

Applying the polluter-pays principle to mitigate greenhouse gas emissions in shipping: potential and challenges

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ABSTRACT

This study conducts a comprehensive analysis of the potential and legal challenges of applying the polluter-pays principle (PPP) as an alternative strategy for reducing greenhouse gas (GHG) emissions from shipping. An extensive literature review is initially carried out to establish the theoretical basis, and a subsequent questionnaire survey was conducted to collect insights and concerns from industry stakeholders regarding both the current International Maritime Organisation measures and the potential challenges of applying the PPP in the context of GHG emissions from shipping. The results demonstrate the stakeholders' concerns regarding shipping-related GHG emissions, and perspectives about the potential for the PPP to be applied as a regulatory tool to address GHG emissions from shipping. However, alarms about several practical issues are also raised, including the necessity for considering the Beneficiary Pays Principle when identifying polluters. The findings provide informed recommendations for employing the PPP for its regulatory influence on mitigating shipping GHG emissions, as well as the pollution law in a broader context.

1. Introduction

In 1992, United Nations Framework Convention on Climate Change (UNFCCC) established the guiding objective of stabilising greenhouse gas (GHG) concentrations in the atmosphere at a level that prevents detrimental anthropogenic interference with the climate system (UNFCCC, 1992). The 1997 Kyoto Protocol reaffirmed the UNFCCC principle (Kyoto Protocol, 1997). The 2015 Paris Agreement was then adopted with an overarching aim of keeping 'the increase in the global average temperature to well below 2°C above pre-industrial levels', while also striving to 'limit the temperature increase to 1.5°C above pre-industrial levels' (Paris Agreement, 2015).

Shipping is essential for global trade, carrying over 80% of the world's commodities by volume, and contributing to global anthropogenic GHG emissions (UNCTAD, 2025). Statistics estimated by the International Maritime Organisation (IMO) show that shipping accounts for around 3% of global annual GHG emissions (Faber et al., 2020). As maritime trade continues to expand, shipping-related GHG emissions are expected to increase even more significantly. The IMO has adopted a series of technical and operational measures for reducing GHG emissions from shipping. However, debates continue over the adequacy and effectiveness of the existing measures, particularly concerning their

potential to contribute effectively to achieving the net-zero target by or around 2050 (Zhang and Feng, 2024; Shi, 2016). In April 2025, the milestone Net-Zero Framework was endorsed at the 83rd session of the Marine Environment Protection Committee (MEPC 83), which is expected to significantly advance the progress towards achieving the reduction goal. However, adoption of this framework will be postponed.

There have been extensive studies on both topics – namely, the Polluter-Pays Principle (PPP) and the control of GHG emissions. Originally conceived as an economic principle to internalize external costs, the PPP is now widely recognized and is often designed to require identifiable polluters to bear the costs of their environmental harm they cause (de Sadeleer, 2020). Similarly, legal and policy measures have been implemented to operationalize the PPP in order to prevent and remedy ship-source pollution at multiple regulatory levels. Preventive measures include permits, emission limits, and charges, while curative approaches typically impose civil liability and compensation for environmental damage (Grossman, 2007; Zhu and Zhao, 2015). Interestingly, studies have increasingly acknowledged the potential of applying the PPP to marine GHG emissions, thereby incentivizing emitters to reduce emissions and compensate affected parties (Zhu and Li, 2025). The PPP underpins IMO's discussions regarding GHG control in shipping, notably through market-based measures (MBMs) such as carbon

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taxes and emissions trading systems (ETS), which require polluters to bear the costs associated with the damage caused by their activities. Despite these developments, there remains a lack of comprehensive analysis regarding the theoretical foundations and practical implementation of the PPP in the context of GHG emissions from shipping. Furthermore, empirical research exploring the perspectives of key stakeholders on the application of PPP in this sector is notably scarce.

Therefore, this study aims to fill the research gap by conducting an in-depth analysis of the application of the PPP and assess its feasibility as an alternative strategy for reducing GHG emissions from shipping. Based on this aim, the following two research questions will be addressed:

- (1) What are the current measures, and how do the mechanisms based on PPP compare to these mechanisms?
- (2) What are the potential benefits and difficulties of applying the PPP in the shipping sector?

Accordingly, this study is organised into six sections. Following this Introduction, [Section 2](#) outlines the research approach and methodologies. [Section 3](#) presents the findings from the comprehensive literature review, and [Section 4](#) presents the survey results. [Section 5](#) provides in-depth discussions on the potential and challenges of applying the PPP. Finally, [Section 6](#) concludes the article.

2. Research method

This research mainly employs two research methods: literature reviews and a questionnaire survey. It begins with a comprehensive and systematic literature review. As a critical research method, literature review is highly effective in synthesizing fragmented knowledge, identifying significant research gaps, and guiding future scholarly inquiry (Snyder, 2024). This method plays a crucial role in our study by providing evidence-based assessments of existing research related to the questions we aim to examine. Specifically, this review systematically evaluates the efficacy of current IMO measures on shipping decarbonization, highlighting their limitations and inadequacy. These limitations further underscore the need for a study on the application of PPP as an alternative or supplementary strategy for controlling GHG emissions from shipping. Additionally, employing the literature review methodology allows us to investigate the application of the PPP within both the broader regulatory framework and the specific context of GHG emissions from shipping.

When designing the questionnaire survey, we invited relevant stakeholders to share their perspectives on the research questions. This empirical method enabled us to gather insights from industry stakeholders. The questionnaire includes single- and multiple-choice questions, 5-point Likert scales and open-ended questions, and was designed to be completed in approximately 10–15 min. We selected over 100 potential participants from a shipowners' association membership list and the directory of shipping and insurance companies issued by the Hong Kong government. Selecting participants from Hong Kong was motivated by the region's proactive efforts to achieve the Paris Agreement's goals, its commitment to IMO emissions reduction targets, and its innovation in green shipping (Marine Department, Hong Kong, 2024). The questionnaire distribution and data collection process were primarily conducted via email, included a detailed description of the survey, a link to the online questionnaire and a QR code for mobile accessibility. After receiving the responses, we analysed the quantitative data via descriptive statistics, using Microsoft Excel and Python. The empirical study was conducted ethically in accordance with the Institutional Review Board of the authors' institute.

3. Literature review

We primarily used ScienceDirect as the main database to collect, summarise and categorise the findings of previous research. In addition,

Scopus and Google Scholar were used as supplementary sources to ensure the robustness of the results. According to the objectives of this study, we employed a multi-layered keyword approach to identify the landscape of current research and divided the literatures into three main categories. Firstly, we gathered research on the current IMO measures by using various combinations of keywords such as 'GHG emissions from shipping', 'IMO technical measures', 'IMO operational measures', 'mid-term measures', and 'Net-Zero Framework'. Our search results from ScienceDirect indicate a significant volume of literature addressing IMO's existing strategies, with queries for IMO's 'technical measures' and 'operational measures' yielding 329 and 529 results, respectively. However, forward-looking topics such as the 'Net-Zero Framework' remain under-researched, returning only 25 results. Secondly, in reviewing the PPP, a general search for the 'polluter-pays principle' produced 3,822 results. To capture the evolution of the PPP and its various functions in addressing environmental harm, we then combined the keywords 'polluter-pays principle', 'ex-post approach', 'curative function', and 'preventive function', which narrowed the results to around 330. Thirdly, we reviewed literature applying the PPP specifically in the context of GHG emissions from shipping. A search combining the keywords 'polluter-pays principle' and 'GHG emissions' yielded 599 results. However, when the keywords 'polluter-pays principle', 'GHG emissions', and 'shipping' are combined, the number of results dropped sharply to only 103 publications. The significant decline in search results for PPP in the maritime context quantitatively confirms the research gap: a lack of feasibility studies on applying the PPP to control GHG emissions from shipping. The final selection of publications was based on several key criteria to ensure the rigor and relevance of our analysis. These criteria included: (1) the alignment with the study's aim and research objectives; (2) the reputation and ranking of the relevant journal; and (3) the demonstrable expertise and contributions of the authors in the field. Furthermore, official websites, notably that of the IMO, were consulted to incorporate the most current and relevant updates on the topic. This multi-faceted approach to source selection strengthens the validity and comprehensiveness of our literature review.¹

3.1. IMO measures

In 1973, the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted to regulate marine pollution (IMO, 1973). In 2011, amendments to Annex VI in the MARPOL 73/78 introduced the first legally binding measures to reduce marine GHG emissions (IMO website, 2021). The Amendments added a new Chapter 4 to Annex VI, which includes Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). In 2018, IMO adopted the Initial GHG Strategy, intending to reduce international shipping's annual GHG emissions by at least 50% by 2050 from 2008 levels (IMO, 2018). In 2023, the IMO updated this strategy with more ambitious goals, including achieving net-zero GHG emissions by or around 2050 and reducing emissions from 2008 levels by at least 20% by 2030 and 70% by 2040 (IMO, 2023a). Additional short-term measures were implemented in 2023 such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) to enhance energy efficiency and operational carbon intensity. However, data and proposals from member states highlighted gaps and challenges in these measures (IMO website, 2024b).

