green fuels, increase the risk of dangerous marine accidents (International Maritime Organization, 2020, p. 1; Rojon et al., 2021).

A large and interdisciplinary literature has emerged in the last few years to study these issues and to guide policy and industry leaders in developing strategies to address them. This includes a wide range of studies on shipping market

regulation, green technology development, and climate policy options. Moreover, a nascent literature investigates adaptation challenges and how ports can adjust to rising sea levels, storm surges, and other weather risks.

This noteworthy proliferation of scientific studies has advanced our collective knowledge and helped policymakers develop carbon countermeasures for the maritime transport industry. However, it has also led to analytical complexity and fragmentation. Studies have become increasingly sophisticated and technical—for example, studies of specific alternative fuels and market designs—which risks accessibility and could undermine broader discussions and efforts to translate scientific findings into policymaking.

Recognizing this problem, scholars have produced useful literature reviews that summarize scientific debates on maritime emissions. These reviews either use quantitative methodologies to provide comprehensive overviews of existing studies, or they describe the state-of-the-art in certain technological and regulatory areas such as green fuels or carbon market designs (e.g., Alzahrani et al., 2021; Dos Santos et al., 2022; Lagouvardou et al., 2020; Mallouppas & Yfantis, 2021; Romano & Yang, 2021; Zadeh et al., 2023; Zhou et al., 2023). However, these reviews do not organize the debate conceptually to facilitate integration between different research areas in shipping's climate change debate. Moreover, existing reviews offer few opportunities for rethinking the existing literature "in ways that generate new and perhaps 'better' ways of thinking" (Alvesson & Sandberg, 2020, p. 1290).

Here, we draw on qualitative methods to synthesize the major scientific approaches and debates on maritime emissions. Our aim is not to provide a comprehensive overview of research. Instead, we develop analytical devices and draw on paradigmatic studies to organize the scholarship and to help facilitate discussions aimed at developing more effective carbon countermeasures for the shipping industry.

We use problematization methodology (Alvesson & Sandberg, 2020; Turnbull, 2006; Webb, 2014), a research strategy from public policy studies that sheds light on the ways in which analysts construct policy problems and the policy solutions and strategies that these problematizations generate. Problematization methodology is thus an excellent method to conceptualize scientific debates aimed at addressing complex policy problems such as how to reduce emissions in the maritime transport industry.

Our analysis finds that four problematizations structure the scientific and policy debate on maritime emissions:

1. Regulatory studies investigate decarbonization as a legal challenge that requires appropriate international laws, polices, and conventions based on common legal norms and principles.
2. Economic and market studies view decarbonization as a market failure or externalities problem that requires economic management and market design tools to restructure economic incentives and activities.
3. Engineering and technology studies analyze decarbonization as an engineering problem that can be addressed through technological innovation and investments in research and development (R&D).
4. Authority and legitimacy scholarship views decarbonization as a political problem that requires legitimate political institutions and coalitions that adopt ambitious climate mitigation strategies.

We argue that these problematizations have advanced debates on climate change significantly, but that they are also often disconnected from one another, and that this undermines further scientific progress and comprehensive and integrated policy debates. We highlight three issues that require more attention and scientific collaboration across the four problematizations: how to develop institutions that generate effective market and engineering solutions, how to integrate climate mitigation and adaptation research, and how to address justice concerns and ensure an equitable green transition in the maritime industry. Our article highlights that redistributing the income of a carbon tax into adaptation projects in climate-vulnerable developing countries will be vital to enhance the legitimacy of mitigation measures and to craft coherent maritime decarbonization policies and governance arrangements.

Our article proceeds as follows. In the next section, we provide a short and concise overview of the increasingly complexity of the debate on climate change in the maritime industry. We introduce our problematization methodology in Section 3 and use it to organize the literature on climate change in shipping in Section 4. In Section 5, we outline analytical gaps and directions for future research. Section 6 briefly summarizes our core findings.

2 | SHIPPING'S CLIMATE CHANGE DEBATE

Climate change in the maritime industry has become a vibrant research field that includes scholars from across the natural and social sciences, including international law (e.g., Shi, 2017), energy and shipping economics (e.g., Psaraftis, 2019; Sou et al., 2022), environmental and sustainability studies (Sdoukopoulos et al., 2019), and

technological innovation and engineering (e.g., Bicer & Dincer, 2018; Dos Santos et al., 2022). Studies investigating different dimensions of the problem have thus proliferated in recent years.

