

## Discussion Paper

# Enabling Net-Zero Shipping

## An Expert Review-Based Agenda for Emerging Techno-Economic and Policy Research

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KAPSARC is an advisory think tank within global energy economics and sustainability providing advisory services to entities and authorities in the Saudi energy sector to advance Saudi Arabia's energy sector and inform global policies through evidence-based advice and applied research.

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# Key Points

Net-zero shipping is emerging as a global priority, underscored by the shipping sector's increasing projected contribution to climate change, making it critical to understand the emerging associated research priorities. We outline key techno-economic and policy research priorities for achieving effective and equitable net-zero shipping. We translate contemporary media issues to techno-economic and policy research priorities, corroborating the identified priorities through the academic literature, and consulting an array of maritime experts in the fields of policy, technology, fuel, and infrastructure.

We delineate 11 overarching themes. The top four research priorities based on expert input are (i) cost-benefit analyses of port initiatives aimed at facilitating maritime

climate action; (ii) the investment and techno-economic aspects of onboard carbon capture and alternative shipping fuels, along with green shipping corridors'

Figure 1. Graphical abstract.



Source: KAPSARC.

potential to facilitate alternative fuel adoption; and (iii and iv) the complex interaction of climate, economic, and socio-political factors in implementing shipping carbon pricing as part of the ongoing negotiations at the International Maritime Organization (IMO), and shipping's inclusion in the EU Emissions Trading System (ETS).

These outlined priorities could guide future industry and academic research in generating actionable recommendations for policymakers and industry stakeholders and expediting the formulation of focused approaches for an equitable transition to net-zero shipping.

# Introduction

Without effective mitigation strategies, the shipping sector, which currently contributes approximately 2%-3% to global greenhouse gas (GHG) emissions, faces a potentially significant increase in emissions. There is a growing aspiration within the shipping sector to reach net-zero GHG emissions to align with other sectoral efforts to limit global warming. Notably, recent developments involving the adoption of an enhanced common ambition by member states of the International Maritime Organization (IMO) to reach net-zero GHG emissions from international shipping by or around 2050 underscore the growing sense of urgency (Gualandi 2023a). As countries work toward fulfilling these obligations, it becomes imperative to identify and deeply investigate emerging issues on the pathways to achieving net-zero shipping. This identification process is key to strategically allocating resources and efforts toward developing effective approaches to achieving carbon neutrality in maritime transport.

In this work, we aim to shed light on the emerging techno-economic and policy research priorities in this critical area. We accomplish this by combining insights from recent academic research on contemporary thematic issues identified in media reports and consultations with a diverse range of experts. Our endeavor not only marks a novel contribution to the discourse but also invites further exploration and debate on how best to navigate the complex pathway toward sustainable maritime transport. The identified priorities offer valuable direction for prospective research endeavors within both the academic and industrial spheres that could create practical suggestions for decision-makers and those involved in the shipping industry. Moreover, we envision that our insights could act as a catalyst for contemplation among those in charge of directing research funding, encouraging a thoughtful consideration of the research priorities we identify, and helping to shape future research agendas.

In considering the landscape of contemporary research, it becomes evident that insights from experts have been instrumental in identifying and prioritizing emerging research across diverse fields. Notable applications of

expert input-based prioritization of emerging research include blue carbon science (Macreadie et al. 2019), smart energy systems (Robison et al. 2023), offshore decommissioning strategies (Watson et al. 2023), governance of high seas (Jarvis and Young 2023), hydropeaking impacts (Hayes et al. 2023), sustainable supply-chain management (Reefke and Sundaram 2017), and the effects of plastic pollution on biota (Provencher et al. 2020), among others. Such precedents underscore the relevance and applicability of expert input-based identification and prioritization of emerging research issues. Besides such limited and emerging literature, it is worth acknowledging that the practice of delineating future research agendas often occupies only a modest space in the conclusion sections of academic works. These agendas tend to focus narrowly on the specific sub-themes investigated, potentially overlooking broader or interconnected issues. This approach, while grounded in the authors' expertise, might benefit from a more collaborative validation process involving a wider array of experts. Equally important is the need for dialogue on how these future research directions align with the needs and perspectives of non-academic stakeholders, who are integral to addressing the sector's contemporary

challenges. This work addresses this gap by transforming current media-reported issues, which include the perspectives of non-academic stakeholders, into emerging research priorities, corroborated by academic literature, and prioritized through consultations with a diverse range of maritime sector experts.

The research agenda for enabling shipping decarbonization is emerging as a vibrant and pressing topic, with a growing body of scholars keenly investigating pivotal questions that underscore the latest research and development trends in this up-and-coming domain. Wang, Cheng, and Zhen (2023) have delved into the areas of green shipping management and green port construction, seeking to identify future research opportunities that could enhance operational efficiency, reduce emissions, and contribute to the realization of net zero emissions through technological innovation and optimization strategies. Similarly, Chen, Zheng, and Sys (2023) have focused on the designs, impacts, and future research avenues of market-based measures that could facilitate shipping decarbonization, employing quantitative reviews and bibliometric analysis to map out existing research. Furthermore, Zhou, Li, and Yuen (2023) have highlighted the interrelationship between environmental and social pillars within sustainable shipping, alongside investment strategies, risk assessment, and the impacts of post-pandemic conditions as critical future research directions. The concept of ‘green shipping corridors’ (GSC) as a means of decarbonizing the maritime industry

has been scrutinized by Song et al. (2023), who consider the current developments, key challenges, and future directions from a stakeholder’s perspective. Alamoush, Ölçer, and Ballini (2022a) have examined the role of policy instruments and tools implemented by ports and public authorities to reduce port GHG emissions. They also propose further research on enhancing GHG emission reductions in port settings. Lastly, Romano and Yang (2021) have systematically reviewed the evolution of the shipping industry’s decarbonization efforts from 2000 to 2020, outlining key developments and directions for future research.

This paper builds on existing research and distinguishes itself by emphasizing a broader scope of techno-economic and policy research priorities for enabling net-zero GHG emissions in shipping. It delves into the contemporary challenges identified through media reports and validated by academic literature, with a distinct focus on expert consultations to prioritize research areas. Unlike other studies that primarily focus on literature reviews, this paper’s three-pronged approach ensures that its research agenda is informed by practical considerations, providing a unique blend of academic and non-academic stakeholders’ perspectives on shipping decarbonization, and integrating diverse contemporary themes. This approach ensures that the agenda covers a broad spectrum of contemporary issues relevant to achieving net-zero shipping, providing a roadmap for future research that is both broad and deep.