The effectiveness and limitations of these measures, and their impact on decarbonising the shipping industry are widely investigated in academia (for example, (Balcombe et al., 2019; Bouman et al., 2017; Dewan and Godina, 2024; Lagouvardou et al., 2020; Lee, 2024; Rauca

¹ The literature review was conducted in two stages: an initial round was completed in February 2025, followed by a comprehensive update that included publications up to 3 January 2026.

and Batrinca, 2023). Smith et al. (2016) projected a mere 3% reduction in GHG emissions by 2050 with EEDI compliance. Shi (2016) and Shi and Gullett (2018) highlight that while EEDI and SEEMP are mandated, they are insufficient on their own to mitigate GHG emissions, which are expected to rise with global trade growth, and must be supported by broader market practices and enhanced technical capacity. Smith et al. (2016) projected a mere 3% reduction in GHG emissions by 2050 with EEDI compliance. Recent regulations require all ships to calculate their EEXI. While EEXI aims to enhance energy efficiency, its design allows owners to comply by implementing power limits rather than by adopting advanced energy efficiency technologies (Maersk Zero Carbon Shipping, 2022). Since many ships already operate below maximum speeds and power, EEXI may not significantly encourage the use of more efficient technologies or substantially reduce emissions compared to current operations). CII evaluates carbon performance based on cargo volume and voyage distance, assigning efficiency ratings to vessels. Wang et al. (2021) note that improved CII ratings do not always equate to actual reductions in CO₂ emissions, suggesting a need for a revised CII framework. Rauca and Ghiorgh (2023) highlights CII accuracy relies on precise operational data, and discrepancies can undermine its effectiveness. A review of the IMO's short-term GHG measures considering such gaps and challenges is underway, and an assessment of the effectiveness of CII and EEXI will be completed by 1 January 2026 (IMO website, 2023; IMO, 2023b).

IMO member states further considered mid-term measures in the 2024 MEPC 81 (IMO website, 2024a), including a global goal-based marine fuel standard and a pricing mechanism (IMO, 2023a). In April 2025, the MEPC 83 approved the IMO Net-Zero Framework for global shipping, incorporating candidate mid-term measures into Chapter 5 of Annex VI of MARPOL (IMO, 2025). The Framework was recognised as a historic milestone in maritime decarbonisation (Maersk Zero Carbon Shipping, 2025). However, it has faced doubts and criticisms. For example, the Clean Shipping Coalition argued that it falls short of the actions needed to align with the Paris Agreement's 1.5°C goal (Bush, 2025a). Additionally, many key details such as how the revenue will be distributed still need to be finalised. Maersk also noted that multiple factors remain unaddressed (Bush, 2025b). The Framework was initially planned to be finalised by the MEPC in October 2025, with detailed implementation guidelines for approval in Spring 2026 at MEPC 84 (IMO website, 2025). However, the MEPC (MEPC/ES.2) has now decided to push back the adoption of Net-Zero Framework to October 2026, creating significant uncertainty for the entire shipping industry.

3.2. Polluter-pays principle

The PPP was initially introduced as an economic principle of cost allocation, rooted in the theory of externalities (de Sadeleer, 2020). English economist Pigou (1932) proposed a solution to address externalities, intending to incentivise polluters to take responsibility for the external costs generated, which is known as 'internalisation of external costs' (Munir, 2013). Internalisation is established when all relevant costs are covered by the polluter, reflecting the true cost of production in the market price of goods (de Sadeleer, 2020). The PPP was then first formally introduced at the international level by the Organisation for Economic Co-operation and Development (OECD) in 1972. The OECD document officially recommended the PPP as a 'Guiding Principle' and '... to be used for allocating costs of pollution prevention and control measures...' (OECD, 1972). Over the decades, the OECD Council has intensively worked to interpret and develop the PPP, which has evolved from an economic principle into a comprehensive legal and regulatory principle involving liability distribution for environmental damage (de Sadeleer, 2020; OECD, 1992), recognised by the OECD in 1992 (OECD, 1992).

Scholars have extensively analysed the PPP's transformation from an economic guideline to a legal principle. Notably, de Sadeleer (2020), Bleeker (2009), Luppi et al. (2012), Zhu (2023) and Zhu and Li (2025)

collectively argued that the PPP has evolved beyond its original role as a mere economic rule to become a legal principle. Bugge (1996) characterises the PPP as an 'economic principle focusing on efficiency', and a 'legal principle' concerned with just cost distribution. While emphasising the economic rationale of the PPP in terms of efficiency, Bleeker (2009) further contextualised its legal dimensions, indicating that it embodies the equity or fairness principle under common law, which operationalises fairness in the allocation of responsibility for environmental harm by distributing pollution costs to the polluter rather than innocent third parties. De Sadeleer (2020) further identifies four main functions of the PPP, providing a valuable theoretical foundation for understanding its application: First, the economic integration function, which is in line with the 1972 OECD recommendation (OECD, 1972), aims to prevent distortions in international trade and investment by prohibiting state aid and ensuring polluters bear the costs of pollution. Second, the redistribution function channels a portion of polluters' profits to public authorities to support regulatory activities. Third, the preventative function seeks to deter pollution by internalising costs beforehand, encouraging emission reduction through economic incentives rather than simply paying fees. Fourth, the curative function involves environmental liability under civil law, ensuring *ex-post* redistribution and comprehensive damage repair, including residual harm. Luppi et al. (2012) add that governments may have joint-and-several liability for environmental damage, enabling them to pursue subrogation actions against polluters. Aragão (2022) emphasised multiple dimensions of the PPP's ecological justice including retributive, restorative, distributive and preventive justice.

3.3. PPP and control of GHG emissions from shipping

Extensive literature has examined the application of the PPP across diverse sectors, including agriculture, energy and aviation, as a means to internalize environmental externalities and incentivize polluters to reduce emissions (e.g., Tobey and Smets, 1996; Goulder and Parry, 2008; Stavins, 2008; Nwosi and Kokpan, 2023). With the growing recognition of the normative significance of the PPP, scholarly discourse has increasingly explored its potential to address ship-source pollution. Studies have argued that the PPP has been incorporated into the regulation of ship-sourced pollution. For example, Gauci (1999) and Mason (2002) demonstrated that liability regimes for oil pollution have adopted the PPP, manifested through strict liability mechanisms backed by compulsory insurance. These mechanisms ensure that those responsible for pollution bear the financial costs of remediation and compensation. Zhu and Zhao (2015) assessed the feasibility of applying the PPP to ship-source pollution in Hong Kong, and highlighted the evolving nature of environmental liability in transnational contexts. Their analyses demonstrate the PPP's potential role in supporting the liability and compensation regime for marine pollution.

More recently, the potential of the PPP in mitigating GHG emissions from shipping has attracted increasing attention. Shi and Gullett (2018) showed that IMO MBMs, such as carbon levy and ETS, are designed to provide economic incentives for shipowners and operators to reduce their GHG emissions, thereby aligning with the PPP. Zhu (2023) discussed the application of the PPP in marine GHG control, emphasizing that polluters should be financially liable for all costs associated with reducing, preventing, or eliminating pollution. Despite its theoretical appeal and potential benefits, the practical implementation of the PPP can be challenging due to its often vague and broad formulation. Zhu (2023) identified several practical and significant uncertainties, including three essential issues regarding the application of the PPP: who qualifies as a polluter, what pollution damage should be compensated, and how payment should be made. Zhu and Li (2025) provided an in-depth analysis of the primary issue of identifying polluters.

Therefore, from a theoretical perspective, the PPP may be considered as a viable alternative for addressing issues related to GHG emissions from shipping for several reasons. First, it holds polluters accountable

for environmental harm and incentivizes potential emitters to reduce pollution by instilling accountability concerns (Zhu and Li, 2025). Secondly, the PPP offers a comprehensive approach for addressing GHG emissions. It facilitates the internalization of pollution costs from an economic perspective and is a legal foundation for addressing gaps that may emerge in the pollution liability mechanism, ensuring that those harmed by polluting activities receive adequate compensation. Thirdly, the PPP may be implemented through either international conventions or domestic legislation and policies, establishing standardised yet flexible mechanisms.

Despite the theoretical analysis highlighting the significant role that the PPP may play in addressing GHG emissions from shipping, it is crucial to consider stakeholders' perspective. The application of the PPP could impose additional burdens on these stakeholders; however, current research rarely addresses this aspect.

4. Survey and the main results

The questionnaire was structured into four parts, aiming to evaluate participants' understanding of GHG emissions from shipping in general, the adequacy of current IMO measures, the scope and implications of the PPP, and the potential and challenges of applying the PPP to reduce GHG emissions. After three rounds of email outreach, we received 22 completed and effective survey forms, resulting in a response rate of 20%. Although this response rate may seem not ideal, it indicates that the opinions expressed by those who participated are particularly significant. All 22 respondents held upper-middle-level positions in their organisations, and the majority had extensive professional experience, with over 10 years in the shipping industry. This background contributes to the quality and reliability in the responses received, providing valuable insights into the study's focus. Moreover, response rates among top executives are typically lower than those of other populations due to factors such as time constraints and concerns about confidentiality (Cycyota and Harrison, 2006).

Part I of the questionnaire collected participants' basic information. The majority are involved in dry bulk shipping (64.7%), followed by oil and gas tankers (41.2%). Additionally, some respondents (17.7%) are engaged in both bulk carriers and tankers. The smallest groups consisted of those focused solely on container shipping or ship management, each representing 5.9%. Furthermore, Protection and Indemnity clubs or insurance companies accounted for 22.7% of respondents.

