

Article

Carbon Revenue Recycling: The Cornerstone of the Carbon Pricing Mechanism Within the Shipping Industry

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Abstract

In a carbon pricing mechanism, the collection of contributions (taxes) and the distribution of carbon revenue are both equally critical, as they constitute the interdependent elements of the same system. While contribution collection serves to economically incentivize stakeholders, carbon revenue distribution fosters participation in decarbonization efforts through mechanisms such as rebates, rewards, and green loans. The economic effects of a carbon pricing mechanism vary significantly depending on how the generated revenues are used. A well-structured organizational framework can assist policymakers in optimizing the allocation of carbon revenues, thereby supporting a robust fiscal policy that promotes efficiency, long-term growth, and equity. Despite the critical role of carbon revenue distribution, there is a notable absence of literature addressing this issue in the maritime context. To address this gap, this study draws on insights from other sectors and global carbon pricing mechanisms to develop a simulatory template for evaluating its applicability to the maritime industry. The simulation yields a comprehensive classification of approaches to carbon revenue recycling, while also examining the associated risks and challenges in implementing future carbon pricing mechanism in the maritime industry.

Keywords: carbon pricing mechanism; carbon revenue; revenue distribution; equitable transition; CO₂ reduction



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1. Introduction

The decarbonization of the shipping industry has advanced considerably in recent years, spurred by the implementation of initial energy regulations in 2013—the Ship Energy Efficiency Management Plan (SEEMP) and the Energy Efficiency Design Index (EEDI)—as well as the adoption of the International Maritime Organization’s (IMO) Greenhouse Gas (GHG) strategy in 2018 and its subsequent revision in 2023. However, there is a growing concern that the energy policies within the shipping industry may not have achieved the anticipated effectiveness. Despite the IMO’s evident commitment to reducing the maritime carbon footprint, numerous experts argue that the current energy regulations, including SEEMP and EEDI, are inadequate, e.g., [1–9]. Maritime scholars have underscored the imperative role of carbon pricing mechanisms (CPMs) in mitigating emissions [10–16]. In 2006, initial deliberations regarding Market-Based Measures (MBMs) commenced at the 56th session of the Marine Environment Protection Committee (MEPC); subsequently, the IMO received ten MBM proposals in 2010. However, in 2013, the debate was ultimately suspended due to a lack of sufficient consensus [8]. In light of recent developments, the consideration of the CPM as a pivotal component of mid-term measures within the IMO

GHG strategy has prompted the resumption of negotiations regarding the formation of a CPM in the shipping industry.

In the context of IMO discussions on CPM, emission trading and emission tax schemes have historically served as the primary mechanisms for addressing emissions in the shipping sector. Numerous experts have compared these approaches within the maritime framework, with some presenting comparative analyses, e.g., [8,17]. Recent developments have introduced innovative carbon pricing mechanisms, including the implementation of a GHG Fuel Intensity (GFI) requirement and flexibility mechanism, a levy and reward system, and a feebate mechanism.

The effective allocation of carbon revenues can enhance policy efficiency, mitigate the regressive financial burdens associated with carbon pricing, and strengthen political feasibility and stability. Nonetheless, the realization of these benefits hinges on the manner in which these revenues are utilized [18]. As highlighted by the World Bank [19], carbon revenues serve as a critical instrument for fostering support for carbon pricing while advancing environmental, economic, and social objectives.

Regardless of the specific structure of future CPM in the maritime industry, the method of carbon revenue distribution remains a critical factor, as it can enhance the credibility of CPM and foster greater acceptability among maritime stakeholders and member states. Despite its critical importance, the role of carbon revenue recycling in the maritime industry remains insufficiently explored, with no detailed proposal for its implementation. Although the World Bank [20] has outlined a general framework for revenue distribution, a comprehensive strategy remains absent. This research aims to address this gap by analyzing existing literature to identify and propose potential methods for carbon revenue recycling, thereby answering the following research questions (RQ):

RQ1: What are the potential strategies and methods for allocating carbon revenue within the shipping industry?

RQ2: What are the key barriers and challenges associated with the revenue distribution mechanism?

The scarcity of literature on carbon revenue distribution within the maritime industry represents a significant challenge in this study. Consequently, the research draws insights from other industrial sectors and countries to construct a comprehensive understanding of carbon revenue management practices. This study primarily conducts a literature review across diverse sectors and proposes a stimulatory framework tailored to the maritime industry.

1.1. Insights from Other Sectors and CPMs on Carbon Revenue Recycling

In the context of implementing a CPM, the strategic allocation of revenue serves as a pivotal mechanism for addressing the interplay between social, economic, environmental, and political dimensions [21]. For example, the US Regional Greenhouse Gas Initiative (RGGI) has demonstrated that regular updates and a tightening of the regional cap can transform the carbon price from a perceived penalty into a mechanism for delivering public benefits. This approach highlights the critical role of carbon revenue recycling in ensuring the long-term viability of carbon pricing as a climate mitigation strategy [22].

The variation in actual and projected carbon revenue from global CPMs is significant, driven by differences in carbon price levels, revenue generation methods, and regional policies. For instance, De Mooij et al. [18] estimated that a carbon price of US\$25 per tonne of CO₂ in developed economies could generate approximately US\$250 billion by 2020. In 2015, carbon pricing initiatives worldwide raised US\$26 billion in revenue [23]. Additionally, the EU Emissions Trading System (EU ETS) generated US\$17 billion through auctions between 2012 and 2016 [24].

The variability in revenue recycling and expenditure levels across CPMs stems from the diverse methods and outcomes of revenue generation. For example, between 2009 and 2014, RGGI allocated 25% of its US\$2.7 billion revenue to consumer benefits or strategic energy purposes, 42% to energy efficiency programs, 11% to bill assistance for low-income residents, 9% to greenhouse gas abatement, 8% to renewable energy development, 4% to program administration, and 1% to RGGI management [25]. Similarly, the EU ETS allocated at least 50% of its US\$17 billion revenue from 2012 to 2016 to climate and energy related initiatives, including retrofitting infrastructure [24]. In California, US\$3.385 billion revenue generated by 2017 was directed toward high-speed rail, low-carbon transit, weatherproofing of low-income housing, and environmental conservation [26].