# Background and Literature Review

We provide a summary of the relevant grey and academic literature clustered by themes.<sup>1</sup> In particular, each theme features a succinct evaluation of pertinent media articles. We also provide specific examples of relevant research questions investigated in the academic literature in relation to the emerging issues concerning net-zero shipping. The derived condensed and organized themes could serve as a valuable resource for time-constrained individuals seeking a concise and broad overview of the emerging net-zero shipping discourse.

## Theme 1: International IMO Negotiations on Carbon Pricing for Shipping

The reports within this theme underscore the critical need for a unified approach to carbon pricing under the auspices of the International Maritime Organization (IMO) (Garside 2022). They also highlight the beneficial effects carbon pricing can have in advancing the shift toward cleaner fuel options and supporting climate initiatives in developing nations (Kiernan 2022c). Furthermore, they bring to light the economic considerations and obstacles associated with decarbonizing maritime transport, including the essential role of a significant carbon levy

(Manuell 2022a) and worries about the possible repercussions of this levy on costs (Manuell 2022b).

Academic inquiry in this domain, as explored by Mundaca, Strand, and Young (2021), revolves around the ramifications of instituting a carbon tax. This research notably delves into the consequential effects of a carbon tax on global carbon dioxide (CO<sub>2</sub>) emissions and the international trade dynamics within the maritime sector. Complementing this perspective, Rojon et al. (2021) focus on the implications of carbon pricing on maritime transport costs. Their investigation is particularly insightful in elucidating the resultant impacts of carbon pricing on developing economies, a critical consideration given the global nature of shipping. Further enriching this discourse, Dominiononi (2023) probes the strategies that could facilitate an equitable decarbonization of international maritime transport. This includes examining the strategic utilization of carbon revenues and potential exemptions, highlighting the complexities and nuances involved in transitioning toward a more sustainable maritime sector.

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<sup>1</sup> The methods section provides an explanation of how the clustered themes are derived.



## Theme 2: Issues, Collaborations, and Perspectives Inside and Outside the IMO's Scope

The investigations in this theme examine the effectiveness and perception of IMO regulations aimed at reducing carbon emissions from ships (Gualandi 2023b). They also explore the need for a just shift toward decarbonization, prioritizing the needs of emerging and at-risk countries (Monahan 2022). Additionally, the media reports investigate the current debate over the implementation of green shipping corridors and their possible economic implications (Garside 2023a).

In addressing the theme of decarbonizing global shipping, the academic literature offers a spectrum of inquiries and discussions. Bach and Hansen (2023) delve into the complexities that the IMO faces in crafting consistent and thorough policies for the decarbonization of the shipping industry. Another pivotal question, raised by Chen (2021), examines the delicate balance between the principles of common but differentiated responsibilities (CBDR) and no more favorable treatment (NMFT) in regulating these emissions. Chen's work is particularly insightful in understanding how developing nations can implement these regulations effectively. Furthermore, the work of Gritsenko (2017) broadens this discussion by evaluating the different approaches to regulating GHG emissions in the shipping sector. This research compares the merits and challenges of global, regional, and polycentric governance models, offering a nuanced view of the multi-layered governance needed to tackle this global issue. Lastly, Wang, Daoutidis, and Zhang (2023) contribute a forward-looking perspective by investigating the potential of ammonia-based green corridors. Their research is pivotal in understanding how these corridors can be designed and implemented, providing a tangible solution to support sustainable maritime transportation.

## Theme 3: Alternative Approaches and Fuels for Addressing Shipping GHG Emissions

The focus of the discussion within this theme revolves around the shipping industry's readiness to embrace alternative fuels such as hydrogen, ammonia, methanol, and electricity, taking into account pricing factors (Gualandi 2023d). It also examines advancements in onboard carbon capture technologies aimed at lowering emissions (Kiernan 2022g) and evaluates the effectiveness of establishing green shipping lanes (Kiernan 2022h). Furthermore, it highlights the economic considerations of decarbonization, stressing the need for significant investment in ship construction powered by clean energy sources and the enhancement of infrastructure to support the production and distribution of carbon-neutral fuels (Kiernan 2022i).

In the academic literature, Xing et al. (2021) delve into the potential pathways for achieving low-carbon maritime transportation, emphasizing the role alternative fuels can play. This line of inquiry is extended by Al-Enazi et al. (2021), who scrutinize cleaner fuel options for maritime transport, alongside the technical and financial challenges inherent to their comprehensive adoption. Stolz et al. (2022) contribute to this discourse by examining the techno-economic dimensions of utilizing renewable fuels, specifically in the context of ships transporting bulk cargo within Europe. Further technological advancements are explored by Ros et al. (2022), who focus on the development of ship-based carbon capture technology, particularly on liquefied natural gas (LNG)-fueled vessels. Complementing these technological and operational perspectives, Krantz, Søgaard, and Smith (2020) provide a macroscopic view, estimating the scale of investment necessary between 2030 and 2050 to reach the IMO's ambitious target of slashing carbon emissions from shipping by at least 50% by 2050.



## Theme 4: LNG: A Transitional Shipping Fuel

The reporting under this theme investigates the number of recently ordered ships powered by liquified natural gas (LNG) (Kiernan 2022e). It delves into the risk associated with these ships potentially becoming stranded assets and considers the increasing economic feasibility of zero-emission fuel alternatives, such as green hydrogen and ammonia (Kiernan 2022e). The reporting includes an analysis of the maritime sector's focus on different endeavors and partnerships aimed at tackling methane emissions and formulating both assessment and reduction approaches (Manuell 2022c).

Research work, such as Livaniou and Papadopoulos (2022), attempts to better understand the potential for LNG to replace conventional marine fuels, namely heavy fuel oil and marine diesel oil. Livaniou and Papadopoulos (2022) assess LNG's effectiveness in contributing to the decarbonization of the international transport sector. The work of Balcombe et al. (2021) complements this inquiry by examining the implications of methane emissions from LNG-fueled ships. Their investigation is pivotal in determining whether LNG, despite its potential benefits, can truly meet the stringent decarbonization targets set for the shipping industry.

## Theme 5: Shipping Companies' Strategies for Attaining Net-Zero GHG Emissions

The discussions under this theme center on the strategic application of improvements in efficiency and the adoption of cleaner energy sources as pivotal steps toward minimizing emissions. They also focus on the role of carbon dioxide removal (CDR) strategies in balancing out any residual emissions (Kiernan 2023). The discourse further sheds light on the formation of strategic partnerships between maritime companies and tech

companies, aiming to leverage technological innovations that boost operational efficacy and lessen the ecological footprint of the shipping industry (Carbon Pulse 2023b). Moreover, the practice of integrating carbon pricing into shipping contracts is gaining momentum. This approach encourages shipping firms to surpass emission reduction benchmarks, thereby securing additional business opportunities, while those falling short may lose future freight contracts (Carbon Pulse 2023a).