Part II assessed participants' understanding and perceptions of GHG emissions to gauge their awareness and attitudes towards the issue. Four questions were designed, Question 2.1 asked respondents to what extent they agree that shipping contributes to global GHG emissions and

climate change. Questions 2.2 and 2.3 were yes/no questions evaluating respondents' awareness of current shipping emission levels and future trends. In addition, Question 2.4 asked respondents to identify factors influencing the amount of GHG emissions from shipping activities. Results show that respondents generally agree on the impact of the shipping industry on global GHG emissions and climate change, with an average score 3.73. Moreover, 95.5% of respondents are highly aware of the shipping industry's contribution – around 3% – to global GHG emissions. Additionally, 77.3% recognize projections that shipping emissions could reach 90% to 130% of 2008 levels by 2050 (Faber et al., 2020), indicating strong awareness of both current and future emission trends within the industry. For factors influencing emissions (Question 2.4, Fig. 1), 'Types of fuel used to power the vessel' and 'Engine efficiency' are most frequently selected (95.5%), followed by 'Speed of the vessel' and 'Quantity of fuel used to power the vessel' (86.4%). All respondents made their own suggestions in the 'other' option, identifying a variety of influencing factors. Operational concerns included voyage planning, the ratio of operation time to total time, port operation and waiting times. Technical factors included resistance to the vessel in water such as ice conditions, hull fouling, hull cleanliness and engine retrofitting. Additionally, other factors include world trade volume, trade pattern and weather during the voyage. These responses highlight the complexity of reducing shipping emissions, involving technology, operations and external environment factors. Overall, in Part II, respondents demonstrated strong awareness of shipping's role in global GHG emissions and its future impact.

Part III explored participants' perspectives on the effectiveness and relevance of current IMO technical and operational measures. In this part, respondents were asked to evaluate the adequacy of the IMO's existing technical and operational measures. This part used a five-level scale from 'Very adequate' to 'Not adequate at all', grading 'Very adequate' with 5, 'Adequate' with 4, 'Neutral' with 3, 'Not very adequate' with 2, 'Not adequate at all' with 1. Question 3.1 addressed the adequacy of technical measures. The average grade was 3.41, indicating a generally positive assessment of the IMO's technical measures. However, 36.4% of respondents chose 'Neutral', reflecting a cautious stance. The combined percentage of those who chose 'Not very adequate' and 'Not adequate at all' was 13.6%, indicating that a minority were critical of and concerned about the existing measures. Question 3.2 asked participants to evaluate the operational measures adopted by the IMO to reduce GHG emissions. The average score was 3.36, indicating a generally positive assessment of the IMO's operational measures. It is worth noting that 36.4% respondents selected 'Neutral' and a minority of respondents (18.2%) selected 'Not very adequate'. It is important to note that while the results show that respondents' attitude

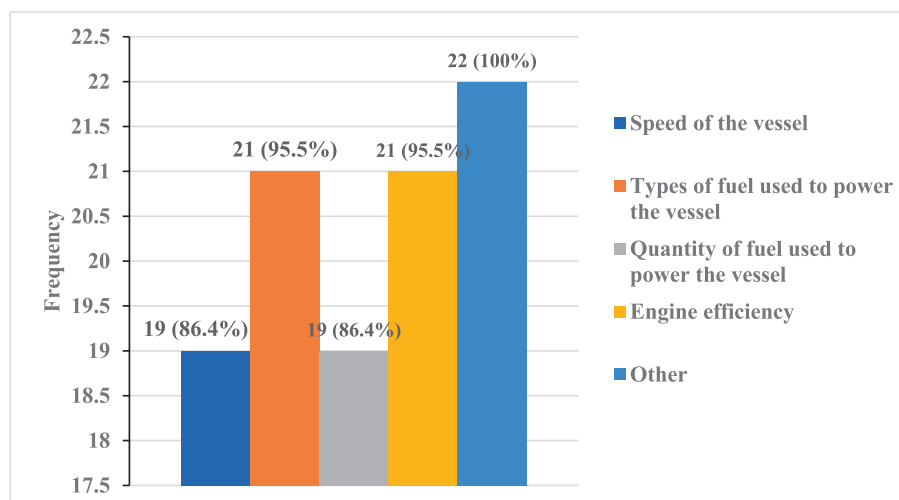


Fig. 1. Respondents' understanding of the factors that may influence the amount of GHG emissions from shipping activities.

toward IMO's technical and operational measures are generally positive, a considerable number remain neutral or critical, demonstrating concerns regarding the effectiveness, implementation, and capability of IMO measures to drive substantial emissions reductions.

Part IV represents the most significant contribution of this study, as it delves into the participants' understanding of the PPP in addressing GHG emissions from shipping. We firstly examined the participants' level of understanding of the feature and implications of the PPP. Subsequently, this part is divided into two sub-parts. The first included six questions to assess respondents' in-depth understanding of the PPP in addressing GHG emissions from shipping, and the second sub-part included two open-ended questions to capture more nuanced perspectives and suggestions.

4.1. General understanding of the PPP

Question 4.1 assessed participants' understanding of the PPP. The results indicate that most respondents (77.3%) understood the core features of the PPP, recognising its aim to enable polluters to compensate for environmental damage. Merely fewer respondents even demonstrated a deeper understanding of the PPP as an economic principle (45.5%) to internalize external cost and legal principle (36.4%) for the distribution of liability for the cost of pollution, suggesting that while the basic idea is widely recognized, its broader implications are less well understood. Question 4.2 sought respondents' perspectives on the potential roles of the PPP, and the frequency of each option is illustrated in Fig. 2. The results reveal that the PPP was widely recognised for its crucial influence on promoting investment in green shipping (90.9%) and driving the industry's green transformation (81.8%), and 54.5% of participants noted the PPP's potential to deter polluting behaviours. However, only 40.9% recognised its role in allocating liabilities for pollution damage. The relatively high percentage of 'Other' responses (45.5%) indicates diverse perspectives on the role of the PPP, with one respondent highlighting its potential to promote market mechanisms through pricing. The results shows that respondents consider the PPP to be highly valuable for advancing green transformation and emissions reduction in shipping.

After evaluating respondents' basic understanding of the PPP, Question 4.3 sought their opinions on the extent to which they agreed that the PPP could serve as an alternative or supplementary approach to mitigating GHG emissions from shipping. The survey used a five-point

Likert scale to measure responses. As shown in Table 1, the average score was 3.59, indicating strong acceptance of the PPP as a viable method for reducing GHG emissions, with overall attitudes leaning towards 'support'. Notably, 63.6% of respondents chose 'Agree' or 'Strongly agree', demonstrating widespread recognition of the PPP's potential. Although only 9.0% (2 respondents) opposed its potential, which still indicates that the PPP's specific implementation and effectiveness warrant further exploration and validation. The Std. deviation is 0.91, indicating that the responses were fairly consistent and show limited variation.

Subsequent sections of the questionnaire were divided into Part IV-I and Part IV-II. Respondents who selected 'Strongly agree' or 'Agree' in the aforementioned Question 4.3 were directed to Part IV-I, which included a detailed survey on the PPP's application. Those who were 'Neutral', 'Disagree' or 'Strongly disagree' were directed to Part IV-II to provide their own thoughts. Consequently, 19 participants completed the questions in Part IV-I. Part IV-II comprises two questions, each of which received 9 comments.

4.2. Details of the PPP's application

Part IV-I included six sub-questions that aimed at exploring specific factors related to the application of the PPP. SQ1 used a multiple-choice format to gather respondents' views on the factors to consider when identifying the polluter. The result indicates that decision-making authority over fuel type and quantity (78.9%) and vessel speed (73.7%) were the most frequently recognized. The causal link between activity and pollution was chosen by 57.9% of respondents. The 'Other' option was selected by 89.5%, with 63.2% (12 respondents) choosing it without further clarification, indicating cognitive ambiguity among some participants. Five respondents proposed advanced standards, three of which suggested that the shipping service beneficiary should be identified as the polluter, aligning with the Beneficiary Pays Principle (BPP), which we explore further in Section 5.

We then asked participants which specific stakeholders should be considered polluters under the PPP. The results are included in a heatmap (SQ2, Fig. 3) to illustrate the frequency of co-selection between options and the strength of associations. The X and Y axes in the heatmap list all options, with cell values representing the frequency of respondents selecting both options. The heatmap employs a gradient color scale where the intensity of the blue color corresponds directly to the

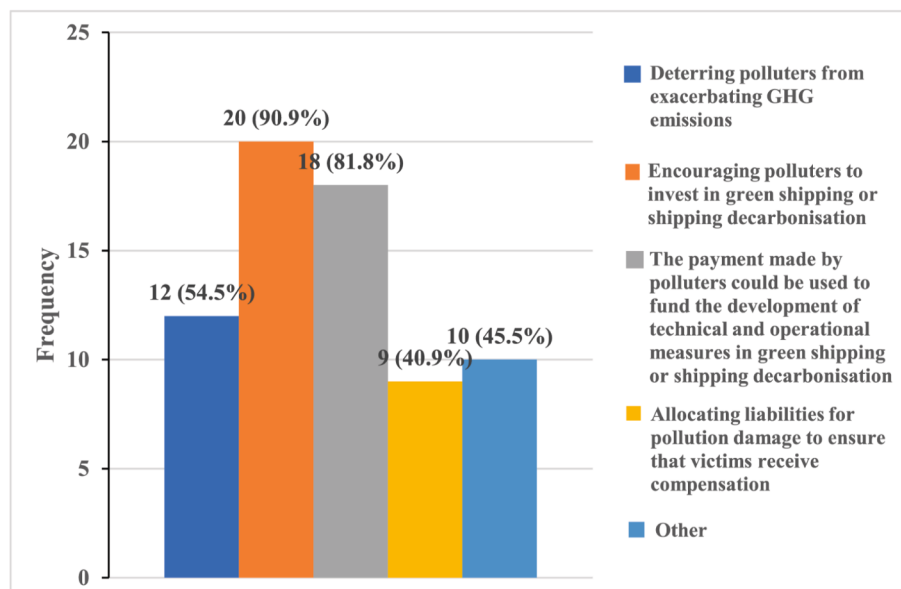


Fig. 2. Respondents' understanding of the roles the PPP.