Carbon tax systems that directly return carbon-pricing revenues to businesses or individuals through tax breaks or rebates are relatively uncommon within cap-and-trade frameworks. Among the seven global cap-and-trade systems, only two (9% of revenues) engage in such direct returns [27]. California's ETS distributes over half of auction revenues as rebate checks. The RGGI, meanwhile, reduces electric utility rates by 12%, ranking second only to California in cap-and-trade recycling proportion. British Columbia allocates 100% of revenues from its neutral carbon tax to corporate and individual tax breaks, as well as rebate checks for low-income residents. Similarly, Switzerland's carbon tax returns two-thirds of its revenues to residents and businesses through flat checks sent to individuals and payroll tax rebates for businesses [27].

1.2. An Estimate of Carbon Revenue in the Shipping Industry

Numerous experts in maritime affairs advocate for the adoption of emission taxes, including a bunker/carbon levy, citing advantages such as simplified implementation, reduced administrative costs and burdens, and enhanced stability and predictability in green investments [8,28–31]. While certain variants of CPM, such as the GFI flexibility mechanism, may yield unpredictable revenue, carbon revenue generated by a levy system is comparatively more stable and predictable. Consequently, the planning and management of its disbursement can be strategically directed to enhance the credibility and acceptability of the overall system.

There exists a broad spectrum of predicted carbon revenue levels in various reports and literature, contingent upon differing levy price rates. Table 1 presents a compilation of these studies. It is important to note that these studies exclusively propose carbon prices (USD) per tonne of CO₂. We have calculated the revenues for 2030 and 2040 based on GHG strategy checkpoints targeting 20% and 70% reductions relative to the 2008 level, while also considering lifecycle GHG emissions (WtW). In this context, Class NK [32] posits that GHG emissions in 2008 amounted to 731 million tonnes CO₂-eq. Consequently, GHG emissions in 2030 (20% reduction) and 2040 (70% reduction) should be 585 and 219 million tonnes CO₂-eq, respectively.

Reviewing the studies presented in Table 1, several key findings emerge: firstly, the levels of revenue vary significantly due to the differing carbon price rates proposed in these studies. The variations in carbon price proposals across these studies may stem from differences in modeling approaches, including divergences in assumptions, scopes, variables, criteria, energy price fluctuations, and other uncertainties. Secondly, the projected revenue levels across the studies are significantly high, providing a basis for the models' assumptions regarding revenue allocation, including its application in alternative fuel production. Thirdly, the discussion on revenue disbursement methods has been superficial and overly general.

Table 1. Carbon revenue levels resulting from the implementation of a levy mechanism, as proposed by various studies.

Proposed by	Carbon Price (USD)/ Tonne CO ₂	Yearly Revenue		Cumulative Revenue Range 2025–2050
		2030	2040	
Marshall Islands and Solomon Islands proposal	Starting with 100 \$ in 2025 and from 2030 onward 250–300 \$	146–175 b\$	55–66 b\$	-
Maersk [33]	150 \$	88 b\$	33 b\$	-
Trafigura [34]	250–300 \$	146–175 b\$	55–66 b\$	-
MMM Center for Zero Carbon Shipping [35]	230 \$	135 b\$	50 b\$	\$1.8 trillion (after deduction of green fuel production cost)
Lagouvardou et al. [36]	150–400 \$	88–234 b\$	33–88 b\$	-
Baresic et al. [37]	191 \$ (zero emission in 2050)	112 b\$	42 b\$	\$1 trillion–\$2.6 trillion
Smith [38]	50–250 \$ (50% emission reduction by 2050, in case of fully re-investing in zero-carbon fuels and technologies)	29–146 b\$	11–55 b\$	-
A conclusion of previous studies by Dominioni et al. [39] and World bank [20]		Yearly average 40–60 b\$		\$1 trillion–\$3.7 trillion

The structure of the paper is as follows: Section 2 outlines the methodology, Section 3 presents findings from investigations in other sectors and CPMs, and Section 4 categorizes approaches to carbon revenue distribution within the shipping industry. Section 5 addresses complexities identified during the research, and the article concludes in Section 6.

2. Method and Materials

This research examines various methods of distributing carbon revenue within the shipping industry, drawing on a review of existing literature. While the scope of this study does not extend to a detailed analysis of the technological, economic, and social impacts of these revenue distribution methods, it provides a comprehensive overview of key literature on the subject. By focusing on the diverse expenditure options for carbon revenue, the research serves as a valuable reference for further exploration.

The initial plan was to undertake a systematic literature review (SLR); however, the first search in the Scopus database using selected keywords uncovered a dearth of peer-reviewed articles on carbon revenue distribution in the shipping industry. To address the limited academic research on carbon revenue recycling in the maritime sector, this study drew insights from other industries and global CPMs worldwide to extract lessons and establish an academic foundation for the research. Accordingly, a literature review was conducted to identify the most prevalent approaches to carbon revenue distribution in other sectors, with the goal of creating a stimulatory template for application in the maritime industry. The results are presented in Table 2. Further, the research was completed by analyzing maritime literature to assess the applicability of distribution methods derived from other industries to the maritime sector. This process culminated in a targeted literature review that integrated gray literature alongside academic sources.

The literature review process in both the maritime sector and other industries employed a targeted literature review (TLR) approach, utilizing Scopus and Google Scholar databases. The employed TLR itself was a combination of structured TLR and pearl-growing techniques [40,41]. In the structured TLR for other industries, search terms included “carbon price”, “carbon tax”, “carbon revenue distribution”, “climate justice”,

and their combinations. For the maritime sector, the structured TLR focused on keywords such as “maritime carbon pricing mechanism”, “maritime carbon tax”, “carbon revenue”, “carbon revenue distribution”, “just transition”, and “mid-term measures”. To ensure comprehensive results, the TLR was supplemented by pearl-growing (snowballing or follow-up) searches, achieving an acceptable level of saturation in the findings.