Although earlier research focused on measuring and quantifying shipping emissions to draw attention to the industry's carbon pollution problem (Cadarso et al., 2010; Eyring et al., 2010; Heitmann & Peterson, 2014), more recent studies have investigated a broad range of issues including specific emission reduction policies, strategies, and technologies, as well as climate adaptation challenges (Alzahrani et al., 2021; Halim et al., 2018; Izaguirre et al., 2021; Lagouvardou et al., 2020; Wan et al., 2018) and governance efforts, institutions, and arrangements aimed reducing shipping emissions (Dong et al., 2022; Gritsenko, 2017; Prehn, 2021).

The growing diversity and complexity of the field has helped advance the debate on climate change in shipping and produced deep technical, behavioral, and regulatory insights that inform policy development. This includes detailed analyzes of zero- or low-carbon fuels and maritime shipping technologies, the impact of different regulatory and marked-based measures (MBMs) on shipping operations and emissions, or the complex legal architecture and principles that regulate shipping emissions and how rising sea levels and changing weather patterns will affect port and supply chain infrastructures across the maritime industry.

However, this growing diversity in terms of disciplines and methodologies has also led to analytical fragmentation. As studies have become more specialized and technical, the space for comprehensive policy debates has narrowed, and it becomes increasingly difficult to integrate policies, organize the science-policy nexus, and translate scientific knowledge into comprehensive regulatory approaches. This concerns, for example, debates about the engineering implications of climate policies and energy efficiency measures, how findings about trade patterns can inform the development of green fuels and ship designs, or how to design MBMs in ways that they can be anchored in international climate laws and policies. Fragmentation also makes it more difficult to spot analytical gaps and to make sure that new regulatory and governance initiatives, such as informal and private sector arrangements, are adequately reflected in the scientific debates.

In short, the proliferation of studies on climate change in shipping has generated important insights and policy options, but it has also led to analytical fragmentation, which undermines broader policy debates and efforts to plan, develop, and coordinate climate policies effectively. We thus need new analytical devices to organize these scientific debates in ways that can inform policy and help coordinate decarbonization strategies for the maritime transport industry. Next, we introduce problematization methodology to structure shipping's climate change debate.

3 | PROBLEMATIZATION METHODOLOGY

In this article, we draw on problematization methodology. Problematization is a qualitative research approach widely used in public policy (Bacchi, 2015; Barry, 2021; Webb, 2014) and international relations studies (Andrä, 2022; Bueger & Edmunds, 2021; Liebetrau, 2023), including global climate governance (Allan, 2017). The approach was developed to provide an analytical device for better understanding the diverse ways in which practitioners structure policy problems and interventions. Intellectually anchored in interpretative policy analysis (Wagenaar, 2011), American pragmatism (Rabinow, 2011; Marres, 2007), and science and technology studies (Barry, 2021; Callon, 1986), problematization has become a favored methodology for reconstructing the complexity of academic and policy controversies and providing analytical structure to them.

The analytical starting point for problematization methodology is John Dewey's principle that all thinking starts with a problem (Rabinow, 2011). "Problems" understood as matters that are "uncertain, partially-known, entangled, contested and in process" (Barry, 2021, p. 99) are hence the key analytical unit. "Problematization" refers to the process of turning an indeterminate problematic situation that requires action (such as climate change in shipping) into a structured problem which can be addressed through available sets of measures and solutions (e.g., science, technology, markets, law, democracy). The approach insists that there is no "natural" and "obvious" way of how a problem should be conceptualized, structured, and solved, although there might be preferrable ones. Instead, the goal of the methodology is to empirically identify patterns of problematizations, to study how they relate to each other, and to reveal gaps and routes not taken.

Problematization methodology is based on a discreet and increasingly formalized set of analytical questions, including (e.g., Bacchi, 2009; Sandberg & Alvesson, 2011):

1. What is the key analytical practice and methodological orientation that underpins the problematization?

2. What is the major problem that this practice helps identify—that is the analytical core that constitutes the problem?
3. What is the preferred solution to address the problem? And finally,
4. What are the major challenges to implementing this solution?

Scholars have used problematization analysis to disentangle and organize complex scientific and policy debates. Sandberg and Alvesson (2011, 2020), for example, have shown how problematization methodology can be used productively to synthesize academic debates. As they emphasize, drawing on problematization as an analytical device enables "researchers to critically interrogate and reimagine existing literature in order to generate new and 'better' ways of thinking about specific phenomena" (Alvesson & Sandberg, 2020, p. 1291).