Within the academic literature on this theme, Bouman et al. (2017) have explored the potential of state-of-the-art technologies and measures to reduce GHG emissions in shipping. Their investigation extends to understanding how combinations of individual reduction measures can lead to significant emission reductions within the sector. Another critical aspect is the impact of maritime decarbonization on the cost of shipping goods. UNCTAD (2023) focuses on this area, including examining the measures necessary to ensure a just and equitable net-zero transition. This includes addressing the diverse impacts of the transition on emerging economies and less developed countries.

## Theme 6: Offsetting Carbon Emissions: Strategies for Reducing Maritime Carbon Footprints and Creating Offsets via Shipping Initiatives

This theme primarily explores the efficacy and dependability of carbon-neutral shipping practices, which involve carbon offset mechanisms. It also includes reporting on issues associated with greenwashing, the accuracy of emissions data, and the standards for emissions reporting (Kiernan 2022b). Furthermore, it delves into the consequences of low assessments of carbon offset projects aimed at enhancing the energy

efficiency of ships, as evaluated by rating agencies, focusing particularly on how these assessments affect regulatory measures (Garside 2023b). Additionally, the examination under this theme extends to the recent cooperative efforts between technology suppliers, maritime transport firms, and stakeholders in the carbon trading market.

Central to the academic discourse surrounding carbon offsetting is the exploration of how carbon offsets can be utilized effectively to decarbonize freight transport generally, thereby accelerating the transition toward a more sustainable and environmentally responsible global transport network (Greene and Façanha 2019). There is a growing body of literature that critically examines the limitations and potential pitfalls associated with carbon-neutral shipping options and carbon offset programs. This scrutiny, echoed in reports such as those by *The New York Times* (Okamoto 2022), challenges the efficacy of these programs and calls for a deeper understanding of their implications.

## **Theme 7: Incorporating Maritime Transport Into the EU's Emissions Trading System (ETS)**

The subject matter under this theme encompasses discussions regarding legislative deliberations among the European Council, the European Parliament, and the European Commission concerning the incorporation of shipping into the European Union Emissions Trading System (EU ETS) (Gualandi 2022a). Moreover, there seems to be a dearth of awareness among shipowners regarding the forthcoming changes (Gualandi 2023c). The discussions explore the potential ramifications of the integration of shipping into the EU ETS, including issues such as inflationary pressures (Gourlay 2022b), alterations in trade routes as vessels seek to circumvent carbon expenses by avoiding EU ports (Kiernan 2022d), and the impact on EU ETS carbon prices (Gualandi 2022b).

Within the recent academic discourse on incorporating maritime transport into the EU ETS, Wang et al. (2021)

have scrutinized the operational implications for shipping companies, and Christodoulou et al. (2021) have concentrated on the direct economic repercussions on the maritime sector. Research by Lagouvardou and Psaraftis (2022) focuses on a more specific aspect of the maritime sector, European container routes, examining the likelihood of container vessels altering their port calls to evade the ETS and the consequent risk of carbon leakage. Vierth et al. (2024) explore the impact of the European Commission's 'Fit for 55' climate policy package (including extending the EU ETS to shipping, among other industries) on cargo ships calling at Swedish ports. They examine the cost implications and changes in freight transport behavior under different ETS inclusion and marine fuel taxation scenarios. Wu, Liu, and Li (2024) explore the strategic options available to competitive ocean carriers for evading the EU ETS, and how these strategies could impact both the carriers and the effectiveness of the EU ETS in reducing carbon emissions. Wu et al. (2022) provide a broader perspective by dissecting the drivers, challenges, and overall impacts of including the shipping sector in the EU ETS. Finally, Goyal and Llop (2024) explore the short-term economic and environmental impacts of extending the EU ETS to the shipping industry, and these impacts could vary among the different stakeholders within and outside the EU.

## **Theme 8: FuelEU Maritime: Regulations, Objectives, and Advancing Sustainable Fuel Usage**

This theme covers the FuelEU Maritime program, including its stipulations, aims, and endeavors in advocating for the adoption of environmentally friendly fuel within the maritime sector. The literature includes discussions on the provisional accord forged by representatives from the European Council and the European Parliament, and a fuel benchmark for ships with the aim of curbing the emissions intensity of onboard energy consumption (Barbiroglio 2023).

Christodoulou and Cullinane (2022) explore viable alternative fuel pathways within the context of the FuelEU Maritime initiative, assessing their impact on both fuel consumption and CO<sub>2</sub> emissions within the European shipping sector. Malmberg (2023) conducted an analysis of the influence of advocacy coalitions in shaping policy dynamics, specifically in the case of the FuelEU Maritime Regulation.

## Theme 9: Integrating Shipping Fuels Within Low Carbon Fuel Standards

This theme pertains to the extension of low carbon fuel standards (LCFS) to include marine and aviation fuels across various regions. This has been legislated for in British Columbia, Canada, with the objective to encourage the uptake of low-carbon fuels within these sectors (Varela 2022).

Recent research, particularly Mandegari et al. (2023), has focused on exploring the integration of marine fuels within the ambit of LCFS. Central to this inquiry is the identification of potentially lower carbon-intensive fuel alternatives, specifically tailored to the marine sector in British Columbia.

## Theme 10: Ports' Contribution to Decarbonizing Shipping

The investigations under this theme examine the pivotal role of ports in mitigating carbon emissions in maritime transportation and addressing the shipping sector's environmental footprint. The inquiries scrutinize the efficacy of ports in fostering the industry's shift toward sustainability through the provision of infrastructure for alternative fuels, including hydrogen-based refueling systems and electrification options at port terminals (Kiernan 2022f). Moreover, they underscore the escalating costs associated with climate change impacts on

seaports, which are anticipated to surge significantly by 2050 (Kiernan 2022f). The inquiries also explore port-centric strategies aimed at curbing GHG emissions from shipping, such as optimizing vessel speeds to achieve just-in-time port arrivals (Gourlay 2022a).

Among recent academic inquiries, Alamoush, Ölçer, and Ballini (2022b) examine ways ports can actively facilitate the reduction of GHG emissions, thereby supporting the decarbonization of the shipping sector. Yu, Tang, and Song (2022) explore how the integration of vessel speed optimization with berth allocation and quay crane assignment (considering vessel service differentiation) can reduce service delays, fuel consumption, and emissions. Jia et al. (2017) examine the potential for reducing fuel consumption and emissions through the implementation of a 'just in time' arrival strategy in ports, highlighting the significant operational changes that could contribute to more sustainable maritime logistics. Song et al. (2022) investigate the impact of government subsidies on the strategies of shipping companies regarding the use of shore power in ports. Wu and Wang (2020) explore how governments can develop subsidy programs that incorporate shore power to maximize the reduction of at-berth emissions from ships in a container shipping network. Zhen, Wang, and Lin (2022) investigate how government subsidy-based and berthing-priority-based incentive policies can impact the deployment of ship-borne power-receiving systems for reducing emissions near ports. The extent to which global port operations are at risk due to climate change is a topic explored by Izaguirre et al. (2021). They assess the potential impacts of climate change on ports worldwide under a high-end warming scenario projected for the year 2100.

