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# A decision-making framework for the funding of shipping decarbonization initiatives in non-EU countries: insights from Türkiye

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**Abstract**

The decarbonization of the shipping industry is a critical imperative in the global fight against climate change. Non-EU countries, being significant contributors to shipping emissions, play a crucial role in shaping the industry's sustainable future. However, securing funding for shipping decarbonization initiatives in these countries presents challenges, such as limited access to capital, lack of financial initiatives, political and regulatory uncertainties, technological risks, lack of local expertise, and the effects of global economic volatility. Addressing these challenges demands innovative strategies. The paper explores ways of effectively allocating funds for decarbonization projects in the shipping industry of non-EU countries, Türkiye in particular, using a structured decision-making framework tailored to their specific needs and challenges. We adopt the Moment Integrated Solution Method (THEMIS) to identify the "best" option from the range of alternative strategies identified in the framework. Our findings show that the use of incentive mechanisms is the most prioritized funding alternative, followed by the implementation of a sound Cap-and-Trade system and the promotion of strict local regulations to combat emissions. These imply that the prioritization of funding mechanisms, market-driven approaches, and more stringent regulation are key drivers in maritime decarbonization efforts. The Türkiye case study on strategies to achieve a greener maritime industry in developing countries also shows that securing funding for decarbonization requires a concerted effort by governments, private entities, and international organizations.

**Keywords:** Shipping decarbonization, Decision making, Funding, Non-EU countries, THEMIS

## Introductıon

In the global battle against climate change, the imperative to decarbonize the shipping industry stands as a pivotal undertaking. According to the International Maritime Organization (IMO), global $CO_2$ emissions from shipping exceeded 1 billion tons in 2022, accounting for approximately 2–3% of world carbon emissions. To align with the ambitious goals of the Paris Agreement, the shipping industry ought to reduce its emissions by at least 50% by 2050 (IMO 2015). However, during IMO's MEPC80 meeting in July 2023, member states agreed on a more expedient action plan, also stipulating the so-called *indicative checkpoints* of reducing emissions by at least 20% (striving for 30%) by 2030, compared to 2008 levels; at least 70% (striving for 80%) by 2040, finally reaching net-zero by or around 2050 (IMO, 2023a). Observers argue that MEPC80 watered down IMO's climate ambitions while significant decarbonization challenges face all segments of the maritime industry (Alamoush et al. 2022; Bilgili 2021). IMO focuses strongly on operational and technical energy efficiency measures, for example through the introduction of the Energy Efficiency Design Index (EEDI), Energy Efficiency Operational Index (EEOI), Energy Efficiency Existing Ship Index (EEXI), and the Carbon Intensity Index (CII) (IMO 2020; Mallouppas and Yfantis 2021). Market-based measures (MBM) are also considered as part of the solution, particularly the inclusion of shipping in the EU Emissions Trading System (ETS) (Meng et al 2023; Psaraftis et al 2021).

In its turn, and as a result of the slow progress at IMO, the European Union pursues further advances in the decarbonization of shipping. As part of the *European Green Deal*, the European Commission has proposed the first set of targets to be met by 2030 under the "Fit for 55" (Mallouppas et al. 2022). The EU aims to be carbon neutral by 2050 and to curb emissions by 55–60% (of the 1990 baseline) by 2030. The package includes a series of EU regulations affecting maritime transport such as Emission Trading System (ETS), Carbon Border Adjustment Mechanism (CBAM), Energy Taxation Directive (ETD), Renewable Energy Directive (RED), Alternative Fuels Infrastructure Regulation (AFIR), and finally Maritime Fuel Initiative (FuelEUMaritime). In May 2023, the EU expanded further its regulatory reach, encompassing transit ports situated up to 300 nautical miles from its borders. The objective of this is to prevent evasive calls at non-EU ports, aiming to avoid ETS payments (starting from January 2024; EU Directive 2003/87/EC). Incidentally, the positive side effect of the "extension" is the facilitation of decarbonization initiatives across a broader maritime landscape.

While the EU is generally considered as a frontrunner in decarbonization efforts in shipping, it is important to recognize the vital role that non-EU countries play in shaping the sustainable future of this industry. Non-EU countries, substantial contributors to shipping emissions, hold the key to steering the industry towards environmentally responsible pathways, being increasingly under pressure to adopt greener shipping methods (Shi 2016). Maintaining competitiveness and getting access to global markets require adherence to international regulations, particularly those established by the IMO (Wonham 1996). Greener technologies and practices are also required, due to the negative health and environmental effects of shipping emissions, as well as to a growing demand for ecologically sustainable activities across the maritime supply chain (Cullinane and Cullinane 2013). Adopting these principles promotes technological innovation, cost savings, enhanced market reputation, and less environmental harm—all of which contribute to global sustainable economic development (Regnier 2023). The path towards net-zero emissions shipping implies important financial implications for shipowners and operators, particularly as regards the hefty investments needed to transition to a greener shipping fleet.

Within this context, our study delves into the fundamental challenges facing non-EU countries and their ship operators, as they strive to secure financial support for decarbonization endeavors. We thus examine available strategies to overcome obstacles, hopefully charting a course toward the desired outcomes. To illustrate potential strategic avenues, this research showcases instances that exemplify best practices in non-EU nations, before narrowing down on Türkiye. We introduce a decision-making framework on strategies in securing funding for shipping decarbonization ınitiatives. Furthermore, The Moment Integrated Solution Method (THEMIS) is used to evaluate and prioritize the strategies identified in the framework. The empirical analysis focuses on determining the challenges involved in the investment and funding processes of shipping decarbonization, from a Turkish perspective, involving ideas and inputs by TCS (Turkish Chamber of Shipping) and TURKLIM (Turkish Port Operators Association). The study elucidates challenges concerning non-EU shipping stakeholders, and underscores the transformative potential of collaborative and innovative approaches in shaping the path of the maritime industry on its road to decarbonization.

The study consists of four sections including the introduction; a literature review on key considerations in maritime decarbonization, highlighting gaps and debates on maritime decarbonization; a methodological section covering the research design, the data collection process, and the adopted analysis method; and finally a discussion of the findings alongside conclusions.

## Literature review: key consideratıons in maritime decarbonizatıon funding

### Academic insights on maritime decarbonization funding

A structural academic literature review was conducted, consisting of a comprehensive three-step process, integrating database selection, keyword identification, and paper selection based on stringent inclusion and exclusion criteria.

Initially, a refined research string was deployed across designated databases, filtering exclusively for peer-reviewed articles. The search parameters included the title, abstract, author keywords, and full-text content to maximize inclusivity. The search scope extended from 2008 to 2023, spanning Scopus and Web of Science databases. The preference for peer-reviewed papers stemmed from the need to mitigate authorial bias and ensure the objectivity of approaches to maritime logistics. Such papers serve as indispensable reservoirs of information, having undergone rigorous scrutiny wherein relevance and quality are discerned. The final sample from the systematic literature search comprised 29 papers (see Fig. 1).