The exclusion protocol was established in alignment with the research objectives and specific research questions to streamline the screening and evaluation of the extracted literature. Consequently, literature lacking a focus on carbon pricing, carbon revenue, or carbon revenue recycling was excluded from subsequent analysis. As anticipated, some of the literature identified through follow-up searches consisted of grey literature, including reports from governments, think tanks, research institutes, and industry organizations.

The screening of the extracted literature was conducted in two stages: an initial scan of titles and abstracts, followed by a full-text review. In the TLR process for other industrial sectors, 78 publications were identified and examined, resulting in 23 being cited in this research. For maritime literature, the two-stage screening yielded 49 cited works, categorized as follows: 18 with a general focus on maritime decarbonization, some of which discussed carbon pricing; 28 with a specific focus on carbon pricing, with limited mention of carbon revenue distribution; and 3 directly addressed carbon revenue distribution in the shipping industry.

3. Results: Classified Approaches to Carbon Revenue Distribution in Other CPMs

This section explores various approaches to carbon revenue distribution, informed by literature examining diverse industrial sectors and various CPMs globally. The categories are as follows:

3.1. *Mitigating the Impact on Affected Groups*

A common concern with carbon pricing is its potential impact on low-income households and the competitiveness of specific industries, often referred to as target groups [18,19,42]. Utilizing a portion of the revenue to compensate target groups represents a pragmatic strategy. Elevating the income threshold for tax exemption in nations where low-income households are subject to income or payroll taxes is likely to enhance rebates for these households. To mitigate the adverse effects of elevated energy prices on the competitiveness of vulnerable firms, temporary subsidies for production or energy-saving technologies could be introduced. In response to the economic challenges and burdens faced by target groups, various design measures have been proposed to limit potential cost increases, including exemptions, preferential tax rates, rebates, and the allocation of gifted allowances [18].

3.2. *Promoting Renewable Energy and Energy Efficiency*

There are numerous global examples of this approach to carbon revenue recycling. Denmark allocates approximately 60% of its tax revenue to industry, while the remaining 40% is directed toward environmental subsidies. In Quebec, Canada, revenue generated from the carbon tax is deposited into a “green fund” which finances initiatives aimed at reducing or avoiding greenhouse gas emissions [43]. The RGGI primarily allocates its revenue toward advancing energy efficiency. These investments, which are more cost-effective than renewable resource initiatives in the participating states, have also contributed to reduced electricity prices, thereby mitigating the regressive effects of the policy [18].

Wiese et al. [44] contend that non-price barriers to energy efficiency cannot be resolved solely through pricing policies. Consequently, they emphasize the need for energy

efficiency programs that target the behavioral, financial, and legal obstacles to achieving greater efficiency. In addition to the significant advantages of mitigating air pollution and addressing energy poverty, Thema et al. [45] assert that energy efficiency investments in EU countries can lead to energy cost reductions of at least 50%. In 2017, Belgium, the Czech Republic, Croatia, Hungary, Italy, and Latvia indicated their intention to allocate 50% to 100% of their domestic auction revenues toward enhancing energy efficiency [44]. In the North-Eastern United States, the RGGI cap-and-trade system allocates a significant portion of auction revenues toward energy efficiency programs for end users. This approach not only contributes to emission reductions but also leads to lower electricity costs for numerous consumers [44].

3.3. Offsets

Emission offsets, as defined by Ramseur [25], are mechanisms that reduce, avoid, or sequester GHG emissions from sources not covered by formal emission reduction programs. Offsets are commonly used to alleviate the financial burden on emissions sources outside these programs, with some programs integrating offset credits either permanently or as a transitional measure. Offset programs may achieve greater total emission reductions under a carbon tax compared to a cap-and-trade system. However, their effectiveness depends on being quantifiable and enforceable, which can be challenging due to high transaction costs for their assessment. Additionally, developing countries may hesitate to engage in decarbonization projects independently, particularly if mechanisms like the Clean Development Mechanism (CDM) under the Kyoto Protocol are available to offset their costs. The CDM is set to be replaced by the Sustainable Development Mechanism, a new international carbon market introduced by the 2015 Paris Agreement and governed by the United Nations [46]. Given concerns about the validity of offset plans, many programs are now exploring ways to limit their application.

3.4. Funding Climate and Environmental Projects

Studies have explored the allocation of tax revenues toward environmental initiatives. For instance, Baranzini and Carattini's survey [47] revealed that 60% of respondents favored directing tax revenues to finance environmental projects. Similarly, Narassimhan et al. [21] suggest that revenues from auctioning allowances could support climate change mitigation. While a carbon price can promote emissions reductions, market failures may hinder participants' ability to respond effectively to price signals. Inadequate private sector investment in low-carbon activities exacerbates these market failures. Governments could address this by funding such investments with carbon revenues, thereby reducing emissions and enhancing public acceptance of carbon pricing [19].

3.5. Utilization of Advanced Technologies and Modernization of Existing Infrastructure

Financing new infrastructure stands out as one of the most cost-effective strategies for emissions reduction. In 2023, 17% of the EU ETS revenue was allocated to the EU Innovation Fund and Modernization Fund which support the development of innovative technologies and investments in energy efficiency and power sector modernization [48]. Urban infrastructure projects are particularly well-suited for attracting such investments. The ITF [49] suggests that earmarking congestion charging revenues for enhancing public transport and active mobility could increase public acceptance of these measures. By using congestion charges to improve public transportation and ensure safer conditions for walking and cycling, a modal shift toward more sustainable transportation modes is more likely to be achieved.

3.6. Administration Costs

Part of the revenues generated from auctioning allowances could be allocated to reducing the administrative costs of the EU ETS [21]. In 2017, 0.3% of the EU ETS auctioning revenue was designated for covering administrative and management expenses [44]. Similarly, the RGGI program has allocated approximately 5% for such purposes [25]. As a general estimate, the administration of a carbon pricing mechanism may require up to 5% of carbon revenue [18].