Table 1
PPP could serve as an alternative or supplementary approach.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Average
Number ^a	2	12	6	1	1	
Percentage (%) ^b	9.1	54.5	27.3	4.5	4.5	
Grade ^c	5	4	3	2	1	
Std. ^d						0.91
Average ^e						3.59

- a. Number of respondents.
- b. Proportion of respondents.
- c. Grade based on quantifying the assignments for each option Strongly agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly disagree = 1.
- d. Standard deviation.
- e. Average was based on Grade × Number/total number.

Polluter Identification Heatmap
Total Respondents: 19

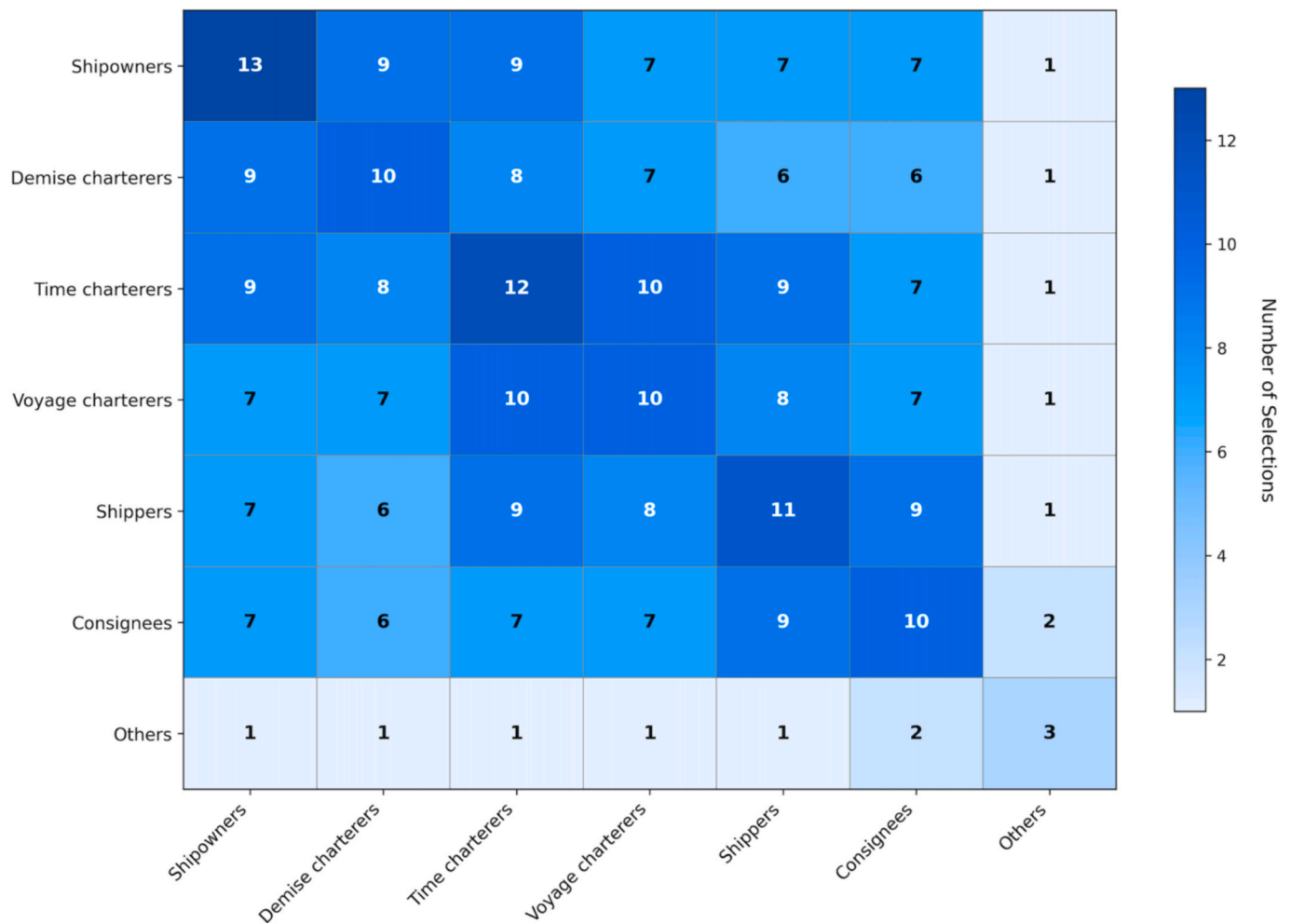


Fig. 3. Respondents’ understanding of parties to be considered polluters.

frequency count. A deeper blue indicates a higher selection frequency, and a lighter blue signifies a lower frequency. The diagonal values show the total number of times each option was selected. In Fig. 3, Shipowners were selected most frequently (13 times), followed by Time Charterers (12 times), Shippers (11 times), Consignees (10 times) and Voyage Charterers (10 times). Shipowners and Demise Charterer, Shipowner and Time Charterers, Shippers and Consignees and Voyage Charterers and Time Charterers were frequently co-selected, with 9, 9, 9 and 10 instances respectively, indicating they are often viewed together as polluters. Notably, the frequent co-selection of Shippers and

Consignees (9 times) indicates support for extending responsibilities to indirect parties/non-operators, which may be consistent with the ideas under the BPP discussion. This will be discussed further in the next Section. In the ‘Other’ category, some respondents suggested that the responsibility could be extend to all stakeholders or even the general public.

Considering the complexity of identifying a polluter and the multiple parties that can be involved, SQ3 asked respondents’ view on the liability rules when multiple parties are recognised as polluters or when other parties bear responsibilities. The most favoured option was

‘Channelling of liabilities’, selected 12 times (63.2%), and ‘Joint and several liability’ was chosen 7 times (36.8%). Among those who selected ‘Other’ option, only one gave a specific comment questioned the nature of the entire environmental movement. SQ4 posed a multiple-choice question regarding pollution damage, asking, ‘What should the polluter pay for if the PPP is applied?’ The survey results show that a significant proportion of respondents (73.7%) selected costs related to preventive measures, while 63.2% chose remedial costs for restoring the environment, and 52.6% selected costs for loss or damage caused by emissions. Additionally, 78.9% chose the ‘Other’ option, with one respondent specifically noting that the PPP should also cover additional costs such as taxes or levies on GHG emissions or their intensity. These findings suggest that most respondents believe the PPP should encompass a broad range of costs, including preventive, remedial, and compensatory measures, as well as other potential financial mechanisms. SQ5 asked respondents ‘How should payments be made if the PPP is applied?’ In Fig. 4, the Emission Trading System (ETS) and Carbon Tax were selected 15 (78.9%) and 14 (73.7%) times, respectively. No other forms of MBMs were chosen. ‘Contribution to a fund’ was selected 8 times, accounting for 42.1%. One respondent who selected the ‘Other’ option indicated that fees should be passed on to consumers through the final price of goods.

SQ6 asked how the PPP could be implemented in shipping practices. Fig. 5 indicates that the majority (89.5%) favored implementation through IMO conventions, reflecting strong support for a unified and authoritative approach suited to the global nature of shipping. The next most popular option was national or domestic legislation (52.6%), though this was significantly less favored, indicating some ambivalence about the effectiveness of domestic measures. Other international conventions (42.1%) and domestic policy initiatives (36.8%) received even less support, likely due to concerns over their authority, uniformity and enforcement capacity. These results underscore a clear preference for international implementation of the PPP by the IMO, while also highlighting the diversity of views on regulatory approaches for reducing shipping GHG emissions.

4.3. Respondents’ perspectives and suggestions

In this part, the first question asked respondents to share their thoughts on other measures that might be more effective. We received a total of 9 comments, which were categorised into four main themes. (1) Fuel alternative technology advancement, for which suggestions were focused on promoting carbon-neutral biofuels for existing ships and advancing research into green fuels like ammonia for future use. (2) Energy efficiency improvements, for which respondents suggested

incentivising shipowners and manufacturers to design more energy-efficient vessels and machinery. Specific measures highlighted included installing vortex fins and air deflector nearby propeller, the use of high-efficiency hull coatings and the optimisation of carbon capture systems. (3) Economic incentives, where respondents emphasised the effectiveness of MBMs such as a carbon levy as economic incentives. This suggestion aligns with the core idea of the PPP and diverse implementation strategies were proposed. (4) Accurate GHG emissions monitoring and digitalisation, which yielded a strong call for accurate measurement of individual ship’s carbon emissions, advocating for the adoption of digitalisation to enhance transparency and accountability in the shipping industry.

The second question invited respondents to share their thoughts on why they do not support the PPP, also capturing comments from those who agreed or were neutral regarding Question 4.3, with a focus on improving the PPP’s implementation. Among these respondents, concerns were raised about the potential tax evasion and regulatory avoidance. One respondent strongly disagreed, arguing that mandatory green fuel adoption could significantly increase global commodity costs.

Furthermore, several suggestions were made to improve the PPP’s implementation. One recommendation was to establish a transparent and measurable compensation distribution framework to ensure that polluters understand how their payments will be used and who will benefit. This addressed concerns about payment traceability, as highlighted by an opponent of the PPP in Question 4.3. Another suggestion was to streamline the process by avoiding complex conventions and multiple stakeholders, proposing to collect the carbon levy directly at bunker fuel purchase, with a carbon tax based on fuel amount. These insights underscored the need for a more transparent and efficient system to enhance the PPP’s effectiveness in addressing GHG emissions from shipping.