In the discourse on maritime decarbonization funding, the literature is concerned with grants and subsidies, loans and loan guarantees, tax incentives, carbon pricing mechanisms, public–private partnerships, emissions trading systems, green bonds, technology funds and prizes, and international aid as key topics. However, it appears that topics such as loans, loan guarantees, technology funds, prizes, and international aid have not been adequately researched, while public–private partnerships (Sari 2023), grants and subsidies (Ghisolfi et al. 2024; Czarnecka et al. 2022; Camargo-Díaz et al. 2022; Chen et al. 2021; Wan et al. 2021), carbon pricing mechanisms (Syriopoulos et al. 2023; Meng et al. 2023; Xue and Lai 2023; Dominioni 2023; Rojon et al. 2021; Mundaca et al. 2021; Bilgili 2021; Dominioni et al. 2018), tax incentives (Tvedt and Wergeland 2023; Lagouvardou and Psaraftis 2022; Camargo-Díaz et al. 2022; Merk 2020; Nikolakaki 2013), emissions trading systems (Sun et al. 2024; Flodén et al. 2024; Cullinane and Yang 2022;

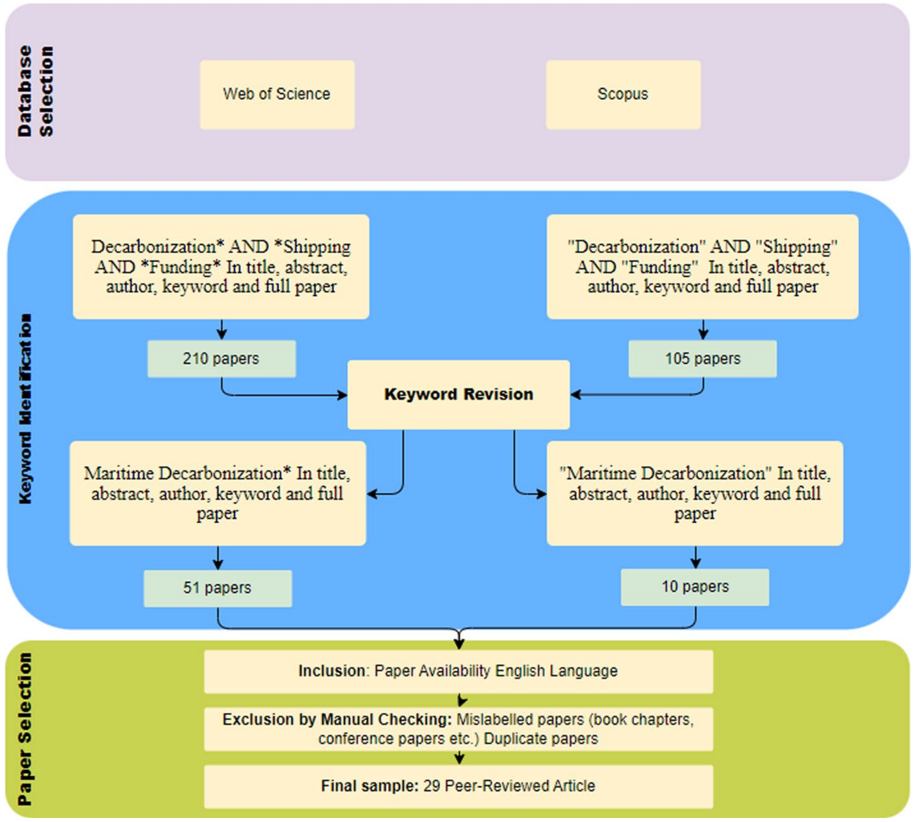


**Fig. 1** Literature review process

Cariou et al. 2021; Lagouvardou and Psaraftis 2022; Wan et al. 2018; Halim et al. 2018; Zhu et al. 2018), and green bonds (Morchio et al. 2024; Rizou 2023; Ozili 2022; Amundsen and Osmundsen 2020) have found limited representation.

A study (Wan et al. 2018) emphasizes the importance of setting carbon reduction targets and highlights the challenges in consensus-building for carbon emissions allocation methods, stressing the need for fair and differentiated approaches. The Dominioni (2023) analysis also underscores the fair equity considerations in designing market-based measures for international shipping, advocating for the strategic use of carbon revenues to achieve greater climate benefits and equitable transition. Mundaca et al. (2021) discuss the design complexities of feebate policies and highlight the importance of careful benchmarking to ensure realistic emission reductions without unduly jeopardizing benefits from trade. Another study (Rojon et al. 2021) delves into the economic impacts of carbon pricing policy measures in maritime transport, particularly focusing on transport costs and their implications for developing countries and small island states.

Camargo-Díaz et al. (2022) reviewed economic incentives for decarbonization in maritime transport, emphasizing the prevalence of differentiated port tariffs. They advocate for governmental support and port initiatives to accelerate decarbonization, noting the role of incentives in promoting fuel transition and clean technology adoption. Syriopoulos et al. (2023) focus on hedging strategies in carbon and bunker markets. They find carbon futures contracts effective in risk management but, nonetheless, they favor simpler rather than complex hedging models. The authors provide empirical evidence supporting their findings and offer insights into practical implementation. Culliane and Yang (2022) discuss the implications of open versus closed Emission Trading Schemes (ETS) in the maritime industry, highlighting debates over efficiency, cost, and regulatory approaches. They delve into the complexities of integrating shipping into existing ETS frameworks and explore alternative mechanisms like carbon taxes, underscoring the importance of market dynamics and policy design in achieving emissions reduction goals.

Ghisolfi et al. (2024) present a simulation model, assessing the impact of various decarbonization policies on freight emissions, emphasizing the urgent need for more ambitious measures, if one is to meet climate targets. Their study highlights the effectiveness of combining policies, like modal shift and alternative fuels to achieve significant emissions reductions, while also recognizing the challenges posed by the short timeframe for implementation and the complexity of long-term forecasting. Czarnecka et al. (2022) examine the role of financial incentives, particularly subsidies and investment plans, in facilitating the transition to green economies, focusing on the European maritime decarbonization context. The authors advocate for a strategic approach to fund allocation and stress the importance of aligning financial mechanisms with sustainable development goals. Morchio et al. (2024) investigate the adoption of green finance solutions in bulk shipping, noting the diversity of approaches among companies and the significance of corporate strategy and size in shaping financing decisions. Their study underscores the potential of sustainability-linked products in supporting broader corporate sustainability goals and calls for further research into the application of green finance instruments in the maritime sector, highlighting both academic and practical implications.

Amundsen and Osmundsen (2020) highlight the pressures and challenges faced by aquaculture companies in obtaining and maintaining green certifications, noting the complexities in implementing sustainability standards. Lagouvardou and Psaraftis (2022) delve into the potential effects of proposed legislation on $CO_2$ emissions in maritime transport, highlighting the intricate consequences such regulations may have on vessel operations, speed reductions, and modal shifts. Both studies underscore the multifaceted nature of environmental governance in maritime industries, emphasizing the need for nuanced understanding and comprehensive analysis to address sustainability challenges effectively.

Such widespread topics may point to a fragmentation of research efforts, resulting in a lack of in-depth understanding and cohesive strategies for addressing specific aspects of maritime decarbonization funding. Therefore, Camargo-Díaz et al. (2022) classify maritime decarbonization funding into three main categories: funding, policies, and incentives. This approach aims to streamline data and enhance overall comprehension. Our study also employs the same categories.

### Insights from policymakers and practitioners

International commitments and goals to decarbonize the maritime industry are prompting to review options that could lead to reduced emissions. Achieving these goals requires the use of alternative fuels, improvements in operational efficiency, and implementation of renewable energies and low-carbon technologies. The leading container shipping companies are placing large orders with this objective in mind, as part of their commitment to become carbon neutral. For example, Maersk launched the Laura Maersk in 2023, the world's first ship with a methanol propulsion system. With 24 dual fuel ships (methanol-ready) under construction, Maersk is making progress in adapting to decarbonization demands (Maersk 2023). Another industry giant, Hapag-Lloyd, has ordered €2 billion worth of twelve ships with LNG propulsion systems, financed through green bond issuance (Deutsche Bank 2022). Also, French CMA CGM Group stands out with the largest single order of sixteen large containerships, twelve with methanol and four with LNG propulsion systems, worth US$ 3.1 billion (Zishuo 2023). HMM of South Korea, signed a US$1.1 billion contract with two local shipyards to build nine methanol-powered containerships (Yonhap News Agency, 2023).