3.7. Funding Research and Development (R&D)

In 2017, 1.0% of the EU ETS auctioning revenue was allocated to funding R&D for clean technologies and energy efficiency, with 0.1% directed toward demonstrating R&D projects aimed at reducing emissions and fostering adaptation [44]. Split incentives, stemming from knowledge or innovation spillovers [42], often lead firms and innovators to underinvest in R&D. Knowledge and innovation are considered public goods with positive externalities, as firms developing new technologies generate benefits for others while incurring costs themselves. Consequently, innovative firms lack sufficient incentives to increase investment when benefits are shared. Governments can mitigate this underinvestment by providing R&D funding. For example, Japan's carbon tax was explicitly designed to support renewable energy and energy efficiency initiatives, including lithium-ion batteries, distributed energy generation, and CO₂ capture and storage [19].

3.8. Adaptation to the Impacts of Climate Change

Developing economies may need to undertake substantial adjustments to mitigate the adverse effects of climate change, with potential costs estimated at approximately US\$90 billion annually by mid-century [23]. Despite these efforts, they may still experience significant residual damages. Climate adaptation measures, such as water defenses, may be financed through public revenues when private sector investments are insufficient [18]. Notably, 1.0% of the EU ETS auctioning revenue in 2017 was allocated to climate change adaptation [44].

At the conclusion of this section, Table 2 presents an abstract overview of identified revenue distribution approaches from other sectors and CPMs, simulating their application to the maritime industry within the framework of a global maritime CPM.

Table 2. Inspiration from other sectors and CPMs to explore potential approaches to carbon revenue distribution in the maritime industry.

Other Sectors and CPMs		Future Maritime CPM	
1.	Mitigating the impact on affected groups	-	A rebate mechanism in response to the CBDR (Common but Differentiated Responsibilities) principle
		-	Capacity building and technology transfer to SIDS (Small Islands Developing States) and LDCs (Least Developed Countries)
		-	Addressing food security
2.	Promoting renewable energy and energy efficiency	-	The production of alternative fuels and renewable energy sources
		-	Ship operational efficiency
3.	Offsets	Technology transfer to SIDS and LDCs	
4.	Funding climate and environmental projects	-	Capacity building, education, and training
		-	Out of sector expenditure
5.	Utilization of advanced technologies and modernization of existing infrastructure	-	Advancement of maritime energy infrastructure and services (e.g., in ports)
		-	Vessels' retrofit and fleet renewal
6.	Administration costs	Implementation costs of the maritime CPM	
7.	Funding research and development (R&D)	Maritime R&D initiatives	
8.	Adaptation to the impacts of climate change	Out of sector expenditure	

4. Results: Strategies for Carbon Revenue Distribution in the Maritime Industry

The analysis of recommendations for revenue recycling in specific carbon pricing proposals, e.g., ICS & Intercargo [50], indicates that the distribution and designated use of revenues exert an influence comparable to the impact of the carbon price itself. According to Pomerleau and Asen [51], “the economic effects of a carbon tax vary significantly depending on how the generated tax revenues are used”. According to the World Bank [19], a well-constructed revenue distribution framework can be achieved through the establishment of robust legal and administrative structures, systematic procedures for revenue management, comprehensive stakeholder engagement, and stringent accountability measures.

Scholars in Carbon Market Watch [52] contend that dispersing carbon revenues across numerous causes and concerns may diminish their effectiveness. They, therefore, recommend concentrating such revenues on a limited number of targeted areas. These areas include financing in-sector climate action, such as developing new technologies, retrofitting existing ships, implementing shoreside electrification, and investing in research and development, as well as supporting sustainable supply and infrastructure related to renewable fuels. Additionally, they emphasize addressing equity and fairness concerns in accordance with the CBDR principle and alleviating socio-economic issues, such as funding re-skilling programs for workers.

This section, inspired by revenue distribution approaches from other sectors outlined in Table 2, examines equivalent strategies within the maritime industry. The template suggests dividing carbon revenue distribution in the maritime sector into two main categories: in-sector and out-of-sector. The effective recycling of revenue, both within and beyond the maritime industry, can play a pivotal role in advancing shipping decarbonization goals. Moreover, it supports broader climate goals and fosters equitable outcomes. According to the World Bank [20], some of the most cost-effective climate change mitigation strategies may not directly pertain to maritime transportation, highlighting the importance of out-of-sector expenditures of maritime carbon revenues. Figure 1 illustrates potential strategies for allocating shipping carbon revenue, aimed at promoting an equitable and fair energy transition within the industry.

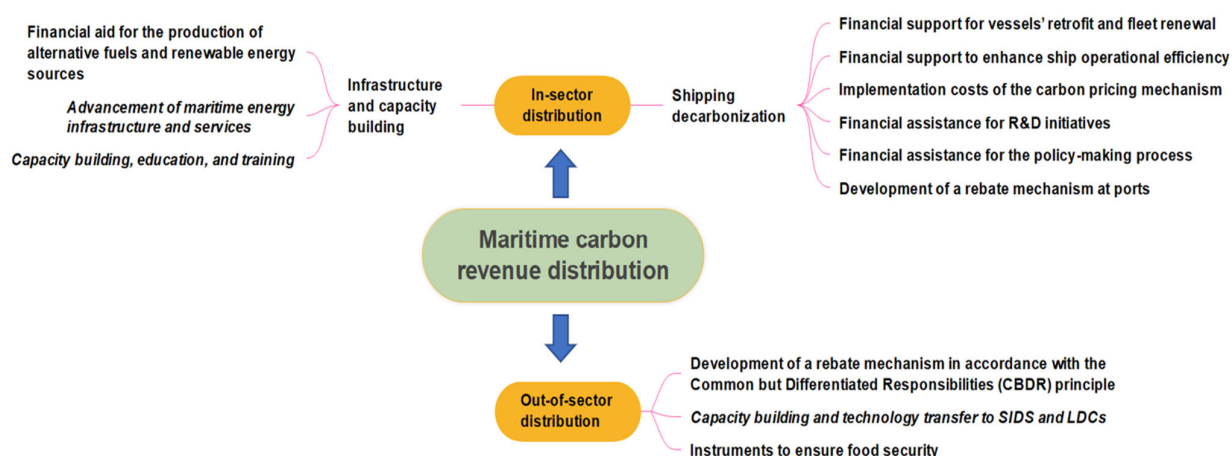


Figure 1. Possible approaches to carbon revenue distribution in the maritime industry.