5. Discussions

5.1. Potential of applying the PPP

The PPP is considered a cornerstone of environmental law and policy that is employed in environmental regulation or as a policy tool to prompt polluters to bear the environmental costs of their actions (Zhu, 2023). This principle also has a significant influence in the realm of marine pollution (Zhu, 2015).

5.1.1. The PPP’s functions

As indicated in Table 1, 63.6% respondents agreed that the PPP can serve as an alternative or complementary method to reduce GHG

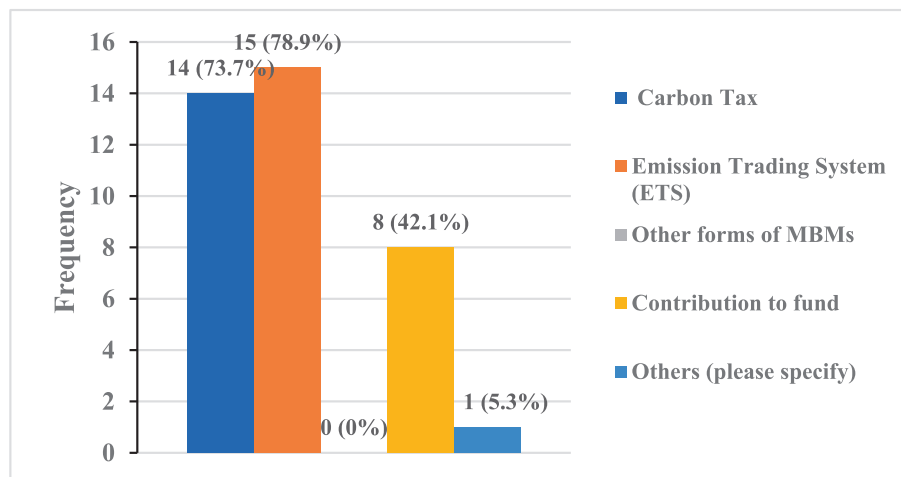


Fig. 4. Respondents’ view on how payments should be made.

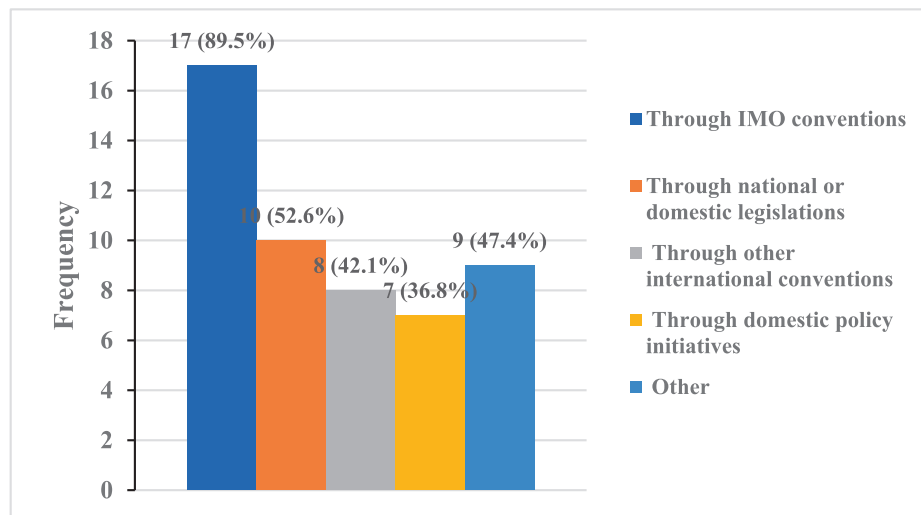


Fig. 5. Respondents' views on how the PPP could be implemented.

emissions from shipping, reflecting awareness of its preventive and curative functions. As defined by the OECD, polluters should be financially responsible for 'the cost of pollution prevention and control measures' (OECD, 1972). It also represents the *ex-ante* approach of allocating pollution prevention costs and control measures and stimulating instruments that prevent pollution in advance (de Sadeleer, 2020). Additionally, implementing a preventive environmental protection policy enables the acquisition of necessary funds and alters the behaviour of those regulated by it (de Sadeleer, 2013). The PPP's preventive function is justified legally, by aligning with other environmental principles such as the prevention principle, and economically, as polluters are incentivised to reduce emissions when the costs of their harmful activities exceed the benefits (de Sadeleer, 2020; Duvic-Paoli, 2018). Therefore, the true aim of the PPP should be to implement a pollution reduction policy that encourages polluters to decrease emissions, rather than merely allowing them to pay fees to continue polluting (de Sadeleer, 2020). Referring to SQ4, the largest proportion of respondents agreed that polluters should pay for costs of reasonable preventive measures, highlighting strong recognition of the PPP's preventive function.

Regardless of how significant or effective preventive measures may be, the risk of environmental degradation, however, persists (de Sadeleer, 2013). It is acknowledged that pollution cannot be fully prevented, and loss and damage will occur. It is essential to ensure that polluters provide compensation as it would be unjust for society to bear the costs of environmental damage for which it is not responsible (de Sadeleer, 2020). GHG emissions can incur irreversible losses such as land loss due to rising sea levels, and repairable damages such as storm-damaged coastlines (Doelle and Seck, 2020). Environmental liability is a key element of the PPP, with civil liability offering a more individualistic form of redistribution, in contrast to traditional distributive functions (de Sadeleer, 2013). Therefore, when considered from a civil liability perspective, the curative dimension of the PPP represents a significant advancement in addressing loss or damage resulting from pollution. It provides compensation for marine and coastal environment impairment, ensuring a form of *ex-post* redistribution (de Sadeleer, 2020; Munir, 2013).

Concerning GHG emissions from international shipping, the PPP's curative function has the potential to fill the gap established by the absence of a dedicated pollution liability mechanism to penalise emitters and compensate those adversely impacted by pollution (Zhu and Li, 2025). In SQ4, 'Loss or damage' and 'Costs of restoring the marine and coastal environment' are two specific manifestations of the PPP's curative dimension. The quantitative evidence shows that over 50% of

stakeholders accept this function. However, support for the curative function is notably weaker than that for the preventive function (73.7%), indicating insufficient attention to the PPP's curative function in addressing the environmental damage caused by GHG emissions and the associated liability for compensation. This aspect may require targeted promotion to ensure that the PPP's curative function is emphasised alongside preventive approaches. Consequently, the PPP has the potential to establish a framework for *ex-post* environmental liability as a principle in developing a comprehensive strategy for reducing GHG emissions from shipping.

5.1.2. Understanding pollution damage

As indicated by our survey results, nearly all participants are aware that GHG emissions from the shipping account for around 3% of overall global emissions, and respondents recognised the predicted severe increase if no further actions or measures were to be implemented (King, 2022). GHG emissions from shipping can result in various types of pollution damage. Analysing specific pollution damage could facilitate a more comprehensive understanding of how the PPP can address shipping GHG emissions and what types of pollution are covered under the PPP.

An academic consensus that GHG emissions from shipping constitute a form of vessel-source marine pollution has emerged (Testa, 2023; Bodansky, 2018; Boyle, 2016).² Furthermore, since GHG emissions from shipping contribute to climate change, the resultant damage is intricately linked to its broader impacts. Vessel-source marine pollution damage has been specifically defined in various conventions (IMO, 1969; IMO, 1992; IMO, 1996; IMO, 2001), which identifies several common types: (1) loss or damage caused outside of the ship by contamination resulting from pollutants carried as the cargo of the ship; (2) costs of restoring impairment of the marine and coastal environment; and (3) the costs of reasonable preventive measures and loss or damage caused by preventive measures. The survey data reveal the respondents' understanding of pollution damage from shipping GHG emissions. As illustrated in SQ4, 52.6% of respondents identified loss or damage occurring outside of the ship, 63.2% believed that the polluter should bear the costs of restoring damage to the marine and coastal environment, and the largest portion of respondents (73.7%) selected the costs associated with reasonable preventive measures.

² Also, the International Tribunal for the Law of the Sea expressed a similar opinion when it delivered the first international judicial opinion on state obligations addressing climate change in its Advisory Opinion.

In the specific context of pollution damage from maritime GHG emissions, the primary consequence is climate change, and such climate change arises from cumulative emissions from various shipping activities and processes (Verheyen and Franke, 2023). Therefore, we may infer that the loss or damage caused by GHG emissions from shipping, as outlined in the aforementioned first type of marine pollution damage, namely “loss or damage caused outside of the ship...”, is analogous to the loss and damage (L&D) associated with ordinary climate change. This concept was used in the UN climate negotiations to represent the harmful consequences of climate change. L&D refers to negative impacts of climate change associated with slow onset events such as rising sea levels, increasing temperatures, ocean acidification, changing ocean chemistry and circulations and glacial retreat, as well as extreme weather events such as droughts, heatwaves and storm surges (UNFCCC, 2011). It has been suggested that the term ‘loss’ represents permanent harm or irreversible loss such as loss of land due to sea level rises, and ‘damage’ represents repairable or recoverable damage such as damage to a coastline caused by a storm (Doelle and Seck, 2020). This analogy enables us to apply the broader concept of climate change-induced L&D to the loss or damage attributable to GHG emissions from shipping. Nevertheless, it is hoped that more scientific evidence and research will be developed in the future to enhance the understanding of pollution damage associated with GHG emissions from shipping.