However, considering the industry as a whole, it seems improbable such investments will be replicated by other industry players. The decarbonization path a single company can walk on is its own, and it is limited by the availability of finance for the acquisition of new technologies, and the purchase of green ships. Therefore, by joining forces, maritime stakeholders, including governments offering the right incentives, can act as catalysts for the greening of ships. Incentives are essential in maritime funding to offset initial high costs, encourage the adoption of environmentally friendly technologies, ensure fair competition, align with environmental goals and regulations, promote market transformation, and respond to public and stakeholder pressure for sustainability. Economic incentives aimed at financing this type of projects can play an important role in supporting a sustainable change in maritime transport, covering different pursuits such as fleet renewal, port investments supporting green shipping (such as OPS) and support to research and innovation. Table 1 provides an overview of available instruments aimed at financing maritime decarbonization projects in selected non-EU countries.

In addition to other government incentives and tax benefits, low-interest loans for investments in decarbonization activities signal the financial sector's interest to contribute in minimizing carbon-intensive behavior.

Governments and businesses are increasingly in agreement on the need for a transition to a low-carbon economy through carbon-pricing. Carbon pricing is one of a government's climate policy instruments to limit emissions. Forty-five nations have adopted some form of carbon pricing legislation, either in the form of a carbon tax, a Cap-and-Trade system, or both (Bilgili 2021). For example, the government of Japan has pledged to provide financial and technological assistance to ASEAN countries to support their efforts to decarbonize and combat climate change. This commitment, addressed at the ministerial meeting of the Asian Zero Emission Community (AZEC), was motivated by Japan's goal of becoming the world's leading hydrogen economy, departing from its heavy dependence on fossil fuels (Obayashi and Golubkova 2023). Another example is the agreement between the Spanish government and Maersk. The agreement between the two sides, which came together to explore large-scale green fuel production in Spain, envisages an investment of around €10 billion (Reuters 2022).

Table 1 focuses on non-EU countries, but it is the EU that has been leading the efforts to fund decarbonization in shipping. In the Autumn of 2019, the new European

**Table 1** Maritime decarbonization financial programs and funding projects (selected non-EU countries)

| Countries | Grants, programs, and funds to finance projects | References |
|---|---|---|
| United States | Port Technological Advancement Program | Clean Air Action Plan (2021) |
| | EPA Port Initiative | EPA (2022a) |
| | Maritime Environmental and Technical Assistance (META) Program | United States Department of Transportation Maritime Administration Maritime Environmental and Technical Assistance (META) Program (2022) |
| | Carbon Reduction Program (CRP) | United States Department of Energy Alternative Fuels Data Center: State Carbon Reduction Program (2021 |
| | FY21 Office of Vehicle Technologies Research Funding Opportunity Announcement | EPA (2022b) |
| | Broad Agency Announcement (BAA) | EPA (2022b) |
| | Grants Program-Port of Los Angeles | Port of Los Angeles Environmental Ship Index Program (2022) |
| | Grants Program—Port of Long Beach | Port of Long Beach Green Ship Program (2020) |
| | Grants Program—Port of New York and New Jersey | The Port Authority of New York and New Jersey Clean Vessel Incentive Program (2021) |
| | Port Infrastructure Development Program (PIDP) | United States Department of Transportation Maritime Administration Port Infrastructure Development Grants (2022) |
| Canada | Salish Sea Marine Emission Reductions Fund | Government of Canada Salish Sea Marine Emission Reductions Fund. (2021) |
| Norway | Enova | Norwegian Government (2019) |
| | NOx Fund | Norwegian Government (2019) |
| | EU Horizon 2020 | European Commission Horizon (2020) |
| | TEN-T Program | European Commission TEN-T (2022) European Commission Horizon Europe (2022) |
| | Horizon Europe | |
| Australia | Australia's Clean Energy Finance Corporation | Clean Energy Finance Corporation (2022) |
| China | GreenVoyage2050 Project | IMO (2023) |
| | Financial subsidies for OPS construction—Lianyungang government (inland waterway ports) | Chen et al. (2021) |
| | Financial subsidies for construction and OPS capacity expansion (maritime ports) | Wan et al. (2021) |
| New Zealand | New Zealand Green Investment Finance | Ozili (2022) |
| Türkiye | The Maritime Decarbonisation and Green Shipping Programme for Türkiye | Sari (2023) |
| India | GreenVoyage2050 Project | IMO (2023) |
| Brazil | Brazil Country Program for the Green Climate Fund | Green Climate Fund (2023) |
| Azerbaijan, Belize, Cook Islands, Ecuador, Georgia, Kenya, Solomon Islands, and Sri Lanka | GreenVoyage2050 Project | IMO (2023) |
| Argentina, Colombia, Nigeria, South Africa, United Kingdom | EU Horizon 2020 | European Commission Horizon (2020) |
| | Horizon Europe | European Commission Horizon Europe (2022) |
| | GreenVoyage2050 Project | IMO (2023) |

**Source:** Adapted from Camargo-Díaz et al. 2022

Commission (EC 2019) led by President Ursula von der Leyen, introduced the "European Green Deal" as a response to global climate challenges outlined in the Paris Agreement. The deal, a key focus for the 2019–2024 period, aims to transition the EU to a fair and prosperous society with no net greenhouse gas (GHG) emissions by 2050. The Deal seeks to decouple economic growth from resource use and turn environmental challenges into opportunities across all policy areas (EC 2021a; EU Directive 2003/87/EC; Sikora 2021).

Complementary to this, in July 2021, the EC presented its "Fit for 55" package, which includes proposals to align EU policies with the goal of reducing net GHG emissions by at least 55% by 2030. Achieving this is crucial for Europe in rerms of becoming the world's first climate-neutral continent by 2050. The "Fit for 55" package provides legislative tools to meet targets set in the European Climate Law and fundamentally transform the European economy and society towards a green, fair, and prosperous future. The "Fit for 55" package proposes regulations for using renewable and low-carbon fuels in maritime transport, encouraging their uptake without disrupting the internal market (EC 2021b).

However, without further policy intervention, it is unlikely that there will be a significant increase in the use of low- or zero-carbon fuels in shipping (von Malmborg 2023). The European Commission predicts a limited uptake of biofuels in international shipping by 2050 (0.1% in 2030 and 1.3% in 2050) (EC 2021a). They aim for low- or zero-carbon fuels to constitute 6–9% of the international maritime transport fuel mix by 2030 and 86–88% by 2050, contributing to EU-wide GHG emissions reduction targets (EC 2021a; 2021b).

Combined with carbon pricing and other measures, this could lead to a 22% reduction in GHG emissions by 2030 and 88–89% by 2050 compared to 2008 levels. To support the Green Deal's goals, the European Commission has established the European Green Deal Investment Plan (EGDIP), committing to mobilize at least €1 trillion in sustainable investments over the next decade. A significant portion of the EU's budget for 2021–2028, including funds from the NextGenerationEU instrument for COVID-19 recovery, is earmarked for green investments.