Others, moreover, have shown that the approach can help organize debates about how to address environmental problems such as climate change. Barry (2021, p. 102), for example, argues that environmental problems "open up a range of future, and contestable, possibilities," rather than inviting singular solutions. In other words, environmental problems such as climate change tend to be messy, and experts often suggest different solutions based on competing framings and assumptions. Callon (2009), moreover, has argued that even if scientists work within a common frame, such as carbon market solutions, contestation continues about whether economic or political institutions should regulate such markets.

In short, problematization methodology allows us to capture scientific and policy controversies over the nature and logic of specific problems and the multiple ways in which they can be addressed and resolved.

4 | FOUR PROBLEMATIZATIONS

This section uses problematization methodology to organize the literature on climate change in the maritime transport industry and to identify its most important analytical perspectives. Answering the four problematizations questions outlined in the previous section, we argue leads us to identity four analytical perspectives: (1) international laws and regulations, (2) markets and economics, (3) engineering and technology, and (4) authority and legitimacy. As summarized in Table 1, each of these four scientific literatures problematizes climate change in specific ways, leading to different policies aimed at reducing shipping emissions.

4.1 | International laws and regulations

One group of scholars investigates climate change in shipping as a global regulatory problem that requires adequate international laws and policies to be addressed effectively. These scholars conduct legal analysis and shed light on regulatory inconsistencies in the global architecture that governs shipping emissions. The key aim of this scholarship is to identify and explain regulatory processes in shipping's climate change regime and to develop comprehensive policy and regulatory frameworks for shipping's emission problem.

TABLE 1 Four key problematizations.

	International laws and regulations	Markets and economics	Engineering and technology	Authority and legitimacy
Analytical practice	Legal and regulatory analysis	Market designs and models	Techno-engineering innovations	Authority and legitimacy analysis
Climate change as a problem of	Regulatory gaps and inconsistencies	Market failures and externalities	Slow technological innovation and research and development (R&D) investments	Lack of legitimate authorities to develop policies
Solution	Developing comprehensive international rules	Designing markets that ensure emission reduction	Building green technologies and infrastructures	Creating legitimate authorities that address climate change
Major challenge	Competing regulatory and legal principles	Competing market designs and economic logics	Competing technologies and operations	Competing governance authorities

Regulatory scholars argue that addressing climate change in the global maritime industry requires adequate international laws, regulations, and policies based on common legal norms and principles. Studies in this field thus primarily analyze the evolution of the existing international legal architecture to address climate change in the maritime industry, especially the relationship between the United Nations Framework Convention on Climate Change (UNFCCC), which provides "the umbrella instrument for the regulation of GHG emissions" (Romera, 2021, p. 57), and regulatory efforts at the International Maritime Organization (IMO), the UN agency responsible for regulating the global maritime transport industry. More recently, scholars have also analyzed legal efforts by other actors, such as the European Union (EU) and China, and how they fit into the global UNFCCC and IMO frameworks (e.g., 2023; Chircop et al., 2018; Dong et al., 2022; Fedi, 2017; Liu et al., 2023; Shi, 2017; Shi & Gullett, 2018; Ringbom, 2011; Yang et al., 2023).

The major focus of regulatory scholars is the IMO's Maritime Environment Protection Committee (MEPC), where states have discussed and developed instruments to regulate marine pollution, including shipping emissions. These efforts started with the 1997 "Regulations for the Prevention of Air Pollution from Ships," which became Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL). The "Regulations on Energy Efficiency for Ships" was adopted in 2011 (also as part of Annex VI) and introduced an Energy Efficiency Design Index (EEDI) with "mandatory energy efficiency requirements for ships" (Romera, 2021, p. 58), as well as a Ship Energy Efficiency Management Plan (SEEMP) and a voluntary Energy Efficiency Operational Indicator. The MEPC also adopted two climate strategies in 2018 and 2023 aimed at developing effective counter emission mechanisms.

Yet regulatory scholars also highlight the limits of IMO decarbonization efforts. They point out, for example, that the IMO has so far failed to adopt a carbon price or other MBMs to reduce shipping emissions effectively. Consequently, they argue, climate change is increasingly addressed outside the IMO (Romera, 2021, pp. 58–59; Shi, 2016). Especially the EU has adopted ambitious policies to address shipping's emission problem, including integrating the industry in its emission trading system. This is leading to a growing debate about the legal implications of these measures and their compatibility with international law (Kotzampasakis, 2023), and whether the new EU regulations are an adequate substitute for global action or if it will inspire or force the IMO to adopt more ambitious climate mitigation policies (Adamowicz, 2022; Kirval & Çalişkan, 2022).