5.1.3. Other issues

Fig. 5 illustrates that the most prevalent method of implementing the PPP is through IMO conventions (89.5%), followed by other international conventions (42.1%), underscoring the significance of the IMO in upholding this principle. National or domestic legislation (52.6%) and domestic policy initiatives (36.8%) also received support. The PPP has arguably influenced the development of environmental liability frameworks across various countries (Larson, 2005). In the context of marine GHG emissions, the IMO dominantly regulates international shipping, while individual countries are responsible for managing GHG emissions within their domestic jurisdictions. However, inadequate domestic implementation of IMO measures or a lack of effective national regulations to control marine GHG emissions could significantly undermine mitigation efforts. Unregulated emissions at the national level may exacerbate environmental challenges (Faber et al., 2020). In this scenario, the PPP may be promoted as it enables each state to adopt distinct approaches to define and implement it within the domestic legal framework (Pinto-Bazurco, 2022), facilitating flexibility and targeted application. Therefore, the PPP has the potential to harmonise international and domestic regulatory frameworks to comprehensively address gaps for mitigating GHG emissions.

5.2. Problems of applying the PPP

Although the PPP has the potential for addressing GHG emissions from shipping, several practical and complex challenges remain. Two main challenges are noteworthy. First, the principle does not explicitly address the polluter, complicating the determination of liability. In the shipping industry, multiple parties are often involved in various contractual arrangements, making it difficult to ascertain who is liable. Second, there are issues related to cost allocation, including how payments should be structured and implemented (Zhu, 2023). These challenges emphasise the need for more concrete guidance and frameworks to effectively operationalise the PPP within the maritime context.

In general, a polluter is an individual or entity that directly or indirectly causes environmental pollution or creates conditions that lead to such pollution damage. Establishing a causal link between a polluter and subsequent pollution damage is considered to be an essential element in identifying a polluter (Zhu and Li, 2025). However, establishing a causal link in the context of GHG emissions can be complicated. Pollution damage from GHG emissions often results from a cumulative process involving historical and current emissions from multiple emitters,

rendering almost everyone partially responsible for the resulting impacts of climate change (Verheyen and Franke, 2023). Unlike traditional marine pollution such as oil spills, pollution damage from GHG emissions may manifest far from the emissions source (Verheyen and Franke, 2023), making it also difficult to trace their origin. GHG is quickly emitted and then merged rapidly into the atmosphere, and their indistinguishable nature means that it may not be possible to link them to any specific source (Kosolapova, 2013). Therefore, these features of GHG emissions pose challenges to establishing the causal link between a polluter and the resulting pollution damage and in the distribution of pollution liabilities (Craik et al., 2023).

Theoretically, the polluter from GHG emissions from shipping can be the party with direct and primary decision-making authority over the vessel’s operation, particularly its speed and fuel consumption, as their activities are causally linked with the pollution (Zhu and Li, 2025). The result of SQ1 demonstrates the positive attitudes of respondents towards this statement. A majority selected both ‘decision-making power over the vessel’s speed’ (73.7%) and ‘quantity and/or type of fuel used’ (78.9%) as factors to consider when identifying the polluter. In Fig. 3, the shipowner was the most frequently selected option as the polluter. This is noteworthy, as the shipowner bears primary responsibility for decisions regarding fuel purchases and consumption and the ship’s speed, and should therefore be considered a polluter (Zhu and Zhao, 2015). Time charterers and demise charterers were also considered, aligning with their specific roles in shipping voyage.

In addition, our survey results reveal that shippers and consignees who are non-operators may also be identified as polluters (Fig. 3). The BPP can explain this paradox between theoretical expectations, in which a causal link must be established between polluter and pollution activity and the empirical findings. Notably, three out of five respondents who selected ‘Other’ (SQ1) advocated for the BPP. The BPP is a principle with a strong intuitive appeal that has been widely investigated in the context of climate change (Baatz, 2013). This principle suggests that those who benefit from activities that cause GHG emissions should bear the responsibility to compensate for environmental harm (Baatz, 2013). Most people seem to share the moral intuition behind it. Baatz’s Qualified Beneficiary Pays Principle (QBPP) further refined this idea, proposing that beneficiaries must compensate victims when the polluter cannot fully do so. The QBPP stipulates that if a polluter cannot fully compensate for the harm caused (due to being deceased, unable or inhumane), then a beneficiary who has received a net benefit from the harmful action must compensate the victim (Baatz, 2013). The QBPP only takes effect when the PPP falls short of providing full compensation (Baatz, 2013). In this case, the BPP could serve as a supplementary principle for the PPP.

In the shipping industry, shippers and consignees are beneficiaries of marine GHG emissions since international shipping mainly facilitates their trade agreements. This perspective addresses concerns that the PPP alone may be perceived as unjust, given the cumulative nature of climate change, and highlights the BPP’s potential role in enhancing justice and supplementing remedy responsibilities. Integrating the BPP alongside the PPP could provide a more comprehensive approach to addressing GHG emissions from shipping. More specifically, liability could first be channelled to the shipowner as the direct polluter, with the possibility for the shipowner to recover costs from other polluters and beneficiaries. In this way, the BPP serves as a supplementary approach, ensuring that compensation is not limited by the polluter’s ability to pay, and that those who benefit from emissions also share responsibility. Integrating the BPP alongside the PPP could thus provide a more comprehensive and just approach to addressing GHG emissions from shipping, guaranteeing that victims receive adequate compensation. A key issue arising from the BPP is determining the extent of beneficiaries’ contributions, which necessitates calculating the net benefits derived from past emissions. However, these considerations go beyond the scope of this study. Future research should focus on developing methodologies for such calculations and refining operational guidelines for the PPP and BPP to ensure

their effective implementation in the maritime sector (Baatz, 2013).

Since multiple parties are often involved in polluting activities, it is crucial to examine several liability related issues such as the basis of liability, mechanisms for distributing liability and potential methods for sharing that liability among polluters. In practice, the operation of international shipping involves cross-regional trade and cost shifting between many parties, including shipowners, charterers, operators, shippers and States, which may raise concerns about fairness and distribution of liability. However, it is crucial to understand that the fundamental purpose of the PPP is to ensure that the identified polluters—usually those with the most effective risk control or the greatest capacity for compensation—bear primary responsibility at the time an incident occurs (Kosolapova, 2013). In SQ3, the doctrine of ‘channelling of liability’ (Craik et al., 2023) garnered more support from our respondents compared with ‘joint and several liability’ in which all liable parties are jointly and severally responsible. The former approach first imposes pollution liability on an identified polluter, ensuring that a simple and prompt process for claims or compensation can be initiated (Kosolapova, 2013). The polluter would then be entitled to bring a recourse action against the primary liable parties. This mechanism has been adopted by the well-established international civil liability conventions adopted by the IMO.

In practice, costs can be charged *ex-ante* by pricing the pollution and then reflecting the cost in the product’s price (Bleeker, 2009). Fig. 4 reveals that the most popular option for payment is the ETS (78.9%) and Carbon Tax (73.7%). A carbon tax or bunker levy sets a fixed price on the amount of marine fuel consumption in proportion to its carbon content, with taxes levied on ships according to emissions (International Transport Forum, 2024). The rationale behind imposing carbon levy on international maritime fuel is that it can cost-effectively promote both short- and long-term carbon mitigation in the shipping sector. This is achieved by narrowing the price gap between conventional fuels and zero- or near-zero GHG fuels, thereby incentivizing the adoption of cleaner alternatives (Kachi et al., 2019). The revenue generated may contribute financially to a fund dedicated to advancing the development of green shipping technology, enhancing capacity-building efforts in developing countries, and mitigating disproportionately negative impacts in specific countries (IMO, 2023c; Zhu, 2023;). In particular, revenue reimbursement mechanisms can help alleviate the disproportionate impacts faced by Small Island Developing States and Least Developed Countries (IMO, 2024). ‘Contribution to a fund’ accounts for 42.1% of our survey respondents. In contrast, an emissions cap is set under an ETS, and polluters are assigned emissions allowances. Thereafter, if their emissions exceed these allowances, they then need to pay for such emissions. Therefore, the carbon price is determined by the supply and demand of emissions allowances (World Bank, 2024). Effective ETS enforcement demands a robust system of emissions monitoring, reporting and verification. Shipping was included in the European Union’s ETS in 2024 (European Union, 2023; Verde, 2020; Branger et al., 2015; Venmans, 2012). It is argued that ETS is effective in reducing emissions in the short term by incentivizing slow steaming (Kotzampasakis, 2025). However, in the implementation of the EU ETS, a major concern is the risk of carbon leakage. Under the EU ETS, shipping companies may adopt avoidance strategies, such as altering shipping routes to stop at nearby non-EU ports to minimize the portion of the voyage subjects to the ETS (Kotzampasakis, 2025). Such practices may undermine the long-term goal of decarbonization. Despite the critical and disapproving voices regarding this system, the EU ETS may provide valuable practical references for the setting up of a global system of paying for pollution damage arising from maritime GHG emissions.

6. Conclusions

This article employs a combined theoretical and empirical methodology to illustrate the current IMO measures, examine how mechanisms based on the PPP would compare to these measures, and assess the

potential and challenges of applying the PPP to address GHG emissions from shipping. Currently, shipping GHG reduction are mainly regulated by the technical and operational measures adopted by the IMO. However, research indicates that they remain insufficient to achieve the net-zero goal set by the IMO. This inadequacy and uncertainty are further exacerbated by delays in adopting the IMO’s net-zero framework. In contrast to the limited scope of existing IMO measures, which primarily utilize an *ex-ante* approach to reduce emissions, the PPP offers a more robust governance framework. As a cornerstone of environmental law and policy, the PPP can serve various functions in the pathway to shipping decarbonization, particularly its preventive function, which deters polluters and promotes emission reduction, as well as its curative function, which ensures *ex-post* redistribution and comprehensive damage repair.