The EC is also finalizing EU taxonomy criteria for shipping decarbonization, which will classify ships based on their environmental impact and facilitate the adoption of sustainable marine fuels. However, revisions are underway to address industry concerns and encourage the use of a wider range of alternative sustainable marine fuels after 2025. The EU Emissions Trading System (ETS) is seen as an effective Market-Based Measure (MBM) to fight climate change. Since January 2024, shipping is on a path toward full inclusion in the ETS by 2026. ETS establishes a maximum quantity of greenhouse gases (GHGs) allowed and issues tradable allowances accordingly. Shipping companies can buy or sell these allowances, which correspond to the right to remit one metric ton of $CO_2$. By integrating maritime transport into the EU ETS, shipping companies face higher costs for emitting $CO_2$, prompting them to consider emissions costs in their commercial decisions. Ultimately, they are incentivized to invest in low-carbon technologies, adopt cost-effective emission reduction solutions, assess risks, and take steps to mitigate them.

Incentives are crucial in encouraging market players to adapt more quickly. For instance, the International Association of Ports and Harbors (IAPH) included the Carbon Intensity Indicator (CII) in the Environmental Ship Index (ESI), which rewards environmentally friendly shipping practices (Marrero and Martínez-López 2023). Various measures can be employed, such as bunker levies, emissions trading, and environmental taxes, to incentivize emission reduction efforts (Xuan et al. 2022).

A strategy of implementing differentiated port tariffs with various incentives to encourage green shipping can contribute to reducing emissions and encourage the use of necessary technologies. Ports, which are the only implementation area of the regulations related to the decarbonization process, have a key role in the transition of the sector. Since differentiated port tariffs, although voluntary, provide an incentive for ships to improve their environmental performance, similar practices should be spread to a wider geography. The shipping industry's decarbonization efforts present enormous opportunities to national economies. However, the incentives and commitments developed to date are insufficient in reaching targets and examples like the above are rather sporadic. It can be argued that adopting green shipping practices will be advantageous in the long run and market participants have a myopic focus on initial investment costs.

Therefore, the shipping industry will need to handle complicated financial instruments, adapt to supportive regulatory frameworks, and encourage industry-wide collaboration, to make sustainable practices commercially viable and attractive. This need is more prominent in non-EU countries, which generally have current account deficits and depend on external financing, and which are predominantly composed of developing countries. This study aims to fill this gap since the existing studies do not provide an answer to the question of what kind of strategies can be emphasized within the scope of funding for transformation.

### Maritime decarbonization in Türkiye

Türkiye is also developing policies to decarbonize its shipping industry. For example, the Green Deal Action Plan for maritime decarbonization, spearheaded by the Turkish Ministry of Trade in 2021, outlines a strategic vision for moving the Turkish shipping sector towards environmental sustainability. The initiative is part of Türkiye's broader Green Deal Action Plan (Türkiye Green Deal Action Plan 2024), encompassing 32 objectives and 81 actions, which span areas such as green and circular economy, secure energy supply, and sustainable agriculture. It is worth noting that, unlike the EU Green Deal established in 2019, the Turkish plan does not delineate specific quantifiable targets or deadlines. In the context of mitigating emissions from the maritime sector and fostering eco-friendly shipping practices, the primary focus of the Turkish initiative is on creating a financial support mechanism.

The mechanism aims to bolster the adoption of innovative technologies on Turkish ships and ports, promoting environmentally conscious, sustainable, and safe transportation. Such technologies encompass the construction of new vessels designed to operate on low-emission alternative fuels, as well as retrofitting existing ones to meet similar standards. Additionally, efforts are underway to establish the necessary infrastructure for onshore power supply (OPS or cold ironing) in port facilities. Under the FuelEU Maritime regulation, container, cruise and passenger ships are required to use OPS services if they stay in port for more than 2 h after January 1, 2030. As a result, many non-EU countries also plan to install OPS facilities by that date. At the same time, the Turkish government announced its intention to produce green hydrogen from domestic energy in January 2021. The green hydrogen will also allow the country to produce alternative fuel energy options including methanol and ammonia. Türkiye has also declared the areas for building offshore wind farms in the northwest (i.e. Bandirma, Biga, and Canakkale) side of the country (Turkish Hydrogen Technologies Strategy and Roadmap, 2023).

Importantly, the Green Deal Action plan is progressing towards designating the Mediterranean Basin as a Sulfur Emission Control Area (SECA) by 2024. If this designation comes to fruition, international vessels operating in the Mediterranean will be mandated to utilize fuels with sulfur content not exceeding 0.1%. The preparations for potentially declaring the Mediterranean as a SECA aim at informing and guiding the maritime sector towards ensuring compliance with fuel regulations, bolstering fuel supply capabilities, and addressing potential implementation challenges. This strategic move underscores Türkiye's commitment to environmental stewardship and the country's ambition to foster sustainable maritime practices.

Sari (2023) asserted that the Turkish government might work with global financial institutions to create a special funding regime, intended only for shipping industry decarbonization initiatives. To attract private capital, the government could initiate public–private partnerships to construct the required infrastructure, providing incentives or concessions to private companies that finance and run these projects. The search for funding sources for decarbonization initiatives necessitates a collaborative effort to navigate the intricate landscape of financial complexities. In the case of Türkiye, the regulatory authorities are actively encouraging shipowners to invest in alternative fuels, and they urge terminal operators to develop bunkering facilities and foster agreements with the energy-producing sector. Anticipating the impacts of regional ETSs on Türkiye's maritime industries, the country heightens awareness of the fact that these systems also exhibit weaknesses, such as carbon leakages (Christodoulou and Cullinane 2023; Lagouvardou and Psaraftis 2022) and limited geographical coverage (Christodoulou and Cullinane 2023). Notwithstanding these, the trilateral collaboration emerges as an indispensable catalyst, channeling financial resources towards sustainable investments with far-reaching impacts.

## Methodology

Our methodology is twofold: (1) the introduction of a decision-making framework to identify the set of strategies to decarbonize shipping and ports; (2) the application of The Moment Integrated Solution method (THEMIS) to assess the best choice in the strategy set.

Table 2 introduces a framework to help identify the "best" option from the range of alternative strategies. Based on extant literature, we identified nine strategic options. These are subjected to a decision analysis, a formal quantitative technique for

**Table 2** Strategies in securing funding for shipping decarbonization ınitiatives

| No | Strategy | Group | Description | Source |
|---|---|---|---|---|
| 1 | Using incentives to cover onshore power service fees | I | Onshore Power Supply (OPS) technology is a strategic initiative for mitigating ship emissions at ports. By enabling vessels to connect to shore-based electricity, OPS reduces onboard engine use, curbing pollutants and greenhouse gases. This eco-friendly approach aligns with environmental goals, enhancing air quality and lowering carbon footprints. Economically, OPS minimizes ship fuel consumption during port stays, yielding cost savings. However, challenges include initial high setup costs and the need for regulatory incentives to drive widespread adoption. Despite hurdles, OPS stands as a pivotal strategy, harmonizing ecological and economic imperatives for sustainable maritime operations | Camargo-Díaz et al. (2022) |
| 2 | Financing maritime decarbonization projects | F, I | Securing financing for maritime projects is crucial to meet global decarbonization goals. Shipowners, shipping firms, and port authorities face challenges in adopting green technologies. These hurdles encompass establishing sustainable fuel chains, incorporating operational changes, and investing in eco-friendly shipbuilding. To overcome financial barriers, a strategic approach involves collaborative efforts among stakeholders, leveraging public–private partnerships, and accessing international funding mechanisms (i.e. carbon revenues). Policymakers must incentivize investments in green initiatives, fostering a transition to cleaner practices in the maritime sector and aligning with the broader imperative of achieving environmental sustainability | Sari (2023), Camargo-Díaz et al. (2022), Czarnecka et al., (2022), Chen et al., (2021), Wan et al., (2021) |
| 3 | Differentiating port charges | I | Differentiated port charges represent a strategic approach to incentivize environmentally friendly practices in maritime transport. This initiative involves offering discounted port charges to ships employing eco-friendly technologies or adhering to sustainable operational practices during port calls. By providing financial benefits to such vessels, this strategy encourages shipowners to invest in greener technologies, ultimately reducing emissions and promoting environmental sustainability in the maritime sector. This approach aligns economic incentives with environmental objectives, fostering a transition toward cleaner and more sustainable shipping practices while enhancing the competitiveness of eco-conscious fleets in the industry | Camargo-Díaz et al. (2022) |