A key insight of regulatory analysists is that legal inconsistencies between the UNFCCC and the IMO undermine MEPC's efforts to address climate change. The UNFCCC process is based on the principle of common but differentiated responsibilities (CBDR), which "means different treatment between developed countries and developing countries" (Dong et al., 2022, p. 8) based on the fact that the latter have contributed less to climate change and have lower capacities to address the problem. Developing countries thus argue that the costs of decarbonizing should apply first to the so-called Annex 1 countries in the UNFCCC, which are industrialized countries and countries in transition. The IMO, however, operates under the No More Favorable Treatment principle, which suggests that all ships should be treated equally "irrespective of the flag they are flying" (Chen, 2021, p. 2; see also Monios, 2022) to ensure fair market competition. Some scholars thus suggest that better enshrining the CBDR principle in IMO climate policies is vital to reconcile disputes between developed and developing countries and to construct effective climate governance instruments (Chen, 2021; Dong et al., 2022). This also includes helping developing countries adapt to climate change, for instance by using the income from a global or EU carbon tax to finance adaptation initiatives (Kotzampasakis, 2023).

In short, international law and policy scholars investigate climate change as a legal problem—that is a problem that requires comprehensive international regulatory frameworks and processes. International law and regulatory scholars thus investigate how to reconcile competing legal principles and how to anchor the IMO's counter emissions strategy in the UNFCCC and the global climate change regimes.

4.2 | Markets and economics

Another group of scholars investigates decarbonization as a market and economic management problem. These scholars are interested in shipping markets and how trade flows can be organized more efficiently to reduce emissions. Economists thus mainly calculate the impact of emission reduction policies and evaluate competing market designs aimed at mitigating climate change.

Market economists view GHG emissions as either a market "failure"—a situation in which the rational behavior of individual actors undermine collective goods—or a market "externality"—that is an indirect market cost that is not "priced" into market processes. The key aim of economists is thus to design markets that correct these failures and that

internalize carbon costs—that is to make sure that agents are either forced to reduce their emissions or that they benefit financially from doing so.

The economic literature discusses two market designs. "Command and control" (Lagouvardou et al., 2020, p. 1) measures restrict "the factors that lead to GHG emissions," such as imposing speed limits or prescribing the use of specific emission reducing green fuels and technologies. This also includes "goal-based" regulations, which "prescribe an emissions reduction target, without prescribing the means for reaching the target, leaving this to the discretion of the ship-owner" (Lagouvardou et al., 2020, p. 1). MBM designs, on the other hand, "use prices or other economic variables to provide monetary incentives for polluters to reduce emissions" (Lagouvardou et al., 2020, p. 2) Based on the polluter pays principle, the idea here is that emissions need to be "costly" and become part of market calculations so that the industry has incentives to reduce them. This includes, for example, "environmental taxes, the provision of subsidies, various offsetting mechanisms, and Emission Trading Systems (ETS)" (Lagouvardou et al., 2020, p. 2).

Economists calculate the emission reducing effect of these market designs and how they affect shipping costs. For example, a large literature evaluates if and how the IMO's EEDI and SEEMP, or the EU's 2013 Monitoring, Reporting, and Verification system, have helped reduce emissions and increased the adoption of green fuels and technologies (e.g., Chang & Huang, 2019; Marrero & Martínez-López, 2023; Shi & Gullett, 2018; Sou et al., 2022; Stevens et al., 2015; Tanaka & Okada, 2019). Scholars also investigate MBMs and other design proposals at the IMO, including how the EU's move to integrate shipping in its ETS will affect shipping emissions, as well as other potential decarbonization scenarios (Gu et al., 2019; Halff et al., 2019; Joung et al., 2020; Lagouvardou et al., 2020; Lagouvardou & Psaraftis, 2022; Psaraftis, 2021; Wang, Liu, et al., 2021).

Economists identify two challenges when it comes to designing carbon markets. First, it is not yet clear which of the two market designs is most effective in reducing emissions. MBMs are in theory more efficient because they distribute emission costs based on market principles (Haehl & Spinler, 2020). However, command-and-control designs are often seen as more effective (Marrero & Martínez-López, 2023), at least in part because they cannot be manipulated so easily by market stakeholders. Only the EU, which has strong regulatory capacities, has so far designed an effective carbon market (Bayer & Aklin, 2020; Green, 2021). Yet integrating the maritime industry in its ETS could undermine the competitiveness of European ports and lead to carbon leakage (Lagouvardou & Psaraftis, 2022). Moreover, the dominance of MBMs in the debate undermines alternative regulatory approaches, including a total ban on fossil fuels (Leeuwen & Monios, 2022b; Monios, 2022; Monios & Wilmsmeier, 2020).