## Theme 11: Accounting and Verifying GHG Emissions From Shipping

This line of investigation delves into GHG emissions accounting and authentication within the maritime sector. It looks at the meticulous acquisition of GHG emissions data, specifically for methane and carbon dioxide emissions (Kiernan 2022a). The literature within this theme

underscores the significance of accurate measurements and thorough documentation in emissions accounting and authentication.

A pivotal research question in this domain, as investigated by Smit et al. (2022), revolves around the efficacy of energy-based ship emission models. This line of inquiry critically examines the performance of these models by

juxtaposing their outcomes with the results obtained from on-board emissions testing and data from the Automatic Identification System (AIS). Lastly, Yan, Wang, and Psaraftis (2021) have contributed to the understanding of the role of data analytics in maritime transportation fuel consumption management. Their research sheds light on how data analytics can be instrumental in reducing emissions and enhancing energy efficiency.

# Methods

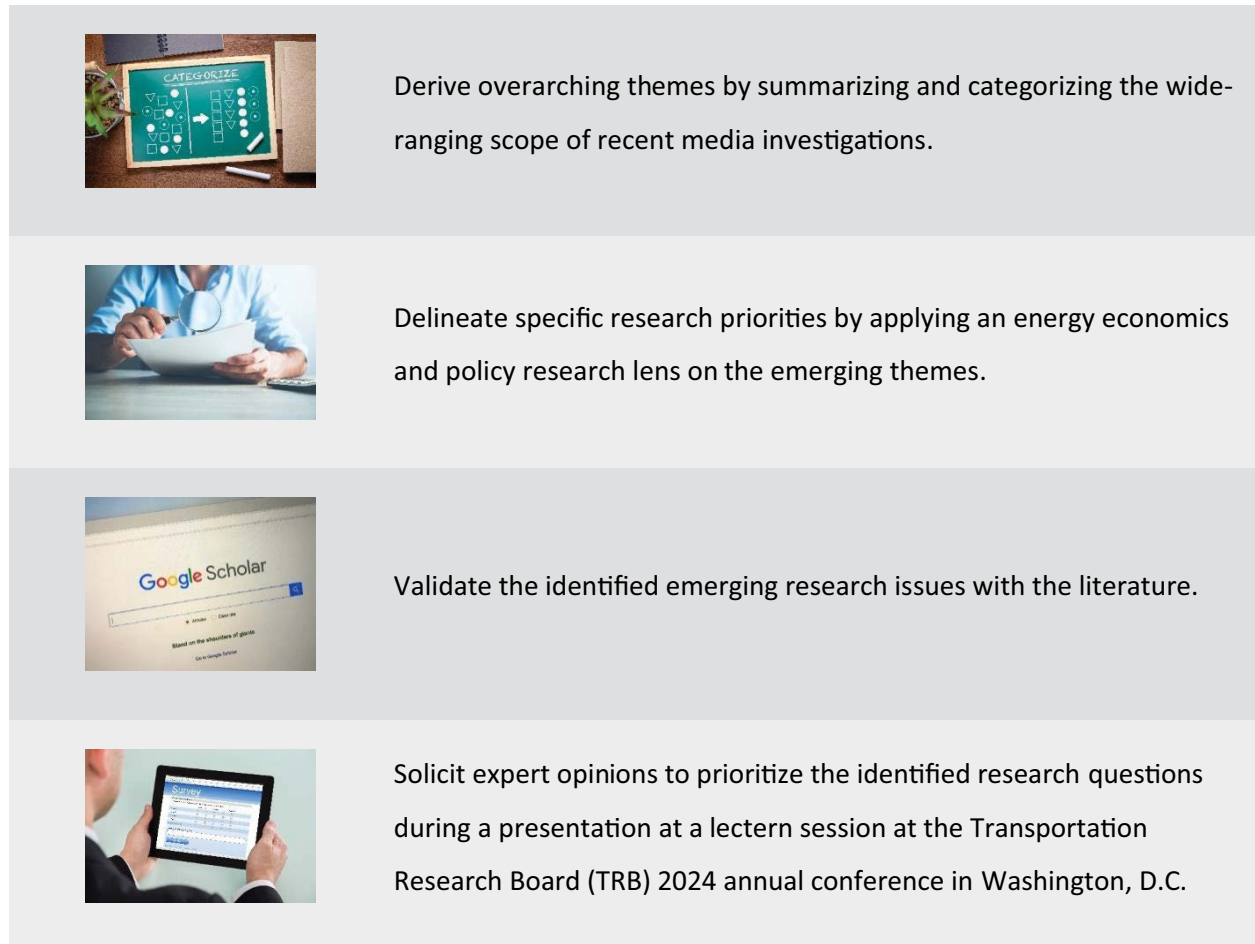
In this section, we identify the key techno-economic and policy research priorities for enabling net-zero shipping using the approach outlined in Figure 1. Specifically, we first derive our overarching themes by summarizing and categorizing the wide-ranging scope of recent media investigations into net-zero shipping.<sup>2</sup> We begin with media reports because they frequently shed light on emerging economic, policy, and sustainability issues before they are thoroughly investigated in the academic literature. This is due to the delays involved in obtaining research funding, as well as the time-consuming peer-review process that characterizes academic publishing. Furthermore, media reports often include perspectives from non-academic stakeholders, which are frequently underrepresented in scholarly articles. Finally, we identify and outline challenges and areas of focus that demand deeper exploration through applying perspectives from techno-economic and policy research on the identified contemporary issues.