**Table 2** (continued)

| No | Strategy | Group | Description | Source |
|---|---|---|---|---|
| 4 | Develop sustainability certifications and suitable schemes | P | Guarantees of Origin (GO) serve as a strategic tool to assure ship operators of the renewable and sustainable nature of a specific fuel. GOs provide a transparent certification, verifying the renewable energy source and origin of the fuel used in maritime operations. By offering a reliable mechanism to track and validate the environmental credentials of fuels, GOs instill confidence among ship operators, facilitating informed choices aligned with decarbonization goals. This strategy promotes accountability, transparency, and trust in the maritime industry's transition towards sustainable and renewable energy sources, contributing to a greener and more responsible shipping sector | Irena (2021), Morchio et al., (2024), Rizou, (2023), Ozili, (2022), Amundsen and Osmundsen (2020) |
| 5 | Promoting stricter local regulations to limit airborne emissions in port and navigation channels, and make OPS at ports compulsory whenever available | P | Enforcing onshore power usage during port operations is a strategic initiative to curb airborne pollutants and greenhouse gas emissions. By mandating vessels to plug into the port's electricity grid, auxiliary engine use is minimized during docking, leading to a substantial reduction in environmental impact. This approach aligns with sustainability goals, fostering cleaner air quality and contributing to global emission reduction targets. Successful implementation requires collaborative efforts among port authorities, shipping companies, and regulatory bodies, ensuring a more eco-friendly and responsible maritime industry | Irena (2021), Amundsen and Osmundsen (2020) |
| 6 | Implementing a Cap-and-Trade system with strict pollution limits and tradable allowances | P | Implementing an emissions trading system (ETS) for shipping incentivizes companies to cut emissions, fostering innovation and sustainability in the shift to a decarbonized economy. By placing a cap on emissions and allowing trading of emission allowances, it encourages efficiency improvements and adoption of cleaner technologies. Companies exceeding the cap can buy allowances from those below, stimulating a market-driven push toward greener practices. This strategy aligns economic incentives with environmental goals, propelling the shipping industry towards a more sustainable and low-carbon future | EPA (2022a, 2022b), Sun et al. (2024), Flodén et al. (2024), Cullinane and Yang (2022), Cariou et al. (2021) Lagouvardou and Psaraftis (2022), Wan et al. (2018), Halim et al. (2018), Zhu et al. (2018) |
| 7 | Implementing enough incentives for attracting operators to nearby non-EU ports | I | The implementation of an emissions trading system (ETS) in the EU may prompt line operators to relocate transshipment activities to nearby non-EU ports. Concerns about increased operational costs due to emission allowances could drive companies to seek more cost-effective options outside the EU jurisdiction. To address this challenge, it's crucial for policymakers to establish global collaboration on emission reduction efforts and create a level playing field. This ensures that companies are incentivized to adopt sustainable practices without resorting to relocation, fostering a globally coordinated approach to maritime decarbonization | Lagouvardou and Psaraftis (2022), Tvedt and Wergeland (2023), Camargo-Díaz et al. (2022), Merk (2020), Nikolakaki (2013) |

**Table 2** (continued)

| No | Strategy | Group | Description | Source |
| --- | --- | --- | --- | --- |
| 8 | Hedging carbon future contracts to manage the carbon pricing risk | P | Carbon pricing risk in the shipping industry refers to the financial exposure shipping companies face due to potential future costs associated with carbon emissions. As companies navigate this risk, a strategic approach involves proactively investing in emission reduction technologies. By adopting cleaner technologies, companies not only mitigate potential carbon pricing liabilities but also position themselves to comply with evolving regulations. This strategy aligns financial prudence with environmental responsibility, fostering a resilient and sustainable business model amidst the global push for carbon pricing and emission reduction in the maritime sector | Meng et al. (2023), Lagouvardou and Psaraftis (2022) |
| 9 | Applying better fund models (i.e. International Maritime Research Fund, IMRF) for helping alternative fuels and technologies | F | Establishing a financing ecosystem is a strategic approach to secure funding for the maritime industry, aligning with the IMO and EU targets for 2030 and 2050. This strategy involves creating robust financial mechanisms, including public–private partnerships, green bonds, and investment incentives. By channeling funds towards research, development, and implementation of sustainable technologies, it facilitates the industry's transition to meet ambitious emission reduction goals. This financing strategy not only addresses the capital-intensive nature of eco-friendly initiatives but also ensures alignment with international regulations, driving the maritime sector towards a low-carbon and environmentally sustainable future | Ghisolfi et al., (2024), Lagouvardou and Psaraftis (2022) |

*Source***:** Authors' Own Elaborations

**Type of Group:** (F) Funding, (I) Incentives, (P) Policy determining the best choices among alternatives. The method requires the development of explicit influence structures that specify a complete set of strategies, possible strategy outcomes, and strategy outcome values. Uncertainty is incorporated directly in this analysis by assigning probabilities to individual outcomes.

Since the 1950s, several empirical and theoretical works on Multi-Criteria Decision Making (MCDM) methods have examined their mathematical modeling capabilities in providing a framework that can help to structure decision-making problems and generate preferences among alternatives (Taherdoost and Madanchian 2023). THEMIS is a method that has been extensively studied in such a context. The method provides a structured decision-making framework, allowing the systematic evaluation of alternatives and the generation of preferences based on multiple criteria. We have used the THEMIS methodology to analyze the data described in Appendix B.

THEMIS demonstrates outcomes congruent to Analytical Hierarchy Process (AHP). Similar to AHP, THEMIS accommodates a comparable number of expert decision-makers. The method produces pairwise comparisons on nxn matrix. THEMIS can be employed in similar contexts like AHP, DEMATEL and BWM, which are methodologies used to calculate criteria weights. While THEMIS produces results akin to AHP, it distinguishes itself in how it handles pairwise evaluations. In AHP, weight values in pairwise comparisons tend to exhibit a slight rightward bias, whereas THEMIS ensures decision-making based on absolute equilibrium in such evaluations (Akan et al. 2020). MCDM methodologies incorporating fuzzy integration, such as THEMIS, allow for a reduction in the number of decision-makers. This reduction is feasible owing to the adept handling of limited numbers through fuzzy sets.