4.1. In-Sector Distribution

- Financial support for vessels' retrofit and fleet renewal

To promote the adoption of zero-carbon fuels, simply reducing the price disparity between fossil-based and alternative fuels may not be sufficient. Shipping companies must retrofit or replace their fleets to transition to green fuels. Numerous cases have been

documented in which shipowners have been reluctant to invest in specific vessel types without greater clarity on the dominant zero-carbon fuel over the next 10 to 30 years. This hesitation is likely to have cascading effects on the equipment supply chains associated with each fuel type [53]. Therefore, a significant avenue for carbon revenue recycling could involve providing financial support to retrofit ships for zero-emission operations [54]. Green loans from the IMO GHG Fund can be utilized to incentivize shipping companies to deploy energy efficiency measures, including both operational software and technical modifications. For example, existing vessels must be retrofitted with modified bulbous bows and propellers to maintain efficiency at reduced speeds, as they were originally designed for higher design speeds rather than today's economic speeds (especially after EEXI enforcement).

- Financial support to enhance ship operational efficiency

Ship operational energy efficiency has long been acknowledged as a crucial element in the decarbonization of the maritime industry. This efficiency can be enhanced through various strategies, including real-time monitoring, hull and propeller performance assessment, weather routing, trim optimization, and autopilot upgrades. These strategies can be implemented by equipping vessels with software and sensor technologies. Some of these operational software solutions require external support, such as reliable internet connectivity and daily weather updates. The integration of data and digitalization offers valuable insights into operational efficiency; consequently, the initial step involves measuring the vessel's performance as frequently and accurately as possible [55]. Therefore, providing seamless internet access and meeting technological software requirements can significantly enhance ship operational efficiency.

The recommendation advocates for the allocation of a small portion of carbon revenue to establish free global internet coverage for all maritime vessels. This initiative would empower ship operators to perform real-time fleet monitoring. It is crucial to acknowledge that a reliable internet connection is also essential for autonomous shipping. Furthermore, providing global internet access to seafarers could significantly improve their welfare on-board and encourage them to change their mindset and adopt energy-efficient operational practices. This comprehensive package may also include the provision of free daily weather reports to all vessels, enabling effective weather routing [56].

- Implementation costs of the carbon pricing mechanism

Compensation for administrative and operational expenses of the forthcoming maritime carbon pricing mechanism has been emphasized in some proposals. As detailed by Masodzadeh et al. [57], the operational costs of the future CPM, such as in the case of a carbon levy, may encompass expenses related to the establishment and maintenance of IT infrastructure, IMO GHG Fund administration, data collection, tendering, audit/inspection costs, and compensation for bunker suppliers for tax collection and transfer. Additionally, their calculations account for payments to data verifiers for data processing, and payments to port authorities for conducting random energy inspections at ports. Based on this cost breakdown, Masodzadeh et al. [58] conclude that CPM implementation costs could constitute a very small fraction of total carbon revenue.

- Financial assistance for R&D initiatives

Financial support for research and development (R&D) projects at universities, research institutes, and laboratories is crucial to ensure the timely availability and maturity of technologies. Additionally, investment in research, development, and deployment (RD&D) is vital for ensuring the effectiveness of future carbon pricing mechanism in the shipping industry.

- Financial assistance for the policy-making process

Legislative bodies, such as the International Maritime Organization (IMO) and classification societies, could potentially receive a portion of carbon revenues. This allocation might incentivize classification societies to accelerate the development of standards for alternative fuel handling and storage, as well as the type of approval process for advanced technologies. Additionally, employing a sufficient number of experts and conducting high-quality policy research, including impact assessments, feasibility studies, and risk assessments, would enhance the IMO's legislative framework. According to Bach and Hansen [59], "the current administrative organization of the IMO would have very limited financial and human resources".

- Development of a rebate mechanism at ports

Masodzadeh et al. [58] propose the implementation of a global port incentive program (PIP) with an exclusive focus on CO₂ reduction, which could function as a rebate mechanism for the forthcoming CPM. They argue that the current diverse port incentive programs should be consolidated, emphasizing CO₂ reduction. This strategy could elevate the financial incentives provided to ships, making them appear more motivating. Furthermore, with the financial support derived from the IMO GHG Fund, the 'polluter pays' principle is incorporated, marking a notable shift from the existing practice where port budgets provide incentives for visiting ships instead of receiving fines from polluting vessels. While this proposed mechanism acts as a rebate for the adopted CPM, it has the potential to amplify the motivational impact of the future CPM, thereby augmenting its influence on decarbonization.

- Financial aid for the production of alternative fuels and renewable energy sources

There is very high global potential for alternative fuel production due to the pathways already planned in developed countries and the promise of untapped potential in developing states. Englert et al. [53] argue that many countries, including developing countries, are well positioned to become future energy suppliers. These countries possess many of the natural resources needed to produce zero-carbon fuels, in addition to favourable access to a large volume of shipping activities.

- Advancement of maritime energy infrastructure and services

Allocating funds to projects aimed at enhancing port infrastructure to facilitate the adoption of zero-emission fuels represents a highly effective strategy for the in-sector distribution of carbon revenue [54]. A portion of carbon revenue could be allocated to upgrade port infrastructure, thereby enhancing its efficiency, effectiveness, and overall performance. For example, many SIDS and LDCs would significantly benefit from upgrades to dock loading facilities, additional storage and warehousing space, and the establishment of segregated areas for cargo and passengers [60]. Furthermore, it is feasible to reinvest a portion of the revenue to implement mitigation measures aimed at safeguarding ports in SIDS that are vulnerable to natural disasters [61].

The IMO GHG Fund has the capability to provide financial support to technology providers, potentially through subsidized insurance coverage for their pilot projects. Such financial assistance can streamline the approval process for new technologies and green fuels, facilitating contractual agreements between technology providers and classification societies.