We solicited expert opinions to identify the research priorities. A live expert voting was conducted during a presentation on this topic at the Transportation Research Board (TRB) 2024 annual conference in Washington, D.C., during a lectern session titled “Research in Maritime Decarbonization” (TRB 2024). This session, organized by the TRB Standing Committee on Marine Environment (AW030), attracted a diverse audience of maritime researchers, policymakers, practitioners, administrators, and representatives from government, industry, and academia. The respondents were requested to assess the range of research questions discussed in earlier sections by employing a Likert-type scale ranging from 1 to 5. This was done to determine their significance in facilitating the achievement of net-zero emissions in the shipping sector. The participants were also asked to choose one of the research questions outlined in this study that, in their opinion, is the most important to address. This is in line

with the established expert voting-based prioritization method employed across diverse fields (Roskladka, Jaegler, and Miragliotta 2023; Lam and Suen 1997; Watson et al. 2023). Among the respondents who shared information related to their backgrounds, 18 represented non-profit organizations while four respondents were affiliated with for-profit entities. More than half of the surveyed individuals indicated they had a decade of professional experience in the maritime sector. Utilizing a familiarity scale, with 1 signifying a minimal understanding of the study’s research questions and 5 indicating extensive knowledge, the average rating provided by these experts was 3.09. Furthermore, when prompted to identify their areas of focus within the maritime sector, both present and historically, the distribution was as follows: policy was indicated by 12 experts, technology by three, fuels by three, and infrastructure by four.

<sup>2</sup> The emerging themes were formulated by performing a thematic analysis of recent shipping and climate reporting from January 2022 to May 2023 in Carbon Pulse (CP). We analyzed all 90 CP articles using CP’s shipping filter, turned them into questions, and grouped them by theme. Given the global nature of the shipping sector, CP’s global coverage, and our focus on questions rather than findings, we use CP to sample recent media investigation themes. Since our only goal is to identify key themes by extracting a wide range of questions, the CP articles are considered to provide a reasonable overview of net-zero shipping themes.

**Figure 2.** Overview of the approach used in this study.



Source: KAPSARC analysis.

# Results

In this section, we delineate the specific research questions that demand further in-depth examination. We achieve this by applying a comprehensive techno-economic and policy research perspective to the identified emerging themes, encompassing both academic and industrial viewpoints. Additionally, we specify the prioritization of the identified research areas, drawing upon insights from experts in the maritime sector. In particular, we detail the distribution of respondents' evaluations regarding the importance of each set of thematic research priorities.

This analysis is presented on a predefined importance scale of 1 (very low) to 5 (very high). We also look at the distribution of importance ratings from two categories of expertise: (i) policy, and (ii) combined infrastructure, technology, and fuels. Furthermore, we present the percentage distribution of votes for the research

prioritized through expert voting. The voting percentages are shown as a range, including an unweighted distribution, which considers all votes equally, and a weighted distribution, which is adjusted according to the experts' familiarity with the research topics.



# Emerging Areas of Research

## Theme 1: International IMO Negotiations on Carbon Pricing for Shipping

Areas of future inquiry could center around the development of effective strategies for global cooperation in the enforcement and management of shipping carbon pricing mechanisms. Another pivotal aspect of this discourse is exploring how revenue generated from shipping carbon pricing may be used strategically to enhance financial support for climate-related projects in emerging markets, thereby contributing to a more equitable global response to climate change. There is also an urgent need to estimate the shipping carbon prices that would be necessary to achieve the IMO's ambitious targets of making the shipping sector net-zero by 2050. Finally, a comprehensive assessment of the socio-economic and distributive consequences of applying carbon pricing to the maritime transportation sector is imperative. This assessment should elucidate the varied implications of shipping carbon pricing for different countries.

Figure 3a reveals that a significant majority (80%) of the respondents assigned a “high” or greater level of importance to the research related to global IMO negotiations on shipping carbon pricing. It also shows considerable variation across the two expert categories. Specifically, 63% of policy experts rated the subject matter as being of high or greater importance, in contrast to 90% of experts within the combined category of infrastructure, technology, and fuels. This distinction is illustrated in Figure 3b. Furthermore, when asked to identify their top priority topic, this theme emerged as joint-third among the diverse research areas highlighted in this paper, receiving backing from 5%-9% of the expert participants.

## Theme 2: Issues, Collaborations, and Perspective Inside and Outside the IMO's Scope

Assessing the effectiveness and implementation hurdles associated with current GHG regulations by the IMO continues to be a critical research priority. This scrutiny is vital in understanding the gaps and strengths in our current strategies. Equally important is exploring the dynamics of consensus building among governments, which vary widely in their priorities and capabilities, thereby underscoring the need to ensure a fair progression toward eliminating GHG emissions from shipping. Such a transition requires not only global agreements under the IMO but also the recognition of the potential impact of country or regional-level efforts. Localized initiatives could play a pivotal role in achieving the broader goals of shipping decarbonization. Additionally, the exploration of smaller-scale green shipping collaborations, such as green shipping corridors, merits attention. These collaborations could serve as critical support mechanisms, reinforcing and potentially accelerating the impact of global IMO agreements.

Eighty-one percent of respondents rated the importance of the areas identified under this theme as “high” or greater. Approximately 3%-6% of the experts advocated for the prioritization of the research areas encompassed by this theme over those identified in other themes, with the aim of facilitating the achievement of net-zero emissions in shipping.

## Theme 3: Alternative Approaches and Fuels for Addressing Shipping GHG Emissions

A key future research area continues to be the techno-economic analysis of alternative shipping fuels. This encompasses a detailed examination of production costs, infrastructure requirements, and the potential for economies of scale. Simultaneously, evaluating the financial viability of installing carbon capture systems on maritime vessels presents an intriguing avenue for research. Moreover, a comprehensive analysis of stakeholder dynamics is essential. This involves scrutinizing the duties, motivations, benefits, and apprehensions of different parties involved in the establishment of green shipping lanes that are considered instrumental in promoting the use of low-carbon shipping fuels. Lastly, a crucial aspect of this thematic exploration is estimating the yearly financial commitment necessary for the maritime sector to reach carbon neutrality by the year 2050.

Figure 3 highlights that, within the scope of research areas identified under this theme, investment and techno-economic considerations pertaining to alternative shipping fuels and strategies were deemed significantly critical, receiving a “high” or greater importance rating from 87% of respondents. Furthermore, when prompted to prioritize their primary set of research questions, this theme emerged as the second most critical, securing 25%–33% of expert votes.

## Theme 4: LNG: A Transitional Shipping Fuel

Future areas of focus could include conducting a comprehensive evaluation of the economic and environmental trade-offs of using LNG as an interim energy solution, considering the near-term benefits, such as immediate emission reductions and fuel efficiency improvements, against the potential long-term costs.

These costs include the risk of stranded assets and the feasibility of transitioning to low-carbon alternatives in the future. Another pivotal aspect of research is the techno-economic analysis of methane slip, a significant issue associated with LNG-fueled ships. This analysis should explore methods for reducing methane slip and evaluate their economic viability and effectiveness in mitigating its environmental impact.