To somehow 'frame' decarbonization strategies, we use THEMIS to offer clarity into the challenges involved in the investment and funding processes. The data collection process was based on the nine strategies listed in Table 2. The data collection tool consisted of 36 questions. To examine the situation in a non-EU country like Türkiye, insights and viewpoints were obtained from the members of TCS (Turkish Chamber of Shipping) and TURKLIM (Turkish Port Operators Association). Terms were translated into the Turkish language and a linguist was present to ensure that the meanings of words in English and Turkish were identical. Respondents were asked about the importance of each strategic option in the shipping decarbonization for non-EU countries, with a specific focus on Türkiye. We have deliberately narrowed down our survey respondents, focusing on seaports that meet stringent environmental criteria, such as possessing a green port certificate or demonstrating adherence to sustainable shipping practices. Specifically, we have identified and reached out to only 20 certified seaports.[1] In doing so, we have engaged exclusively with the management teams of these ports. Out of the 20 seaports, only 3 have responded to our survey. Subsequently, we extended the same questionnaire to 25 stakeholders associated with TCS, resulting in feedbacks

[1] Aksa, Altintel Port, Asyaport, Bodrum, Borusan, Ege Port, Evyapport, Hopaport, Kumport, Limakport, Limaş, Mardaş, Marport, Petkim, Solventaş, Nemport, Efesanport, Qtermınals Antalya, Poliport, and Samsunport.

**Table 3** Importance of weights, normalization and ranking of criteria

| | Criteria | Weights | Rank |
|---|---|---|---|
| $C_9$ | Applying better fund models (i.e., International Maritime Research Fund) incentivizes investments in alternative fuels and technologies | 0.212 | 1 |
| $C_6$ | Implementing a Cap-and-Trade system with strict pollution limits and tradable allowances | 0.147 | 2 |
| $C_5$ | Promoting strict local regulations to limit airborne emissions at ports and inland waterways, and make cold-ironing at ports compulsory whenever available | 0.139 | 3 |
| $C_8$ | Hedging carbon futures contracts to manage the carbon pricing risk | 0.129 | 4 |
| $C_2$ | Financing maritime decarbonization projects | 0.115 | 5 |
| $C_4$ | Developing sustainability certifications and suitable schemes | 0.093 | 6 |
| $C_7$ | Devising attractive incentives to attract operators to nearby non-EU ports | 0.075 | 7 |
| $C_3$ | Differentiating port charges | 0.052 | 8 |
| $C_1$ | Using incentives to cover onshore power service fees | 0.038 | 9 |

from 5 company managers. Thus, eight respondents returned in our questionnaire (see Appendix—Table 4 for respondent profiles).

In the context of our study, the utilization of only 8 expert decision-makers does not impede the model's resolution. MCDM methods can be applied with a limited number of participants, typically ranging from 1 to 5 individuals, with 3 being a common choice. The THEMIS method, as an MCDM approach, does not exhibit consistency issues related to sample size (Akan et al. 2020). The crucial factor is the involvement of experts in the relevant field. It is customary for MCDM to rely on the insights of a few experts well-versed in the specific domain. If the method incorporates Fuzzy Logic, considering the inherent uncertainty in human judgment, the evaluation of decision-making, even with a smaller number of individuals, would not pose a problem. In such cases, fuzzy integration would address the inherent uncertainty among the experts. In the realm of Multiple Criteria Decision Making (MCDM), the inclusion of only 8 decision-makers aligns with established practices and expert opinion. Conversely, empirical studies, particularly those employing survey methodologies, advocate for a more extensive participant list, often requiring a minimum of 80 contributors to ensure robustness and confidence level requirements.

## Findings

The methodology applied to the criteria for maritime decarbonization strategies yields nuanced insights into the relative importance of each criterion. The final results are included in Table 3 with further summary Appendix in Tables 5, 6 and 7. At the forefront of significance is the criterion related to funding models, exemplified by the International Maritime Research Fund ($C_9$).

This criterion is assigned the highest weight, indicating that stakeholders consider financial support for alternative fuels and technologies as the most critical factor in driving decarbonization efforts. The emphasis on this criterion suggests a recognition of the pivotal role that funding mechanisms play in incentivizing and facilitating the adoption of sustainable practices in the maritime sector. In summary, our analysis highlights a prioritization of funding mechanisms, market-driven approaches, and stringent regulations as key drivers for maritime decarbonization. These insights provide valuable guidance for policymakers and industry stakeholders seeking to formulate effective and impactful strategies to reduce carbon emissions in the maritime sector.

The *funding models* option is closely followed by the criterion concerning the implementation of a Cap-and-Trade system with strict pollution limits ($C_6$). The relatively high weight assigned to this criterion underscores the recognition of market-driven mechanisms as being instrumental in steering the industry towards environmentally friendly practices. The Cap-and-Trade system is viewed as a potent tool for regulating emissions and encouraging proactive measures to reduce pollution, reflecting an awareness of the economic levers that can drive sustainable behavior. In particular, the private sector is eagerly waiting to see how effective global market-based measures, such as carbon-pricing, will be in internalising the costs of decarbonisation investments. Similarly, the promotion of strict local regulations for limiting airborne emissions at ports and navigation channels, coupled with mandatory OPS when available ($C_5$), claim significant importance. The weight assigned to this criterion suggests a recognition of the importance of regulatory frameworks in curbing emissions. The inclusion of the OPS mandate underscores a commitment to concrete actions that directly address emissions in port, aligned with broader sustainability goals.

When examining the issue from the perspective of green transition and sustainability, it is evident that the heaviest burden and investment requirements of the maritime business will fall on the shoulders of the manufacturing and exporting sectors. In the logistics sectors serving foreign trade, ports will gain a comparative advantage, compared to road and air transport, but they will be disadvantaged compared to railways. Therefore, many investments in ports will be mandatory in the next 3–4 years.

The main source of emissions in port areas is ships. However, the commercialization of emission-free fuels will take long, making OPS investments necessary. Conversely, the criterion related to using incentives to cover onshore power service fees ($C_1$) is deemed the least critical. The lower weight suggests that, in the decision-making process, stakeholders may perceive this approach as less impactful compared to other strategies. The lower emphasis on this criterion could be indicative of a preference for more direct and systemic interventions, such as regulatory frameworks and financial incentives.

Leading the list is the criterion involving the development of sustainability certifications and suitable schemes ($C_4$). This criterion, although not highly weighted, indicates that stakeholders recognize the importance of establishing clear sustainability standards and frameworks. The emphasis on certification and schemes suggests a commitment to formalizing and standardizing sustainable practices within the maritime sector, potentially facilitating easier adoption and evaluation of environmentally friendly initiatives. In the case of our example, despite the existence of a world of energy-producing companies in Türkiye, there is currently no certification that the energy purchased from these companies is 100% renewable. Therefore, the obligation to produce renewable energy, whether through wind energy plants, solar power plants, or other methods, rests with the ports, as certification may take many years.

## Discussion and conclusions

The availability of finance and of financial sources poses a significant barrier to the transformative journey towards a green shipping industry. The barriers to the adoption of renewable energy in the shipping sector are complex. These can be categorised as organisational/structural; behavioural; market; and non-market factors. This complexity in part reflects the unique, international, nature of the shipping industry, entailing constraints and factors that lie beyond the ability of an individual state to introduce shipping incentives (i.e., Environmental Ship Index-ESI, the Green Award-GA, the Clean Shipping Index-CSI, GHG emissions rating-GHG ER, Green Marine Environmental Program-GM), and the policy and regulatory framework needed to overcome barriers. With regard to organisational, structural and behavioural barriers, the limited R&D financing, particularly for initial proof-of-concept technologies, is a major factor, together with shipowner and port operator concerns over the risk of additional, hidden, costs, as well as opportunity costs of renewable energy solutions. This is particularly true since, historically, there has been a lack of reliable information on costs and potential savings of specific operational measures or renewable energy solutions for this sector.