The second problem concerns the distribution of emissions costs. Some studies have found that the IMO's emission reducing efforts could have a negative impact on the trade and shipping costs of developing countries (Rojon et al., 2021; United Nations Conference on Trade and Development, 2021; Wang, Zhen, et al., 2021). Consequently, economists continue to calculate alternative emission distribution mechanisms based on national allocation and the CBDR principle, suggesting that shipping emissions should be addressed within the UNFCCC framework rather than the IMO (Selin et al., 2021). Others, however, argue that developing countries could become major producers of non- or low-carbon fuels for the maritime transport industry, thus benefiting from shipping's green energy transition.

There is also a growing awareness among economists that climate adaptation programs need to be part of the mitigation debate. For example, the income from a carbon tax could be used, at least in part, to pay for adaptation measures in climate-vulnerable developing countries, which would help increase their support for such a tax (Englert et al., 2021). Some econometric studies, moreover, calculate the risks and costs of port adaptation measures and how to strengthen port infrastructures against the impact of climate change (e.g., Izaguirre et al., 2021; Yang et al., 2018).

In short, carbon economists view shipping emissions as a market design problem—that is, a problem that requires regulatory interventions aimed at redesigning shipping markets to incentivize the adaptation of emission reducing strategies. Carbon economists thus study which market designs can achieve that objective most effectively and how market designs distribute emission costs between market participants, including mechanisms to finance adaptation measures in developing countries and help secure port infrastructures against the impact of climate change.

4.3 | Engineering and technological innovation

Engineers and technology scholars are interested in the technological challenges and implications of shipping's green energy transition. Here, climate change is studied as an engineering and operational efficiency problem that can be addressed through technological innovation and energy optimization. Engineering scholars thus develop and evaluate alternative green fuels and other technical solutions to shipping's emission problem.

The key assumption that underpins engineering and technology scholarship is that emissions are a problem of slow technological innovation and the lack of R&D for green fuels and technologies. A major effort of this scholarship is thus to support technological innovation in the maritime shipping industry through studies of emission reducing strategies and technologies. This includes, for example, technical measures such as ship design and innovative propulsion systems, operational measures such as slow steaming, speed optimization, the development of eco-friendly fuels such as synthetic and biofuels, carbon capture and storage technologies, and alternative power sources such as wind energy and solar energy (e.g., Xing et al., 2020; see also Beukelaer, 2022; Mallouppas & Yfantis, 2021; Risso et al., 2023). Other studies, moreover, investigate different strategies to decarbonize ports, including the use of renewable energy resources and decentralized energy systems and cost performance optimization strategies (Alzahrani et al., 2021; Sdoukopoulos et al., 2019; Zadeh et al., 2023).

Engineering scholarship analyzes the emission reduction potentials of these countermeasures and evaluates their advantages and disadvantages from different technological and operational perspectives. A key challenge in the engineering literature, then, is how to choose between competing technological and operational solutions and how to identify the most effective and efficient technologies to reduce emissions in the maritime industry (Ashrafi et al., 2022; Balcombe et al., 2019; Kim et al., 2020; Serra & Fancello, 2020; Xing et al., 2020).

One major strand of research in this literature studies alternative fuels to power merchant vessels such as liquified natural gas (LNG), ammonia, hydrogen, and methanol (Dos Santos et al., 2022). Studies adopt a full life-cycle approach to account not only for emissions released when fuels are used in engines but also during their production, such as the use of fertilizer and changing land-use patterns in bio- fuel production (e.g., Gilbert et al., 2018, p. 864). Many studies suggest that hydrogen and ammonia are the most promising green fuels for the maritime industry, yet, most hydrogen and ammonia are currently produced from natural gas and other carbon sources (Al-Aboosi et al., 2021; Ampah et al., 2021; Bicer & Dincer, 2018; Ejder & Arslanoğlu, 2022; Herdzik, 2021; Liu et al., 2022; Shi et al., 2023).

Scholars also consider the operational and commercial implications of different fuel alternatives (e.g., Moshiul et al., 2023). LNG, for example, "is currently the only green fuel that is scalable commercially and globally for the deep-sea segment" (Serra & Fancello, 2020, p. 10), but its climate impact is "of the same order of magnitude" (Serra & Fancello, 2020, p. 10) as conventional bunker fuels. Methanol, on the other hand, is easier to "store and distribute than LNG" and "can be mainly used in dual-fuel engines" (Serra & Fancello, 2020, p. 10), but it is not currently scalable. Hydrogen requires "10–20 times more storage space" (Ampah et al., 2021, p. 5) on vessels compared to conventional bunker fuels and is highly inflammable, while ammonia can be stored more easily and at lower pressure but is very toxic (Ampah et al., 2021, p. 6). Developing new safety standards and vessel designs is thus vital to ensure that these fuels can be used in the maritime industry.