This set of research questions received the lowest proportion of “high” or greater ratings from survey participants (29%), ranking it last among the themes evaluated. In fact, a more or less equal proportion of respondents, 31%, gave it a “low” or lower importance rating. Intriguingly, none of the respondents identifying as experts in the fields of fuels, technology, and infrastructure rated the subject matter as being of “high” or greater importance. This is in contrast to the 27% of policy experts who assigned it a “high” or greater importance rating. Furthermore, when participants were asked to identify their top priority theme, none of them chose this theme.

## Theme 5: Strategies of Shipping Companies for Attaining Net-Zero GHG Emissions

Central to ongoing research is the effectiveness of shipping companies’ strategies, which encompass reducing, removing, and offsetting emissions, and how these strategies inevitably interact with shipping costs. Techno-economic analyses are crucial in establishing how to reduce energy consumption, lower emission levels, and improve efficiency across maritime operations. It is equally important to investigate the implementation of carbon pricing strategies within freight contracts between shippers and shipping companies. Such an investigation should not only focus on the motivations for adopting these mechanisms, but it should also critically evaluate their associated risks and benefits. It is also imperative to understand the broader economic and environmental impacts of these mechanisms.

In assessing the perceived importance of the theme, a significant majority of the respondents (80%) attributed

a “high” or greater level of importance to it. Yet, intriguingly, when prompted to identify their top priority, no respondents selected this option.

## **Theme 6: Offsetting Carbon Emissions: Strategies for Reducing Maritime Carbon Footprints and Creating Offsets via Shipping Initiatives**

The efficiency and dependability of strategies aiming for carbon neutrality in the shipping sector through the use of carbon offsets warrant close scrutiny. This research should also address prevalent concerns such as greenwashing and the accuracy of emissions data and reporting practices. Additionally, exploring the consequences of rating agencies allocating low scores to carbon offset initiatives aimed at enhancing ship energy efficiency is another avenue for investigation. Another inquiry could investigate the dynamics and sustainability of recent partnerships formed between shipping firms, technology suppliers, and stakeholders in carbon trading, as they might be pivotal in establishing a sustainable maritime carbon offsetting ecosystem.

Among the participants, only 45% attributed a “high” or greater level of importance to the subject in question. Approximately 30% perceived it to be of “low” or lesser importance. Consequently, when considering the proportion of respondents who allocated a “high” or greater importance rating, this subject emerged as the second-least prioritized issue within the research areas we identified. Moreover, when prompted to identify their primary set of research questions, none of the respondents selected this subject.

## **Theme 7: Incorporating Maritime Transport into the EU’s Emissions Trading System (ETS)**

One area of future investigation could center around the complex stakeholder negotiations that are integral to the inclusion of shipping in the EU ETS. This could involve delving into the interests, power dynamics, positions, and strategies for consensus building among various actors. Additionally, there is a pressing need to assess ship owners’ understanding of the EU ETS and to develop effective strategies for raising awareness of it, ensuring that those at the helm of this change are well-informed and prepared. Another critical aspect to explore is the potential impact of this inclusion on various economic parameters. This includes examining how incorporating shipping into the EU ETS might influence trade flows, freight expenses, and inflation, offering a comprehensive view of the economic repercussions of this policy. Moreover, the effects of this inclusion on the carbon credit market are paramount. Research must be conducted to understand how integrating shipping will affect the supply, demand, and prices within the carbon credit market, a key component of the EU ETS. Finally, conducting an evaluation of the economic implications of the maritime industry’s adherence to the EU ETS is essential. This analysis should not only consider the direct financial implications but also explore EU port evasion as a potential circumvention strategy.

Approximately 50% of the respondents attributed a “high” or greater level of importance to the issues under this theme. Nevertheless, when prompted to prioritize their research questions, it garnered 11%-18% of the votes from experts, placing it in a tie for third place among the areas of research identified in this paper.

## Theme 8: FuelEU Maritime: Regulations, Objectives, and Advancement of Sustainable Fuel Usage

Evaluating the feasibility and effectiveness of the FuelEU Maritime initiative's provisions and targets, particularly in the context of promoting clean fuels within the maritime sector, merits an in-depth investigation.

Over half the respondents (53%) rated the importance of the research questions under this theme as “high” or above. However, despite this acknowledgment, none of the respondents identified these areas as their foremost priority.

## Theme 9: Integrating Shipping Fuels within Low Carbon Fuel Standards

A critical area of future research that warrants deeper investigation is the cost ramifications of adjusting maritime fuels to align with the carbon intensity thresholds outlined by LCFS. Roughly 4%-5% of the experts voted in favor of prioritizing both the research questions identified in this theme relative to the other themes in order to enable net-zero shipping.

Approximately 45% of survey respondents rated these research questions as of “high” or greater importance, with approximately 5% indicating them as their foremost priority among the areas of research identified in this paper.

## Theme 10: Ports' Contribution to Decarbonizing Shipping

One significant area of future research involves conducting cost-benefit analyses of port initiatives, such as the implementation of onshore power supply and the development of infrastructure for alternative fuels. Additionally, there is an urgent need to estimate the potential economic losses induced by climate change for key stakeholders, including ports, shippers, and carriers. Another area ripe for exploration is the emissions reduction potential of enhanced collaboration between vessels, terminals, and ports.