However, the effective implementation requires both international coordination and robust national frameworks. At the international level, the IMO could operationalise the PPP by integrating it into future regulatory instruments, such as in the heavily debated economic elements. At the national level, the PPP could be incorporated into existing policies and regulations by clarifying its legal status and functions in addressing GHG emissions from shipping. This would provide a basis for implementing mechanisms such as carbon levies and financial sanctions at the national level. Additionally, national courts could play a crucial role in interpreting and applying this principle, setting important precedents in liability law by holding polluters accountable for environmental harm.

Our findings also reveal that challenges in applying the PPP to mitigate GHG emissions from shipping will persist, emphasising essential directions for developing regulatory measures. In terms of liability distribution, the channelling of liability could designate the shipowner as the primary liable party, with provisions allowing for cost recovery from other polluters and beneficiaries. This approach would streamline enforcement and facilitate effective compensation. Furthermore, the findings indicate that majority participants place considerable trust in IMO conventions. Therefore, the IMO and regulators should move beyond theoretical support and establish a practical and enforceable framework for reducing GHG emissions from shipping.

The findings of this study delineate critical avenues for future research. While we have argued that the BPP serves as a necessary complement when the PPP falls short of providing adequate compensation, further research is needed to focus on how to establish a comprehensive liability mechanism that equitably distributes liability between polluters and beneficiaries. Furthermore, while current discourse primarily focuses on private stakeholders, the potential liability of states regarding GHG emissions remains underexplored. Therefore, subsequent research may shift the analytical lens to examine the role of states both as supervisor or regulators and as potentially liable parties responsible for their contribution to the climate change. Additionally, as awareness of the potential application of the PPP increases, coupled with ongoing discussions regarding the necessity of establishing liability and compensation for damages caused by GHG emissions, the empirical study conducted in this paper may be extended to encompass areas beyond those surveyed herein.

Ethics approval statement

The empirical study for this research was conducted ethically in accordance with the Institutional Review Board of the Hong Kong Polytechnic University (Reference Number: HSEARS20221017005).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used GPT-4o to improve the language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the article.

CRedit authorship contribution statement

Ling Zhu: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Xinwei Li:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Aragão, A., 2022. Polluter-Pays Principle. In: Cremades, J., Hermida, C. (Eds.), *Encyclopaedia of Contemporary Constitutionalism*. Springer, pp. 1–17.
- Balcombe, P., Briertley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., Staffell, I., 2019. How to decarbonise international shipping: options for fuels, technologies and policies. *Energy Convers. Manage.* 182, 72–80. <https://doi.org/10.1016/j.enconman.2018.12.080>.
- Baatz, C., 2013. Responsibility for the past? Some thoughts on compensating those vulnerable to climate change in developing countries. *Ethics Policy Environ.* 16 (1), 94–110. <https://doi.org/10.1080/21550085.2013.768397>.
- Bleeker, A., 2009. Does the polluter pay? The polluter-pays principle in the case law of the European court of justice. *Eur. Energy Environ. Law Rev.* 18, 289–306. <https://doi.org/10.54648/eeelr2009024>.
- Bodansky, D., 2018. Regulating Greenhouse Gas Emissions from Ships: The Role of the International Maritime Organization, in: Scheiber, H.N., Oral, N., Kwon, M.-S. (Eds.), *Ocean Law Debates: The 50-Year Legacy and Emerging Issues for the Years Ahead*. Brill | Nijhoff, pp. 478–501.
- Bouman, E.A., Lindstad, E., Riiland, A.I., Strømman, A.H., 2017. State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping—a review. *Transp. Res. Part D: Transp. Environ.* 52 (408), 418. <https://doi.org/10.1016/j.trd.2017.03.022>.
- Boyle, A., 2016. Climate Change, Ocean Governance and UNCLOS, in: Barrett, J., Barnes, R. (Eds.), *Law of the Sea: UNCLOS as a Living Treaty*. British Institute of International and Comparative Law, p. 218.
- Branger, F., Lecuyer, O., Quirion, P., 2015. The European union emissions trading scheme: should we throw the flagship out with the bathwater? *Wiley Interdiscip. Rev. Clim. Chang.* 6 (1), 9–16. <https://doi.org/10.1002/wcc.326>.
- Bugge, H.C., 1996. The Principles of “Polluter Pays” in Economics and Law. In: Eide, E., Van den Bergh, R. (Eds.), *Law and Economics of the Environment*. Juridisk Forlag, Oslo, p. 53.
- Bush, D., 2025a. IMO Approves Historic Carbon Price Agreement. *Lloyd’s List*. <https://www.lloydlist.com/LL1153160/IMO-approves-historic-carbon-price-agreement> (accessed 18 April 2025).
- Bush, D., 2025b. New IMO Framework Gets Cautious Industry Welcome. *Lloyd’s List*. <https://www.lloydlist.com/LL1153192/New-IMO-framework-gets-cautious-industry-welcome> (accessed 18 April 2025).
- Craig, N., Davenport, T., Mackenzie, R., 2023. In: *Liability for Environmental Harm to the Global Commons*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/9781108866477>.
- Cycyota, C.S., Harrison, D.A., 2006. What (not) to expect when surveying executives: a meta-analysis of top manager response rates and techniques over time: a meta-analysis of top manager response rates and techniques over time. *Organ. Res. Methods* 9 (2), 133–160. <https://doi.org/10.1177/1094428105280770>.
- de Sadeleer, N., 2013. The Polluter-Pays Principle in EU Law - Bold Case Law and Poor Harmonisation. In: Backer, L.L., Fauchald, O.K., Voigt, C. (Eds.), *Pro Natura*. Universitetsforlaget, Festschrift til H.-C. Bugge, pp. 405–418.
- de Sadeleer, N., 2020. *Environmental Principles: From Political Slogans to Legal Rules*, second ed. Oxford University Press, Oxford.
- Dewan, M.H., Godina, R., 2024. An overview of seafarers’ engagement and training on energy efficient operation of ships. *Mar. Policy* 160, 1–17. <https://doi.org/10.1016/j.marpol.2023.105980>.
- Doelle, M., Seck, S., 2020. Loss & damage from climate change: from concept to remedy? *Clim. Pol.* 20 (6), 669. <https://doi.org/10.1080/14693062.2019.1630353>.
- Duvic-Paoli, L.A., 2018. *The Prevention Principle in International Environmental Law*. Cambridge University Press, Cambridge.
- European Union, 2023. Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 Amending Directive 2003/87/EC Establishing a System for Greenhouse Gas Emission Allowance Trading within the Union and Decision (EU) 2015/1814 Concerning the Establishment and Operation of a Market Stability Reserve for the Union Greenhouse Gas Emission Trading System [2023] OJ L130/134.
- Faber, J., et al., 2020. *Fourth IMO Greenhouse Gas Study*. International Maritime Organization, London.
- Gauci, G., 1999. Protection of the marine environment through the international ship-source oil pollution compensation regimes. *Rev. Eur. Community Int. Environ. Law* 8 (1), 29–36.
- Goulder, L.H., Parry, I.W.H., 2008. Instrument choice in environmental policy. *Rev. Environ. Econ. Policy* 2 (2), 152–174.
- IMO, 1969. International Convention on Civil Liability for Oil Pollution Damage (1969 CLC). Vol. 973, 1-14097.
- IMO, 1973. International Convention for the Prevention of Pollution from Ships (MARPOL), London (United Kingdom (UK)), (2 November 1973), in force only after the 1978 London Protocol on 2 October 1983.
- IMO, 1992. International Convention on Civil Liability for Oil Pollution Damage (1992 CLC).
- IMO, 1996. International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (1996 HNS Convention).
- IMO, 2001. International Convention on Civil Liability for Bunker Oil Pollution Damage (Bunkers Convention).
- IMO, 2018. Initial IMO Strategy on Reduction of GHG Emissions from Ships. RESOLUTION MEPC.304(72) (13 April 2018).
- IMO, 2023a. 2023 IMO Strategy on Reduction of GHG Emissions from Ships. RESOLUTION MEPC.377(80) (7 July 2023).
- IMO, 2023b. Review Plan of the Short-Term GHG Reduction Measure. MEPC 80/17/Add.1 Annex 13.
- IMO, 2023 c. Comparative Analysis of Candidate Mid-term Measures Fact Sheet. IMO GHG-EW 3/INF.4.
- IMO, 2024. Report of the Steering Committee on the Comprehensive Impact Assessment of the Basket of Candidate GHG Reduction Mid-term Measures- Executive Summary of the Report on Task 3 (Impacts on States). MEPC 82/7/4/Add.3.
- IMO, 2025. Draft Revised MARPOL Annex VI. Circular Letter No.5005 (11 April 2025).
- IMO website, 2021. Cutting GHG Emissions from Shipping: 10 Years of Mandatory Rules. <https://www.imo.org/en/MediaCentre/PressBriefings/pages/DecadeOfGHGAction.aspx> (accessed 17 February 2025).
- IMO website, 2023. EEXI and CII - Ship Carbon Intensity and Rating System. <https://www.imo.org/en/MediaCentre/HotTopics/Pages/EEXI-CII-FAQ.aspx> (accessed 21 February 2025).
- IMO website, 2024a. Marine Environment Protection Committee 81st session (MEPC 81), 18-22 March 2024. <https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-81.aspx> (accessed 2 April 2025).
- IMO website, 2024b. Marine Environment Protection Committee 82nd session (MEPC 82), 30 September – 4 October 2024. <https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-82nd-session.aspx> (accessed 17 February 2025).
- IMO website, 2025. IMO Approves Net-Zero Regulations for Global Shipping. <https://www.imo.org/en/MediaCentre/PressBriefings/pages/IMO-approves-netzero-regulations.aspx> (accessed 13 April 2025).
- International Transport Forum, 2024. Carbon Pricing for International Shipping. <https://www.itf-oecd.org/node/26613> (accessed 26 December 2024).
- Kachi, A., Mooldijk, S., Warnecke, C., 2019. Carbon Pricing Options for International Maritime Emissions. Project no. 818008, New Climate Institute, Cologne.
- King, A., 2022. Emissions-Free Sailing is Full Steam Ahead for Ocean-Going Shipping. Horizon – The EU Research & Innovation Magazine. <https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shiping> (accessed 11 April 2025).
- Grossman, M.R., 2007. Agriculture and the Polluter Pays Principle. *Electron J Comp Law* 11 (3), 1–66.
- Kosolapova, E., 2013. *Interstate Liability for Climate Change-Related Damage*. Eleven International Publishing, The Hague.
- Kotzampasakis, M., 2025. Maritime emissions trading in the EU: systematic literature review and policy assessment. *Transp. Policy* 165, 28–41. <https://doi.org/10.1016/j.tranpol.2025.02.014>.
- Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997. 2303 UNTS 148 (10 December 1997). http://unfccc.int/kyoto_protocol/items/2830.php (accessed 7 January 2025).
- Lagouvardou, S., Psarftis, H.N., Zis, T., 2020. A literature survey on market-based measures for the decarbonization of shipping. *Sustainability* 12(10), 1, 5. <https://doi.org/10.3390/su12103953>.
- Larson, E.T., 2005. Why environmental liability regimes in the united states, the European community, and japan have grown synonymous with the polluter pays principle. *Vanderbilt J. Transnat. Law* 38 (2), 541–550.
- Lee, S.S., 2024. Analysis of the effects of EEDI and EEXI implementation on CO₂ emissions reduction in ships. *Ocean Eng.* 295, 1–10. <https://doi.org/10.1016/j.oceaneng.2024.116877>.