Another challenge identified by engineering scholars is that green hydrogen and ammonia, which are produced with renewable energy, are very costly and not currently available commercially and in the quantities that are required to decarbonize the global maritime industry. Building green fuel production and distribution infrastructures to ensure the availability of these fuels in ports remains a major challenge (Grzelakowski et al., 2022; Tan et al., 2022).

Finally, a large literature studies port sustainability measures and evaluates different technologies and policies to minimize port emissions and other pollutants (Alamoush et al., 2021; Lim et al., 2019; Zheng et al., 2020). Moreover, analysts have started to discuss port adaptation measures and developed strategies to protect port operations against extreme weather events caused by climate change (Becker et al., 2018; Christodoulou et al., 2019; León-Mateos et al., 2021). In short, marine engineering scholarship studies decarbonization as a technological and innovation problem that requires R&D investments to develop green energy solutions for the maritime industry. The key challenge in this literature, then, is how to evaluate competing technologies and strategies and how to identify and assess the best technologies and optimization strategies for shipping's green energy transition.

4.4 | Authority and legitimacy

Finally, scholars investigate climate change as a problem of authority and legitimacy. These scholars ask who—that is which actor and institution—has the authority and legitimacy to steer shipping's green energy transition. They thus study power struggles and how competing political interests and processes affect decarbonization strategies. Their key argument is that establishing legitimate institutions is vital to develop effective emission control policies.

The starting point of authority and legitimacy scholarship is the insight that "the main obstacles [for the development of effective counter emission policies in shipping] are neither technical nor economic, but political"

(Psaraftis, 2019, p. 355). Put differently, the problem is not that legal, economic, or technical solutions to shipping's emission problem are not available, but that these solutions lack strong political support among governments and industry stakeholders.

Most scholars in this area have focused on the IMO and analyzed why the organization has so far failed to adopt effective decarbonization policies. The key insight here is that the IMO is politically ill-equipped to deal with climate change. The IMO is a technical organization that facilitates the development of consensus-based vessel safety and counter-pollution measures (Prehn, 2021). Yet the organization is heavily influenced by the maritime industry, which worries that climate regulations could raise their business costs, and developing and emerging countries, who worry that climate regulations could undermine their trade. The IMO thus favors a "business-as-usual" and incremental approach that does not lead to the adoption of ambitious climate regulations. The IMO's authority and legitimacy as shipping's regulatory agency is thus increasingly contested (Corbett et al., 2020; Hendriksen, 2022; Leeuwen & Monios, 2022a; Monios & Ng, 2021; Psaraftis & Kontovas, 2020; Stockbruegger, 2021).

Yet the literature also notes that actors' incentives are changing. For example, pressure from NGOs, European countries, and major flag states, such as the Marshall Islands, has led to the adaptation of the IMO's 2018 Initial Climate Strategy (Corbett et al., 2020). Major brand retailers such as Walmart and Ikea—the largest customers of container shipping companies—also want to reduce their carbon footprint and therefore support stricter maritime emission controls (Lister, 2015; Lister et al., 2015). A.P. Møller–Mærsk and other big shipping companies support such policies "to consolidate and capture markets" (Alger et al., 2021, p. 146) from smaller companies who cannot comply with higher environmental and climate standards.

Scholars also study how actors circumvent the IMO, focusing on new initiatives to reduce maritime emissions. Some studies, for example, investigate the EU's efforts to address maritime pollution and shipping emissions—including shipping's integration into the EU's ETS—arguing that EU policies have historically forced the IMO to adopt more ambitious environmental regulations (Adamowicz, 2022; Leeuwen & Kern, 2013). Other scholars shed light on private governance, such as "green shipping networks" through which maritime companies try to increase and coordinate investments in emission reducing technologies and infrastructures (Hessevik, 2022; Saether et al., 2021; Wuisan et al., 2012). Moreover, studies have investigated shipping operations and how climate governance arrangements, such as emission disclosure arrangements, affect the industry's emission practices (Poulsen et al., 2021; Poulsen & Sampson, 2019, 2020).

Finally, a growing number of studies analyze the politics of ports in climate change governance. On the one hand, research investigates how and under what conditions ports try to reduce their carbon and other emissions, and how such efforts contribute decarbonizing the maritime industry (DeSombre et al., 2023; Sornn-Friese et al., 2021). And on the other hand, studies analyze port adaptation strategies, including the impact of different regulations aimed at ensuring that ports build climate resilient infrastructures and capacities to protect operations against natural disasters and extreme weather events (Gong et al., 2020; Ng et al., 2013; Zheng et al., 2021).