Concerning market barriers, the major problem is no other than what Garrett Hardin (1968) described as *the tragedy of the commons*: the split of incentives and diffusion of benefits among stakeholders (shipowners, port operators, vessel charterers, and cargo owners) limits the motivation of a single stakeholder group to invest in clean energy solutions, since the benefits do not always accrue to the investing party and, hence, investment costs cannot always be fully recouped.[2] Funds are essential for financing the transition to cleaner technologies and infrastructure, while incentives provide motivation and rewards for shipowners and operators to enable them to make sustainable choices. These two elements work together to drive progress in reducing greenhouse gas emissions and in improving the environmental performance of the maritime sector. Therefore, limited R&D financing, concerns over hidden costs, lack of information on costs and savings, and split incentives might be major barriers to the adoption of decarbonization technologies (Alamoush et al. 2022).

Non-EU countries, being significant contributors to maritime emissions, play a central role in shaping the industry's sustainable future. With Türkiye as an example, this paper focused on the primary challenges facing non-EU countries in obtaining funding for decarbonization initiatives in shipping and explored potential strategies to overcome such obstacles. In this regard, a decision-making framework was presented covering nine strategic options. The empirical analysis focused on determining the challenges involved in the investment and funding processes of shipping decarbonization, from a Turkish perspective, using the THEMIS method.

[2] We have often made this point in our earlier works with regard to public investments in automated transshipment terminals whose impacts are defused rather than localized. See for examples Haralambides (2017, 2019).

We find that funding models and Cap-and-Trade systems (EPA 2022a, 2022b), that is, ETS, should be operationalized to enable the switch to alternative energy sources. Shipping companies and ports will be the ones to undertake these investments. It has often been argued (Erdemir 2023) however that, in the absence of incentives or funding systems similar to those in the EU, the cost of these investments would be passed on to freight rates, and from there to consumers who pay taxes to fund the investments: in actual fact, a vicious circle. We have claimed in earlier works (Haralambides 2019) that such concerns are unwarranted and costs could instead be easily absorbed in shipping profits. This would happen if economic and technical regulation (the latter considerably higher and more effective than what IMO has accustomed us so far) could ensure society a fair, rules-based, competition, in place of an, as often called by some, 'wild west' industry. For decades, shipping has been burning sludge, with irreparable environmental impacts, being an impenetrable bulkhead to change, often through 'capture', until the push came to shove. With ETS, fuel taxes, or other MBMs, the time has come, for one of the richest industries known, to return some 'economic rent' back to society and assume itself responsibility for the environmental impacts its operations are causing.

The development of sustainability certification and appropriate schemes ranks as the least significant criterion for shipping stakeholders, including terminal operators. The Turkish Green Port Regulation (UAB 2023) has been officially published, marking a significant milestone, as Turkish terminal operators are now required to obtain green certification and assess sustainable schemes through this regulatory framework. However, operational challenges still persist, notably the requirement for the installation of a cold-ironing system at a single pier. When a port embarks on such a project, it undertakes to extend its implementation to other piers too. Similarly, in the selection of transformers, the planning cannot be limited to a single pier but it must inlude the planning of the entire port. This entails integrated planning and infrastructure development while, in practice, equipment will be procured specifically for the pier under consideration. Furthermore, there is no mandatory provision for ships to source energy from the port; this is explicitly stated as an option for ships that request it. However, the details regarding electricity prices remain unclear. Therefore, this criterion is deemed least important, primarily due to the operational challenges it presents in the sector.

Energy transition is met with reluctance, especially considering the current fleet structure, its increasing age and the fact that, presently, more than 90% of the global fleet burns fossil fuels (UNCTAD RMT, 2023). Other factors that create resistance to change include the lack of commercial viability of renewable techniques and the lack of motivation of ship operators to adopt alternatives (Stavroulakis et al. 2023). Governments and shipping companies have a great responsibility to ensure that IMO, as a regulatory body of the United Nations, is able to achieve its comprehensive emission targets and that action is taken as soon as possible. While the alternative technologies in the decarbonization journey have both advantages and disadvantages, the chances of success in the long term are very low without structured policies and initiatives from governments and industry (Stavroulakis et al. 2023).

Given the regulatory developments, a considerable amount of investments will be required in the next few years for the adaptation to green shipping. Investments in ports will be more frequently prioritized by industry stakeholders. Given that ships are the main source of emissions in port areas and the commercialization of emissions-free fuels will take time, cold-ironing investments will become a priority. Although financial incentives have been developed to promote the installation of onshore power supply, it is obvious that more initiatives and incentives are needed in this direction, because CI involves benefits, applicable to ships of any size, and an ability to manage the environment. As mentioned by Abu Bakar et al. (2023), these incentives can take many different forms, including one-time subsidies for the installation of the system, pricing schemes (tariff reduction), energy taxation (tax reduction or exemption), and environmental penalties.

State incentives and tax advantages have gained significance. However, the design of financial mechanisms and the distribution of financial resources among stakeholders emerge as important questions (Masodzadeh et al. 2022). Financial institutions are also actively offering green transformation-themed packages. Xue and Lai (2023) examined carbon emission-linked financial leasing, emphasizing its significant impact in the adaptation process. As highlighted by Clausius (2014), financial leasing has long been an alternative financing method, extensively used by industry stakeholders, now notably also benefiting from green transformation.

As reported by Prenc et al. (2018), some ports in Europe are able to build shore power with EU funding, which greatly lessens the financial stress of the individual port. However, incentives could be diversified further. Traditional debt financing channels have been blocked as a result of recent global tightening policies. Meeting the needs for external funding, particularly for decarbonization in the shipping industry, has become more difficult and expensive, especially with the increase in U.S. interest rates from almost 0% to over 5%. The Petropoulos (2019) study highlights that alternative funding sources, mainly leasing and internal equity, have been utilized to fulfill financial needs. Credit banks in particular demand that sustainability standards be met, along with extra requirements, for ships that run on renewable energy, emphasizing the importance of ESG standards. As a result, it is getting harder to extend credit to ships that do not support green transformation. About half of all new ship orders are dual-fuel ships, and this ratio is predicted to rise quickly (Petropoulos 2019). In conclusion, financial innovation and technological advancement are intimately related in the context of the green transition (Schinas 2018). Different financial solutions will be evaluated, as the percentage of green ship tonnage rises, and eventually many of these solutions will be accepted as the "new normal".

A review of existing incentives shows that some leading ports offer discounts under specific programs, which include a percentage reduction in port dues for ships with a satisfactory level of green content. In practice, The Maritime and Port Authority of Singapore offers a 20% to 30% discount on port dues for ships calling at the port, using renewable energy or low carbon emission fuels (The Maritime Executive 2022). Also, the Freight Technology Incentives Program of Transport Canada, which aims to reduce GHG emissions by lowering fuel consumption and promoting the use of energy efficient technologies, or the Port of Hamburg, which offers publicly funded discounts on port dues for a limited period of time to ships that meet certain emissions criteria, have a significant effect on motivating market players towards faster adaptation (Balcombe et al. 2019). It would be advisable to increase such initiatives. Subsidies, however, need to be properly designed, closely watched, and adjusted when circumstances so dictate, to avoid distortions of competition (Nicolini and Tavoni 2017).

Although incentives are important for rapid and effective adaptation, lack of coordination among stakeholders can lead to difficulties in compliance. In particular, significant differences between IMO and the EU may create unintended negative consequences (Monios and Ng 2021). The absence of quantitative evaluations of the viability of mitigation technologies in the post-decarbonization age of the EU is causing mistrust in the industry (Psaraftis and Kontovas 2020).