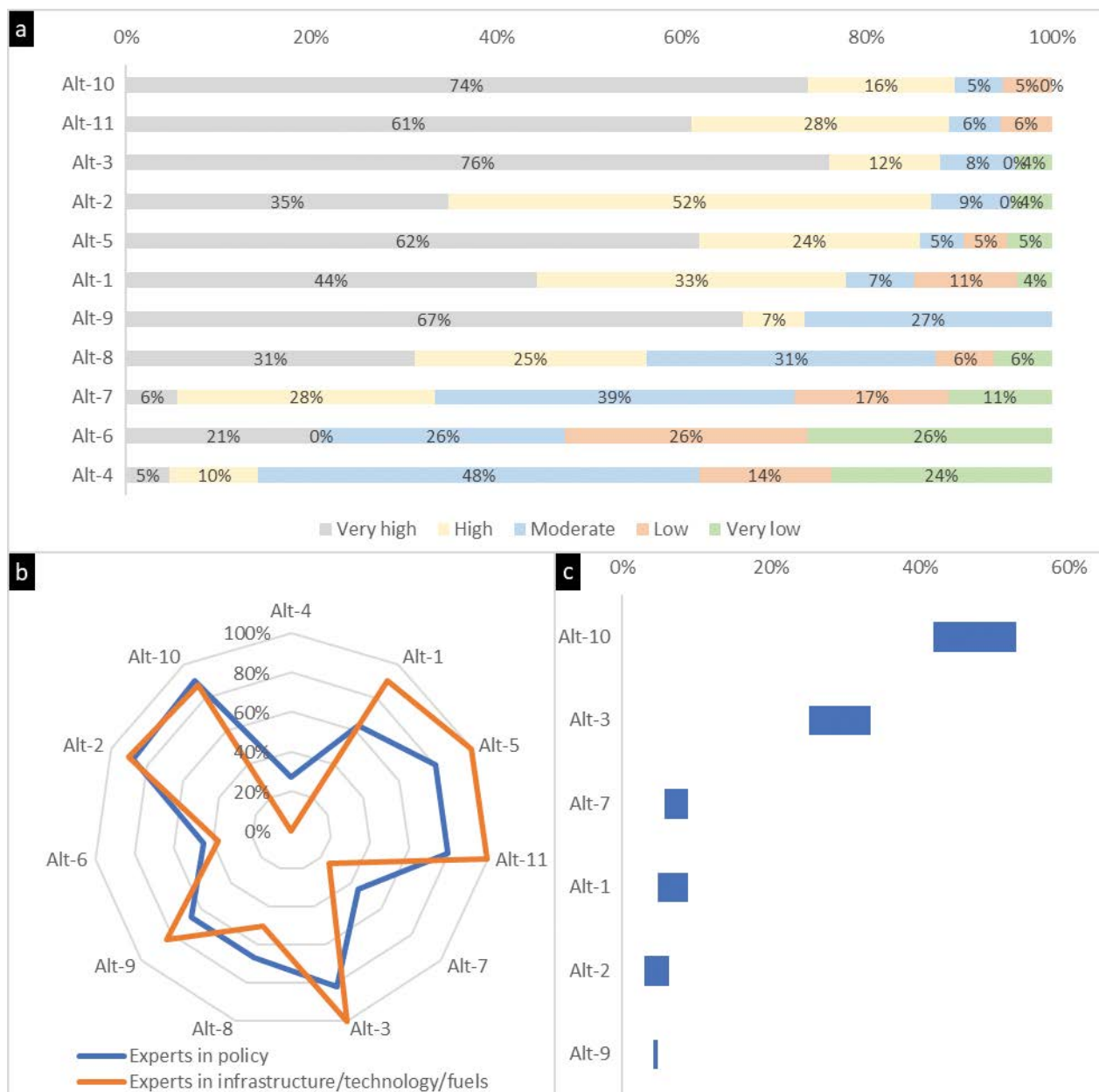
Cost-benefit analyses of initiatives aimed at advancing maritime climate action have emerged as a significant area of interest, with 82% of respondents attributing a “high” or greater level of importance to them. Furthermore, this thematic area of research has been identified as the most important: When participants were asked to choose their single most important set of research questions identified in this paper, this topic received between 42% and 53% of the votes from experts.

## Theme 11: Accounting and Verifying GHG Emissions from Shipping

The emerging research questions associated with this theme include exploring the various obstacles to effective GHG emissions accounting in the shipping sector, as well as developing and refining precise methods and protocols for measuring and calculating shipping GHG emissions.

A combined 81% of experts rated the importance of questions within this theme as “high” or greater, positioning it prominently among the research questions identified in this paper. However, intriguingly, when participants were asked to select just one set of research questions from the entire set of identified potential research, none opted for it.

**Figure 3.** (a) Distribution of respondents' ratings of the importance of exploring each theme/alternative with their specific set of research questions. The themes are ranked by the percentage of respondents assigning a "high" or greater importance level. (b) Distribution of "high" or greater importance ratings by expertise category. Percentage of respondents who assigned a "high" or greater importance rating to the different themes within the two expertise categories: (i) policy, and (ii) combined infrastructure, technology, and fuels. The themes are displayed with the percentage point differences between expert categories decreasing in a clockwise direction. (c) Range of frequency distribution for the research themes selected by the experts as the most important to address for enabling net-zero shipping, considering the three cases of equal weights for all respondents, respondent familiarity-based weights, and respondent experience-based weights.



Source: KAPSARC analysis.

# Discussion

As can be seen in Figure 3, the prioritized emerging research questions are multifaceted and interlinked. We delineate the implications of these research topics, emphasizing their intricate interconnections.

# Implications of the Prioritized Research Areas

## Ports' Contribution to Decarbonizing Shipping:

Cost-benefit analysis of port initiatives: Implementing onshore power supply and alternative fuel infrastructure involves significant upfront costs but could reduce GHG emissions and improve local air quality. The challenge lies in balancing these costs with long-term benefits for the climate, local environment, and health.

Economic losses from climate change: Ports, shippers, and carriers face potential operational disruptions and infrastructure damage due to extreme weather events and rising sea levels, leading to economic losses. Estimating these losses is crucial for planning and investing in resilience measures.

## Alternative Fuels and Decarbonization Strategies:

Techno-economic analysis of alternative shipping fuels: This challenge involves evaluating the cost, availability, and infrastructure requirements of alternative fuels compared to conventional fossil fuels. The aim is to identify the most viable options for scaling up alternative fuels to meet global shipping energy demand while considering its environmental impacts.

Onboard carbon capture feasibility: The economic and technical feasibility of implementing onboard carbon capture for ships poses significant challenges, including

the development of compact, efficient systems suitable for ships and the storage of captured CO<sub>2</sub>.

Developing green shipping corridors: This involves fostering collaboration among stakeholders to create supply chains that prioritize low-carbon shipping fuels. The challenge is to align incentives, regulatory frameworks, and infrastructure investment to support these corridors.

Investment in decarbonizing the maritime sector: Estimating and securing the required annual investment poses a substantial challenge. This involves calculating the direct costs of fuel transitions and technology upgrades and mobilizing public and private funding toward these goals.

## International IMO Negotiations on Carbon Pricing for Shipping:

Global cooperation challenges and strategies: The primary need is for a unified global framework that encourages all countries to participate in carbon pricing for shipping. This involves navigating geopolitical interests, differing economic capabilities, and the varying environmental impacts of shipping across regions. Effective strategies must address these disparities to ensure broad and equitable participation.



Directing revenues to support climate finance in developing economies: The challenge here is to design mechanisms that ensure carbon pricing revenues are used effectively to aid climate adaptation and mitigation in developing countries. This raises questions about governance, transparency, and the criteria for allocating funds, ensuring that the revenue supports those most affected by climate change and the distributional impacts of shipping carbon pricing. Furthermore, there is the question of how to address the hesitancy of developing countries to engage with such climate finance promises, which appears justifiable especially considering the historical context. Previously, developed nations have made significant pledges regarding climate finance, yet these promises have frequently failed to materialize within the specified timeframes. This pattern has understandably led to skepticism and caution among developing countries when considering new commitments or collaborations in this domain.