Moreover, the IMO GHG Fund could offer critical support to stakeholders in the energy supply chain. This support can manifest itself as financial aid to foster joint ventures among ports, rail/road operators, and fuel producers. Additionally, green bonds and loans can catalyze the development of innovative business models among diverse stakeholders,

exemplified by models such as Maritime Energy Contracting (MEC) and Energy Supply Contracting (ESC).

- Capacity building, education, and training

A recent report by DNV underscores the significance of decarbonisation and digitalisation as pivotal trends in maritime transformation, alongside the requisite skills for seafarers to adapt to these changes [62]. This report highlights a notable skills gap in managing alternative fuels. Similarly, Ölçer et al. [63] have identified the primary skill deficiencies as the capability to handle alternative fuels and the expertise to maintain and operate advanced and electrified propulsion systems. Consequently, continuous skill enhancements and refresher courses throughout a seafarer's career are imperative to stay abreast of the latest environmental technologies and regulations. The future's dominant fuel option and the regulatory landscape remain uncertain. This uncertainty complicates the planning for the maritime workforce's transition and the attraction of investments towards new skills programs [64]. Nevertheless, irrespective of the ultimately preferred fuel or fuels, transitioning to a decarbonised shipping industry will necessitate additional training for at least hundreds of thousands of seafarers by 2050 [64].

Developing new training courses can be financially burdensome and should be pursued in response to specific regulatory or industry mandates [62]. The financial constraints and limited resources pose significant challenges for maritime education and training institutes (METI) in maintaining and upgrading their equipment and facilities. The resource gap in seafarers' training is more pronounced in SIDS and LDCs, necessitating the design of targeted support programs to address the specific needs of these developing states. Ölçer et al. [63] have proposed mobilizing funding among maritime stakeholders to ensure that the costs of upskilling and reskilling are not imposed on seafarers. Establishing partnerships between shipping companies, governments, and training institutions may offer a viable solution to this issue [62].

Achieving an ambitious decarbonization target for the shipping industry is essential to mobilize the necessary investments for reskilling and training the maritime workforce [64]. This objective has been established through a consensus on achieving net-zero GHG emissions by 2050 [65]. Consequently, discussions regarding CPMs have been revitalized, with a significant focus on the allocation of carbon revenue [39]. A key recommendation of this study is to allocate a portion of the GHG Fund towards the training and reskilling of the maritime workforce. Investments could be channelled through METIs to upgrade or renovate training facilities, train instructors, and offer subsidized courses for seafarers. Additionally, with this financial backing, METIs can partner with technology providers to offer refresher and specialized courses for seafarers. Another approach could involve providing financial support to shipowners to implement computer-based training (CBT) onboard their vessels. Moreover, port technicians involved in alternative fuel bunkering infrastructure and electrification technologies, such as battery chargers and onshore power supply equipment, could benefit from these funds to update their expertise and skills. To stay current with the latest technological developments and regulations, even Port State Control Officers (PSCOs) at the forefront of policy enforcement should participate in refresher courses [58].

4.2. Out-of-Sector Distribution

- Development of a rebate mechanism in accordance with the CBDR principle

It is apparent that SIDS and LDCs are the most susceptible to decarbonization's economic repercussions, as well as to the physical impacts of climate change. Consequently, an equitable transition can be realized by addressing disproportionately negative impacts

(DNI) in an effective and objective manner. This can be achieved, for instance, by prioritizing the allocation of a portion of the revenues to countries that are particularly vulnerable due to their socioeconomic conditions and the higher shipping costs they will incur. Additionally, these countries are the most vulnerable to climate change impacts, which carbon revenue should help them to combat these natural disasters [53,66]. Providing carbon revenues to developing countries may help bridge the financing gap between current climate finance flows and their climate finance needs [20]. In light of the CBDR principle, a working group comprising economists and maritime experts should be established to develop and manage a rebate mechanism to compensate SIDS and LDCs for adverse trade impacts.

- Capacity building and technology transfer to SIDS and LDCs

A significant portion of carbon pricing revenues should be allocated to climate-mitigation and adaptation projects in SIDS and LDCs [54]. According to several CPM proposals, a primary expenditure category is capacity building and technical cooperation facilitated by the IMO through its Integrated Technical Cooperation Programme [54]. Redirecting carbon revenues into technical projects aimed at renewable energy production in developing nations holds substantial promise, particularly for generating zero-emission fuels [53] suitable for eco-friendly maritime vessels. Consequently, investing in activities outside the maritime sector will positively influence decarbonization efforts within this industry.

- Instruments to ensure food security

Global food insecurity is profoundly shaped by rising food prices, which are driven by inflation, geopolitical events, trade disruptions, and climate change-induced events. Low-income food-importing countries, particularly poor households in Sub-Saharan Africa and the Middle East, are disproportionately affected and highly vulnerable to price fluctuations. On the other hand, peripheral positioning within the shipping network has a more significant impact on maritime transport costs than geographical distance. In this context SIDS and LDCs are especially vulnerable to disruptions in maritime transport, as high shipping costs, limited connectivity, and inefficient port operations hinder trade and economic development. These regions often face a disproportionate share of transport costs, resulting in higher food import prices and significant challenges in ensuring food security [67].

Food security is commonly characterized by four dimensions or pillars: availability (the physical presence of food—is the food supply sufficient?), access (economic and physical access to food—can individuals obtain the food they need?), utilization (the effective use of food—do individuals receive adequate nutrients?), and stability (continuous and uninterrupted access to food—can individuals consistently access food?). Transport costs, particularly maritime transport costs, are among the primary factors influencing these dimensions. It is important to note that the impact of maritime transport costs extends beyond the movement of food products, as the availability of essential agricultural inputs such as seeds, fertilizers, pesticides, and machinery is also heavily reliant on maritime transport [67].

Maritime GHG mitigation strategies, including carbon pricing, influence economic outcomes across four interconnected domains: transportation costs, modal choices, import prices, and international trade and national economies. The introduction of carbon pricing in maritime shipping is anticipated to increase freight and import costs, with more pronounced effects on low-value bulk commodities. The compounded effects of rising shipping expenses, climate-related disruptions, and geopolitical events present substantial challenges to food security, particularly in developing nations and regions heavily dependent on imports [67].