A key insight of this scholarship is that shipping's climate regime is increasingly complex and fragmented, leading to a multilevel and polycentric governance system in which different actors and initiatives compete for regulatory authority and legitimacy. Some evidence suggests that this fragmentation makes efforts to steer shipping's green energy transition more difficult (e.g., Monios & Fedi, 2023). Moreover, existing tools and regulations often fail to limit shipping emissions significantly (e.g., Poulsen et al., 2021) and do not help ports adapt to climate change (Zheng et al., 2021). Yet others point out that institutional diversity facilitates policy experimentation and learning to develop more effective climate mitigation and adaptation strategies (Gritsenko, 2017; Leeuwen, 2015).

In short, scholars interested in authority and legitimacy shed light on the political logics of shipping's climate change regime. The key challenge here is governance competition and the lack of authoritative and legitimate climate institutions, coalitions, and initiatives in the maritime industry. Constructing such institutions is thus seen as the key solution to shipping's emission problem.

4.5 | Summary: The problem of analytical fragmentation

Using problematization methodology, we have identified four problematizations that structure shipping's climate change debate. Each of these problematizations frames the problem in specific ways and generates important solutions for addressing it. The four problematizations are thus productive analytical devices that help advance the debate on how to reduce the maritime transport industry's carbon footprint.

Yet the debates that these problematizations generate are also often disconnected from one another and lack attention to common and cross-cutting themes. For example, there is a lack of studies investigating the link between engineering solutions and market designs or the relationship between legal arrangements and political coalitions in efforts to develop new market regulations and innovative green technologies.

The lack of cross-cutting scientific research also undermines broader policy debates on how to reduce shipping emissions. For example, policymakers need a better understanding of how to anchor carbon markets in international law, how to build such markets to overcome political resistance against costly decarbonization policies, and how to develop institutions that facilitate technological innovation and experimentation in the maritime industry. In short, a closer integration between regulatory, market, engineering, and authority scholarship is vital to advance scientific research aimed at addressing shipping's emission problem. In the next section, we therefore highlight three cross-cutting policy challenges and areas for future research.

5 | DISCUSSION: ADDRESSING ANALYTICAL GAPS THROUGH CROSS-FERTILIZATION

Our analysis suggests three problems in shipping's green energy transition that require more analytical attention: (1) how to develop institutions that facilitate market and engineering solutions, (2) integrating climate mitigation and adaptation research, and (3) addressing justice concerns to ensure an equitable green transition in the maritime industry. We argue that addressing these problems requires scientific collaboration across the four problematizations.

5.1 | Institutions facilitating market and engineering solutions

First, our literature review shows that the debate can benefit from a closer integration of regulatory, market, engineering and authority and legitimacy scholarship. Market and engineering solutions evolve in an increasingly fragmented institutional and legal environment. Market solutions to shipping's emission problem are currently spearheaded by the EU, which has included shipping in its ETS and adapted decarbonization targets for marine fuels in its FuelEU Maritime regulations. Ports around the world are building new rules and technologies to reduce maritime emissions, and alternative marine fuels and infrastructures are increasingly developed in private shipping networks. This includes the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping and the maritime industry's green corridor initiative, which aims at establishing trade routes where vessels using alternative fuels can operate (Energy Transition Commission, 2020).

Institutional fragmentation can facilitate technical and policy experimentation. Yet it requires coordination and needs to be managed carefully to avoid duplication and to mitigate competition between initiatives. Scholars interested in issues of regulation, authority and legitimacy should therefore study these new institutional designs and initiatives and shed light on how they shape market and engineering solutions to shipping's emission problem. For example, they should investigate the political conflicts and coalitions that underpin these initiatives and what kind of legal tools and approaches are available to anchor them in shipping's broader climate change regime. Market and engineering scholars, on the other hand, should consider these insights to develop specific market designs or green fuels that match these institutional and legal structures. For example, such a concerted effort could help integrate the industry's green corridor initiative into the EU's ETF and mitigate conflict with the IMO and the UNFCCC process.

5.2 | Integrating climate mitigation and adaptation research

Second, climate adaptation research and concerns need to be better integrated into climate mitigation debates. Many adaptation challenges are increasingly well studied and understood. This includes especially adaptation challenges facing ports, such as storm surges and poor visibility, which affect berthing operations, as well as infrastructure damage and destruction due to rising sea levels and tropical cyclones (Becker et al., 2018; Christodoulou et al., 2019; Izaguirre et al., 2021; Yang et al., 2018). Yet other challenges, such as the impact of changing weather patterns on the risk of shipping accidents and oil and chemical spills have not yet been studied in detail and require further research.