- Luppi, B., Parisi, F., Rajagopalan, S., 2012. The rise and fall of the polluter pays principle in developing countries. *Int. Rev. Law Econ.* 32 (1), 135–136. <https://doi.org/10.1016/j.irle.2011.10.002>.
- Maersk Zero Carbon Shipping, 2025. Maritime Decarbonisation Strategy 2022, 22. <http://www.zerocarbonsshipping.com/files/maritime-decarbonization-strategy-2022.pdf> (accessed 12 March 2025).
- Maersk Zero Carbon Shipping, 2025. Countdown: Historic IMO Agreement Lays Groundwork for Maritime Decarbonization. <https://www.zerocarbonsshipping.com/news/countdown-historic-imo-agreement-lays-groundwork-for-maritime-decarbonization> (accessed 18 April 2025).
- Marine Department, Kong, H., 2024. Marine Department Launches Green Incentive Scheme to Facilitate Green Transformation of Hong Kong-Registered Ships. accessed 17 February 2025. <https://www.info.gov.hk/gia/general/202406/28/P2024062800156.htm>.
- Mason, M., 2002. Transnational Compensation for Oil Pollution Damage: Examining Changing Spatialities of Environmental Liability. LSE Research Papers in Environmental and Spatial Analysis (RPESA), London School of Economics and Political Science, 20.
- Munir, M., 2013. History and evolution of the polluter pays principle: how an economic idea became a legal principle? *SSRN Electron. J.* <https://doi.org/10.2139/ssrn.2322485>.
- Nwosi, K.A., Kokpan, B.S., 2023. The polluter pays principle and nigerian legal framework for aviation pollution mitigation. *J. Jurisprudence Int. Law Contemp. Legal Issues* 17 (2), 145–154.
- OECD, 1972. Recommendation of the Council on Guiding Principles Concerning International Economic Aspects of Environmental Policies. C(72)128, 11 ILM 1172.
- OECD, 1992. The Polluter-Pays Principle: OECD Analyses and Recommendations. OCDE/GD(92)81. [https://one.oecd.org/document/OCDE/GD\(92\)81/En/pdf](https://one.oecd.org/document/OCDE/GD(92)81/En/pdf).
- Paris Agreement, 2015. FCCC/CP/2015/L.9/Rev.1 (12 December 2015). http://unfccc.int/paris_agreement/items/9485.php (accessed 7 January 2025).
- Pigou, A.C., 1932. *The Economics of Welfare*, fourth ed. Macmillan, London.
- Pinto-Bazurco, J.F., 2022. How to Enforce the Polluter-Pays Principle. International Institute for Sustainable Development. <https://www.iisd.org/system/files/2022-02/still-one-earth-polluter-pays-principle.pdf> (accessed 3 January 2025).
- Rauca, L., Batrinca, G., 2023. Impact of carbon intensity indicator on the vessels' operation and analysis of onboard operational measures. *Sustainability* 15 (14), 2. <https://doi.org/10.3390/su151411387>.
- Shi, Y., 2016. Reducing greenhouse gas emissions from international shipping: is it time to consider market-based measures? *Mar. Policy* 64, 123. <https://doi.org/10.1016/j.marpol.2015.11.013>.
- Shi, Y., Gullett, W., 2018. International regulation on low-carbon shipping for climate change mitigation: development, challenges, and prospects. *Ocean Dev. Int. Law* 49 (2), 134–136.
- Smith, T., Raucci, C., Haji, H.S., Rojon, I., Calleya, J., Suárez de la Fuente, S., Wu, P., Palmer, K., 2016. CO₂ emissions from international shipping: possible reduction targets and their associated pathways. *UMAS* 38 (1), 38 (accessed 28 March 2025).
- Snyder, H., 2024. Designing the literature review for a strong contribution. *J. Decis. Syst.* 33 (4), 551–558. <https://doi.org/10.1080/12460125.2023.2197704>.
- Stavins, R.N., 2008. A meaningful U.S. cap-and-trade system to address climate change. *Harvard Environ. Law Rev.* 32, 293–371.
- Testa, T., 2023. Controlling GHG emissions from shipping: the Role, relevance and fitness for purpose of UNCLOS. In: PLATJOUW, F.M., Pozdnakova, A. (Eds.), *The Environmental Rule of Law for Oceans: Designing Legal Solutions*. Cambridge University Press, p. 35.
- Tobey, J.A., Smets, H., 1996. The polluter-pays principle in the context of agriculture and the environment. *World Econ.* 19 (1), 63–87.
- UNCTAD, 2025. Review of Maritime Transport 2025. United Nations Publication, Geneva. https://unctad.org/system/files/official-document/rmt2025_en.pdf (accessed 17 December 2025).
- UNFCCC, 1992. United Nations Framework Convention on Climate Change. 1771 UNTS 107 (9 May 1992).
- UNFCCC, 2011. FCCC/CP/2010/7/Add.1, 15 Mar 2011, para 25. <https://unfccc.int/documents/?f%5B0%5D=session%3A3454> (accessed 28 March 2025).
- Venmans, F., 2012. A Literature-based Multi-criteria Evaluation of the EU ETS. *Renew. Sustain. Energy Rev.* 16 (8), 5493–5510. <https://doi.org/10.1016/j.rser.2012.05.036>.
- Verde, S.F., 2020. The impact of the EU emissions trading system on competitiveness and carbon leakage: the econometric evidence. *J. Econ. Surveys* 34 (2), 320–343. <https://doi.org/10.1111/joes.12356>.
- Verheyen, R., Franke, J., 2023. Climate change litigation: a reference area for liability. In: Gailhofer, P., Krebs, D., Proelss, A., Schmalenbach, K., Verheyen, R. (Eds.), *Corporate Liability for Transboundary Environmental Harm: an International and Transnational Perspective*. Springer, pp. 388–409.
- Wang, S., Psaraftis, H.N., Qi, J., 2021. Paradox of international maritime organization's carbon intensity indicator. *Commun. Transp. Res.* 1, 1. <https://doi.org/10.1016/j.commtr.2021.100005>.
- World Bank, 2024. Carbon Pricing: Carbon Pricing is Critical to Scaling up Climate Action. <https://www.worldbank.org/en/programs/pricing-carbon> (accessed 11 December 2024).
- Zhang, S., Feng, C., 2024. Evolutionary game model for decarbonization of shipping under green shipping corridor. *Int. J. Low-Carbon Technol.* 19, 2502–2513. <https://doi.org/10.1093/ijlct/ctae133>.
- Zhu, L., 2015. Is the polluter paying for vessel-source pollution? *J. Bus. Law* 4 (348), 359.
- Zhu, L., 2023. Some thoughts on application of the polluter pays principle for controlling marine greenhouse gas emissions. *Mar. Policy* 158, 1. <https://doi.org/10.1016/j.marpol.2023.105877>.
- Zhu, L., Li, X., 2025. Identifying key polluters: the feasibility of applying the polluter pays principle to marine greenhouse gas emissions. *Trans. Environ. Law* 1–27. <https://doi.org/10.1017/S2047102524000372>.
- Zhu, L., Zhao, Y.C., 2015. A feasibility assessment of the application of the polluter-pays principle to ship-source pollution in Hong Kong. *Mar. Policy* 57, 36–44. <https://doi.org/10.1016/j.marpol.2015.03.010>.