Regulatory measures, in contrast to unpredictable and temporary disruptions to supply chains and maritime transport, can be anticipated, planned for, and implemented over an extended period. This enables the mitigation of adverse effects through international or national policies and interventions. Consequently, allocating a portion of carbon revenue to address the negative impacts on global food security resulted from a carbon pricing mechanism is of significant importance.

5. Discussion: The Complexities of Carbon Revenue Disbursements

As noted, the absence of a comprehensive study proposing a detailed mechanism for carbon revenue recycling is evident. The design and formulation of such a mechanism could constitute a significant aspect of future research. In this context, the authors aim to provide a more in-depth discussion by addressing some key issues related to carbon revenue disbursements.

5.1. *The Interface Between In-Sector and Out-of-Sector Expenditure*

The prevailing consensus among maritime experts is that funds collected through any maritime CPM should be allocated within the sector to address CO₂ emissions in the shipping industry, e.g., Koesler et al. [68]. This perspective is predominantly held by direct shipping stakeholders who advocate for the reinvestment of all revenues back into the industry. Conversely, several IMO member states and observers argue for the redistribution of a portion of these revenues outside the industry. Nonetheless, it is considered premature to determine the exact proportion of revenues that should be allocated to sectors beyond the maritime industry [66].

The delineation between in-sector and out-of-sector activities presents a notable challenge. In assessing the lifecycle impact of technologies and the well-to-wake carbon footprint of alternative fuels, it is crucial to recognize that only a fraction of these technologies and fuels, which are primarily produced in land-based industries, are suitable for marine applications. For instance, the production of zero-carbon bunker fuels necessitates that 87% of investments be directed towards land-based industries, with the remaining 13% allocated to ship-specific investments [69]. Furthermore, to achieve comprehensive climate objectives, it may sometimes be more effective to allocate carbon pricing revenues to out-of-sector initiatives. This perspective is supported by Dominioni et al. [39], who contend that international shipping does not always represent the most cost-effective avenue for climate change mitigation.

The authors aim to distinguish between two types of out-of-sector expenditure. The first pertains to financial support for land-based energy and alternative fuel producers, who are contractually obligated to supply energy packages (green electricity or alternative fuels) to the port and shipping industry. Despite being out-of-sector, these firms could be perceived as in-sector actors due to their products' use in the port and shipping industry, rendering this revenue recycling as in-sector expenditure. This represents the interface between in-sector and out-of-sector. The second type of out-of-sector expenditure involves financial support for SIDS and LDCs. This could be considered real out-of-sector expenditure, with the specifics and destinations of this expenditure to be determined by local governments, under stringent monitoring and reporting mechanisms.

5.2. *Risk of Split Incentives*

As previously stated, the literature detailing carbon revenue distribution mechanisms is notably scarce. The World Bank is the only entity that has proposed a high-level revenue distribution mechanism for the shipping industry [20]. In that study, the World Bank's approach predominantly employs a top-down strategy for recycling carbon revenue. This

approach suggests that the distribution framework will primarily engage with governments rather than directly with maritime stakeholders at the bottom level. The distribution framework proposed by the World Bank relegates maritime stakeholders to a secondary position within the distribution network. Instead, governments are placed as intermediaries between the IMO GHG Fund and maritime stakeholders. This structure could potentially lead to *split incentives* between governments and maritime stakeholders. Split incentives arise when the entity responsible for financing a transaction or investment, such as an energy efficiency upgrade, differs from the entity that reaps the associated benefits, such as receiving credits or accessing green finance (in the case of this study). While shipowners are compelled to invest in their fleet's energy transition, under a malignantly structured carbon revenue distribution plan, the recycled credits are directed to governments, leaving shipowners with no assurance of receiving an equitable share. Consequently, shipowners might be discouraged to make substantial investments in the energy transition. This principle can be extended to other stakeholders, including ports, technology providers, and alternative fuel/energy producers. Ciple et al. [70] highlight a deficiency in data regarding the control of climate finance within countries post-distribution. They highlight the significant role of elites in shaping climate finance governance, a phenomenon described by Frank [71] as the 'lumpenbourgeoisie', which has the potential to deepen inequalities within nations.

This study advocates for a balanced public–private distribution network for the recycling of carbon revenue (see Figure 2). In this approach, with no interference by governments, revenue is directly allocated to major maritime stakeholders who have shown significant commitment and investment in shipping decarbonization. Conversely, in SIDs and LDCs, where maritime stakeholders are not the primary actors, carbon revenues may be redirected to the governments of these nations. This approach requires a comprehensive analysis of stakeholders, including investigation of their interests, potential, and interactions. Furthermore, as shown in Figure 2, it is feasible to connect the stakeholder analysis to the areas where carbon revenues could be effectively utilized. A balanced public–private distribution scheme, as proposed in this study, by incorporating a well-designed monitoring mechanism can enhance post-distribution transparency and eliminate bureaucratic inefficiencies between governments and executive stakeholders.

5.3. Stability of Carbon Revenue

Over the course of the green transition through 2050, the IMO net-zero fund is expected to experience a gradual decline in carbon revenue due to the increasing adoption of alternative fuels. The likelihood of this phenomenon increases if the implementation of a carbon pricing mechanism in the shipping industry is treated as an isolated system, particularly in cases of in-sector expenditures without external financial support. However, the literature offers no clear predictions regarding the future of green financial instruments in shipping, specifically whether current financiers will maintain their support following the implementation of carbon pricing mechanisms and in-sector expenditures. This gradual decline in carbon revenue may impact the implementation of mid- and long-term strategies that rely on anticipated carbon revenue trends. To address this concern, the distribution of carbon revenue through green loans, structured with predetermined payment schedules and appropriate interest rates, could help ensure the stability of future financial flows. Furthermore, establishing a guaranteed base funding volume for the foreseeable future should be considered. A phased-in increase in carbon prices represents a predictable and methodical approach to designing a complex mechanism for the shipping industry.