One of the key issues facing the industry is how to build resilient green ports and marine fuel infrastructures. Engineering scholars should therefore consider adaptation challenges when designing zero-emission ships and alternative clean fuel technologies. They should also consider the safety implications of using toxic and highly inflammable green fuels such as ammonia and hydrogen on vessels operating in increasingly harsh and unpredictable weather conditions. Economists, moreover, need to calculate if these new safety and weather conditions affect trade flows and if they should be incorporated into market designs aimed at ensuring the adaptation of green fuels and technologies. Regulatory and authority scholarship, on the other hand, should investigate how to develop safety and resilience rules and integrate them in shipping's safety and climate change regime. For example, even though the IMO has so far failed to adapt effect carbon control policies, it might be better suited to address safety challenges.

There is also a growing awareness among scholars that addressing adaptation challenges can help increase the legitimacy of mitigation measures, such as a carbon tax. Thus, economists should try to design specific mechanisms to redistribute climate funds into adaptation projects, while engineering scholars can help identify port adaptation projects that require such investments. Legal and authority scholars, moreover, can help construct legitimate governance arrangements to develop such mechanisms aimed redistributing the income from carbon markets into adaptation projects, especially in climate-vulnerable developing countries.

5.3 | Maritime emissions and blue justice

Third, our analysis shows that blue justice concerns need to be a core part of shipping's climate change agenda. Justice concerns have become a core issue in wider ocean governance (Armstrong, 2022) and climate change debates (Newell et al., 2021; Okereke & Coventry, 2016; Schlosberg & Collins, 2014). They are also central in shipping's climate change discussion, especially in legal studies concerning the CBDR principle and in developing countries' resistance to emission regulations that could increase their trade costs. Yet despite their political salience, justice concerns have not yet featured prominently as a major analytical and policy challenge in maritime decarbonization debates. The lack of efforts to address justice concerns is indeed a key reason for why the maritime industry has so far not made much progress in its green energy transition.

Addressing justice concerns will be vital to ensure the legitimacy of shipping's climate change regime and to build strong political coalitions that support the transition to costly green marine fuels and technologies (Shaw & Beukelaer, 2022). Thus, engineering scholars could focus on technology transfers—an important goal of many developing countries—and develop sustainability technologies and infrastructures that developing countries can use to strengthen their maritime economies. Economists, on the other hand, could design market mechanisms that help channel investments into green maritime infrastructure and adaptation projects, as we have pointed out, and increase the maritime connectivity and trade of small island developing nations. Regulatory and authority scholars, moreover, should investigate innovative institutional designs that could facilitate such efforts, for example by strengthening the role of the United Nations Conference on Trade UNCTAD—which represents the concerns of developing nations—and develop programs that address their adaptation concerns, for example by investing in resilient green port and other coastal infrastructures.

6 | CONCLUSION

This article has drawn on problematization methodology to review the literature on climate change in the maritime transport industry and to help identify major gaps and challenges in this debate. We have shown that scholars problematize climate change from four distinct analytical perspectives: international law and regulations, markets and economics, engineering and technology, and political authority and legitimacy. Each of these literatures and scientific debates problematizes climate change in specific ways, leading to different policies aimed at reducing shipping emissions.

The key insight of our study is that these four problematizations have generated important scientific insights that inform policy debates. Scholars should therefore continue to use and advance these problematizations to help solve shipping's emission problem. Yet we have also shown that the current debate has gaps and shortcomings. Better integrating the four problematizations is vital to address cross-cutting issues. This includes investigating how to build institutions that facilitate the development of market and engineering solutions, integrating climate mitigation and

adaptation research, and focusing on climate justice to ensure an equitable green transition. Most importantly, our review shows that redistributing the income of a carbon tax into adaptation efforts in climate-vulnerable developing countries—including small island developing nations—will be vital to enhance the legitimacy of mitigation measures and to develop a compressive decarbonization strategy for the maritime industry.

AUTHOR CONTRIBUTIONS

Jan Stockbruegger: Conceptualization (equal); investigation (equal); resources (equal); writing – original draft (equal); writing – review and editing (equal). **Christian Bueger:** Conceptualization (equal); investigation (equal); resources (equal); writing – original draft (equal); writing – review and editing (equal).

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The authors have declared no conflicts of interest for this article.

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Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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