Estimating the carbon prices needed to reach net-zero shipping by 2050: Determining the carbon price required to reach the IMO's target of net-zero shipping by 2050 involves the complex modeling of future shipping activity, fuel prices, and technological advancements. The challenge is setting a price that is high enough to drive emission reductions but avoids undue economic harm to the global shipping sector.

Socioeconomic and distributional impacts: Assessing these impacts involves understanding how carbon pricing affects different stakeholders, including shipping companies, countries dependent on maritime trade, and consumers. The challenge is to implement carbon pricing in a way that is fair and does not disproportionately burden developing nations or certain sectors of the economy.

Incorporation of Maritime Transport Into the EU's ETS:

Impact on freight costs and trade flows: Including shipping in the EU ETS could affect freight costs, trade flows, and inflation, necessitating a thorough economic analysis.

Effects on the carbon credit market: This inclusion could also significantly impact the supply, demand, and prices of EU carbon credits, with implications for the broader carbon market.

Cost-benefit analysis and evasion strategies: Analyzing the costs and benefits of compliance versus evasion strategies like port evasion is critical for understanding the potential effectiveness and loopholes of including shipping in the EU ETS.

# Interrelationships Between Prioritized Research Areas

The areas of research outlined above are interconnected in several ways.

## Port Initiatives and the Adoption of Alternative Fuels:

Feedback loop: Ports implementing initiatives such as onshore power supply and alternative fuel infrastructure directly facilitate the use of cleaner energy sources by ships. As the maritime industry shifts toward alternative fuels, there will be an increased need for ports worldwide to adapt and provide the necessary infrastructure, creating a feedback loop that accelerates the adoption of green shipping practices.

## Economic Analyses and Stakeholder Dynamics:

Policy and investment decisions: Techno-economic analyses of alternative fuels and onboard carbon capture technologies provide critical data for policymakers and investors, guiding decisions on where to allocate resources for maximum impact on decarbonization. Understanding the economic viability of these technologies influences regulatory frameworks and investment in research and development, shaping the market for low-carbon shipping solutions.

Stakeholder engagement: Analyses highlighting the roles, incentives, and concerns of stakeholders across different initiatives such as global shipping carbon pricing, the inclusion of shipping in the EU ETS, and the development of green shipping corridors, etc., can foster collaboration among the different stakeholders. By identifying mutual benefits and addressing shared challenges, these analyses encourage joint efforts on decarbonization, enhancing the effectiveness of such initiatives.

## Carbon Pricing's Dual Role: Incentivizing Alternatives and Funding Investments

The impact of carbon pricing on alternative fuels and decarbonization: Effective carbon pricing can incentivize the shift toward alternative fuels and decarbonization strategies by making carbon-intensive fuels more expensive. Conversely, the development of alternative fuels and decarbonization technologies can influence the optimal level of carbon pricing needed to achieve emission reduction targets.

Investment needs and carbon pricing revenue: Revenue generated from carbon pricing could be a significant source of funding for the investment needed to support the transition to alternative fuels and onboard carbon capture technologies. This creates a feedback loop where effective carbon pricing supports decarbonization efforts, which in turn can lead to a reduction in carbon prices over time as emissions decrease.

## Global Carbon Pricing and Regional Regulatory Measures:

Complementary and competing effects: The discussion on global shipping carbon pricing and the inclusion of shipping in the EU ETS are interrelated through their potential to set a precedent for international and regional regulatory approaches. A global carbon pricing mechanism could influence or be shaped by the EU's efforts, with both sides having the potential to complement or undermine the other, depending on how the pricing mechanisms are implemented and aligned.

Climate Finance Redistribution and Socioeconomic Equity:

Mitigating adverse impacts: The use of carbon pricing revenue to support climate action in developing economies will help mitigate its socioeconomic and distributional impacts. By redirecting funds to support adaptation and mitigation efforts in developing and vulnerable regions, these mechanisms can limit the potential inequalities arising from carbon pricing, ensuring a more equitable approach to global decarbonization.

Enhancing cooperation: The promise of climate finance can also serve as an incentive for broader cooperation

among nations to implement carbon pricing and other decarbonization strategies. Developing economies, in particular, may be more willing to engage in and support global efforts if there are clear mechanisms to support and compensate for the economic impacts of transition policies.

Overall, these interrelationships underscore the complexity of addressing shipping decarbonization in a holistic manner. To be effective, strategies must consider the interconnectedness of technological, economic, and regulatory challenges, and foster cooperation across sectors and regions to achieve global emissions reduction targets.

# Concluding Remarks

This paper systematically explores the multifaceted challenges and emerging research priorities pivotal to enabling net-zero shipping. By delving into diverse themes, it provides a comprehensive analysis of the current state of research on net-zero shipping and its possible future directions.

We pinpoint critical emerging challenges using expert voting-based prioritization. The research areas we identified for in-depth exploration include (i) a cost-benefit analysis of port initiatives like infrastructure for alternative fuels, onshore power supply, and optimizing port arrivals, including avoiding economic losses for ports, carriers, and shippers from climate change-induced impacts; (ii) investment and techno-economic dimensions of onboard carbon capture and alternative shipping fuels, as well as the potential for green shipping corridors to facilitate alternative fuel adoption; and (iii) the intricate dynamics of climate, economic, and socio-political elements caused by the imposition of carbon prices on shipping. These inquiries would be undertaken within the framework of the ongoing international negotiations conducted by the IMO and the inclusion of shipping under the EU ETS.

While this paper offers a broad overview of the issues at hand, it acknowledges certain limitations. The rapidly evolving nature of emerging issues in net-zero shipping means that findings might require continual updates. Moreover, the reliance on expert inputs, although

valuable, may not fully capture the diversity of perspectives in this global industry.

This work contributes to the field by offering a structured framework to analyze and prioritize research areas in sustainable shipping. It bridges the gap between academic discourse and practical application. In particular, the delineated priorities could serve as a potential roadmap for guiding forthcoming research endeavors within both the industrial and academic domains. Research findings from such initiatives may yield practical recommendations for policymakers and industry stakeholders, fostering the formulation of strategies aimed at expediting an equitable transition toward a net-zero and resilient shipping sector.

In conclusion, the emerging issues identified through journalistic reports, the review of published literature, and expert consultations provide a solid foundation for identifying the imperative research priorities necessary to facilitate net-zero shipping.

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# Notes

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# About the Project

The project “Field Inquiry-Based Assessment of Sectoral Challenges and Opportunities” is aimed at ‘questioning the questions’ in order to identify and prioritize questions that can lead to impactful, policy-relevant research. It seeks to identify and prioritize emerging challenges and opportunities within policy and economic research across diverse sectors.



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