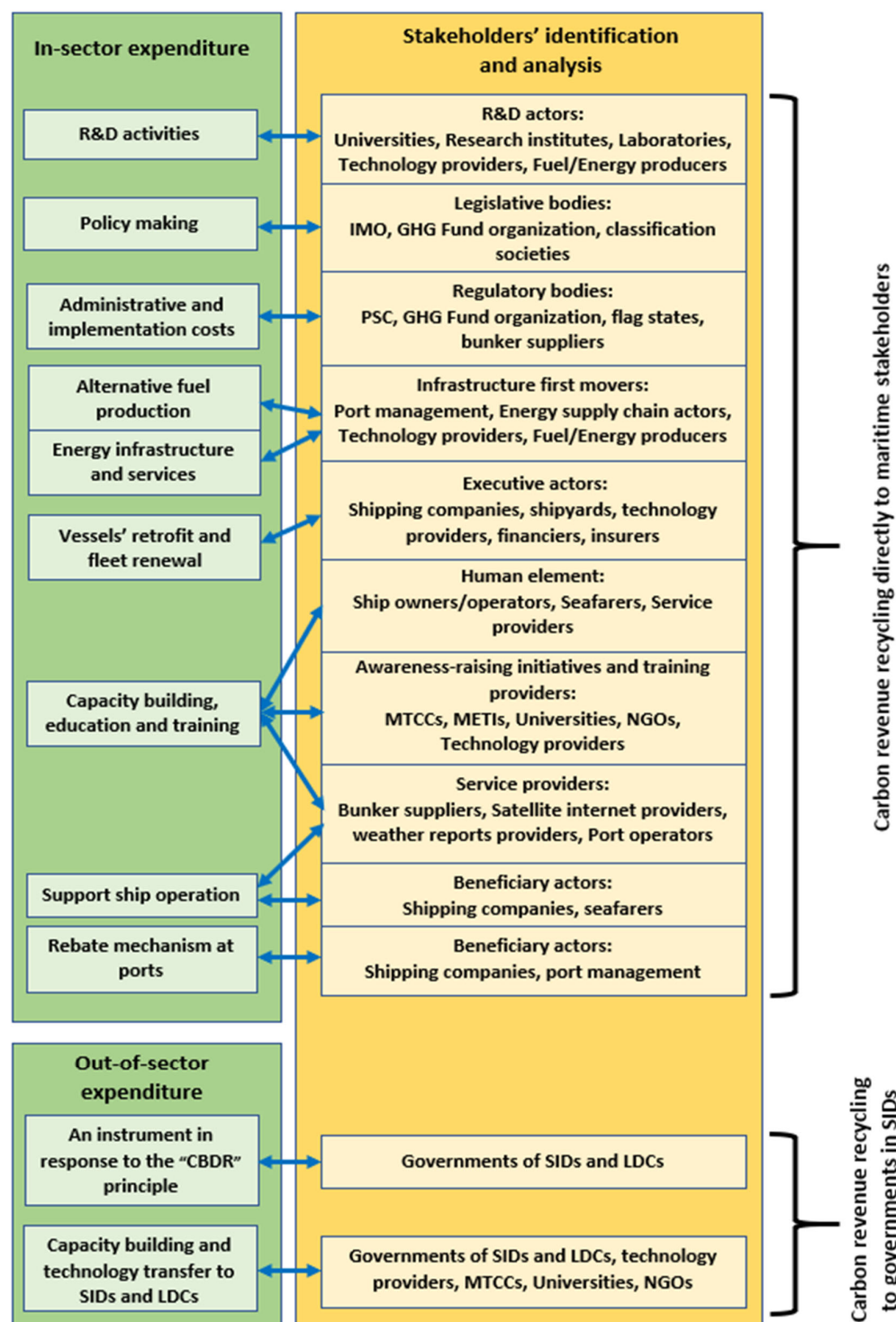


Figure 2. A public–private framework for carbon revenue distribution (PSC: Port State Control; MTCC: Maritime Technology Cooperation Center; NGO: Non-Governmental Organization) (prepared by authors).

The gradual decline in carbon revenue may not be as evident in other sectors, which often lack global and measurable decarbonization objectives, defined timelines, and exclusive carbon revenue streams. Unlike the shipping industry, which exhibits predictable isolation following CPM implementation, as previously noted, other sectors benefit from access to diverse external sources of green financial support. Nevertheless, the shipping industry can draw upon insights from other industries and existing green financial instruments, which may provide a basis for future research. These green financial instruments are specifically

designed to direct capital toward environmentally beneficial projects by mandating the earmarked use of proceeds for designated green activities. They align with established frameworks, such as the International Capital Market Association (ICMA) Green Bond Principles, which emphasize clear project eligibility criteria, transparent tracking of proceeds, and robust reporting mechanisms to assess project impacts [72,73].

6. Conclusions

The effectiveness of a carbon pricing mechanism hinges on the strategic reinvestment of revenue to advance decarbonization efforts. Despite limited scholarly focus on the allocation of carbon revenue within the maritime industry, this study investigated optimal approaches to its distribution. In response to the paucity of maritime literature on this topic, the research drew insights from other sectors and carbon pricing mechanisms (CPMs) to develop a simulatory framework and assess its feasibility in the maritime context. This framework facilitated the categorization of revenue distribution strategies, encompassing both in-sector and out-of-sector expenditures.

In-sector distribution supports activities such as vessel retrofitting and fleet renewal, improving ship operational efficiency, covering the implementation costs of the mechanism, funding research and development, policy-making, implementing rebate mechanisms at ports, producing alternative fuels and renewable energy, upgrading port infrastructure, and training seafarers and port operators. On the other hand, out-of-sector expenditure can be aligned with the CBDR principle and facilitates capacity building and technology transfer to SIDS and LDCs. The research also highlighted several potential challenges within the revenue distribution mechanism, including the ambiguity surrounding the distinction between in-sector and out-of-sector expenditures, the potential for split incentives arising from the redirection of green credits solely to governments, and the long-term instability of carbon revenue.

Future research should focus on establishing a robust framework for the equitable allocation of carbon revenue among stakeholders in the maritime sector. Furthermore, the cost-effectiveness, implementation challenges, and potential synergies or conflicts associated with various revenue distribution methodologies warrant further investigation.

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