Our research has focused on the relative importance of criteria, without delving into potential obstacles, feasibility issues, or stakeholder perspectives. Additionally, subjectivity in stakeholder judgments and the complexity of the THEMIS methodology, akin to AHP, may have introduced inconsistencies, or made it challenging for non-experts to grasp, potentially impacting the reliability of our outcomes. Future studies should investigate the feasibility of industry perspectives on implementing these strategies, thus providing a nuanced understanding of the dynamics involved in maritime decarbonization efforts.

Since this study is a country-specific study focusing on Türkiye, the findings cannot be easily generalized across other non-EU countries. Different findings might be reached in other geographies as these might be subjected to different market dynamics and governance settings. Considering that there are uncertainties about how the EU ETS system will work in the maritime context, and that there is no clarity on the implementation of the pooled fund and how it will be managed, future research can be conducted on the competitive advantage that countries outside the ETS are expected to provide. In particular, studies can be conducted on whether the EU ETS system is working properly and which countries have an advantage in terms of carbon leakage.

## Appendix A

See Tables 4, 5, 6, 7.

**Table 4** Profile of shipping-related respondents

| Resp. no. | Age | Education | Experience (years) | Job position |
|---|---|---|---|---|
| 1 | 36 | Bachelor | 6 | Container shipping branch manager |
| 2 | 41 | Master of business | 8 | Terminal manager |
| 3 | 38 | Bachelor | 5 | Terminal manager |
| 4 | 40 | Master of business | 10 | Ocean shipping consultant |
| 5 | 38 | Bachelor | 7 | Container shipping manager |
| 6 | 39 | Bachelor | 10 | Terminal manager |
| 7 | 59 | Master of business | 25 | Council of association |
| 8 | 36 | Bachelor | 8 | Container shipping manager |

**Table 5** Decision matrix for decision makers

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $C_1$ | E. E. E. E. E. E. E. E | W. W. A. S. S. V. A. S | S. S. A. -W. -S. -V. -V. W | S. S. A. V. V. W. -V. V | V. V. A. E. -W. A. A. V |
| $C_2$ | -W. -W. -A. -S. -S. -V. -A. -S | E. E. E. E. E. E. E. E | S. S. A. -W. -V. -V. -A. W | S. S. A. E. -A. -V. -A. E | V. V. V. -S. -V. A. S. E |
| $C_3$ | -S. -S. -A. W. S. V. V. -W | -S. -S. -A. W. V. V. A. -W | E. E. E. E. E. E. E. E | S. S. A. S. S. E. E. -W | W. W. A. S. -S. S. V. -W |
| $C_4$ | -S. -S. -A. -V. -V. -W. V. -V | -S. -S. -A. E. A. V. A. E | -S. -S. -A. -S. -S. E. E. W | E. E. E. E. E. E. E. E | S. S. A. E. W. E. V. W |
| $C_5$ | -V. -V. -A. E. W. -A. -A. -V | -V. -V. -V. S. V. -A. -S. E | -W. -W. -A. -S. S. -S. -V. W | -S. -S. -A. E. -W. E. -V. -W | E. E. E. E. E. E. E. E |
| $C_6$ | -V. -V. -A. -W. W. -V. -V. -V | -V. -V. -A. W. W. -V. A. E | -V. -V. -A. -S. W. -V. -W. E | -S. -S. -A. W. -W. -W. -S. E | -S. -S. -V. E. S. E. E. E |
| $C_7$ | -S. -S. -S. E. V. E. V. -S | -V. -V. A. W. A. E. A. -W | -V. -V. -A. -W. S. W. A. E | -S. -S. A. W. S. V. -S. E | -V. -V. A. W. W. W. V. E |
| $C_8$ | -S. -S. -S. -S. S. -W. E. -W | -S. -S. -V. E. S. V. A. S | -S. -S. -A. -V. -W. W. -S. -W | -S. -S. -A. E. W. W. -S. -W | -S. -S. -A. E. S. W. V. -W |
| $C_9$ | -S. -S. -A. -V. -S. -S. -A. -S | -W. -W. -A. E. -W. E. E. S | -S. -S. -A. -W. -S. E. -A. -W | -S. -S. -A. E. -S. -W. -A. -W | -S. -S. -A. E. -W. E. -S. -S |

See Table 3 for explanations of the letter codes

**Table 6** Decision matrix for decision makers (*continued*)

| | $C_6$ | $C_7$ | $C_8$ | $C_9$ |
|---|---|---|---|---|
| $C_1$ | V. V. A. W. -W. V. V. V | S. S. S. E. -V. E. -V. S | S. S. S. S. -S. W. E. W | S. S. A. V. S. S. A. S |
| $C_2$ | V. V. A. -W. -W. V. -A. E | V. V. -A. -W. -A. E. -A. W | S. S. V. E. -S. -V. -A. -S | W. W. A. E. W. E. E. -S |
| $C_3$ | V. V. A. S. -W. V. W. E | V. V. A. W. -S. -W. -A. E | S. S. A. V. W. -W. S. W | S. S. A. W. S. E. A. W |
| $C_4$ | S. S. A. -W. W. W. S. E | S. S. -A. -W. -S. -V. S. E | S. S. A. E. -W. -W. S. W | S. S. A. E. S. W. A. W |
| $C_5$ | S. S. V. E. -S. E. E. E | V. V. -A. -W. -W. -W. -V. E | S. S. A. E. -S. -W. -V. W | S. S. A. E. W. E. S. S |
| $C_6$ | E. E. E. E. E. E. E. E | V. V. -A. -S. -S. -W. -S. S | E. E. V. -W. W. -W. E. S | E. E. A. -W. S. E. V. W |
| $C_7$ | -V. -V. A. S. S. W. S. -S | E. E. E. E. E. E. E. E | E. E. V. E. S. -W. V. W | W. W. A. W. V. E. A. S |
| $C_8$ | E. E. -V. W. -W. W. E. -S | E. E. -V. E. -S. W. -V. -W | E. E. E. E. E. E. E. E | S. S. A. -W. W. W. A. S |
| $C_9$ | E. E. -A. W. -S. E. -V. -W | -W. -W. -A. -W. -V. E. -A. -S | -S. -S. -A. W. -W. -W. -A. -S | E. E. E. E. E. E. E. E |

See Table 3 for explanations of the letter codes

**Table 7** Aggregated decision matrix for decision makers

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$ | 0 | 0.181 | 0.500 | 0.250 | 0.188 | 0.194 | 0.458 | 0.354 | 0.153 |
| $C_2$ | 0.819 | 0 | 0.528 | 0.542 | 0.340 | 0.396 | 0.590 | 0.563 | 0.410 |
| $C_3$ | 0.500 | 0.472 | 0 | 0.319 | 0.333 | 0.257 | 0.438 | 0.264 | 0.229 |
| $C_4$ | 0.750 | 0.458 | 0.681 | 0 | 0.278 | 0.313 | 0.563 | 0.354 | 0.229 |
| $C_5$ | 0.813 | 0.660 | 0.667 | 0.722 | 0 | 0.417 | 0.576 | 0.451 | 0.278 |
| $C_6$ | 0.806 | 0.604 | 0.743 | 0.688 | 0.583 | 0 | 0.556 | 0.438 | 0.354 |
| $C_7$ | 0.542 | 0.410 | 0.563 | 0.438 | 0.424 | 0.444 | 0 | 0.368 | 0.229 |
| $C_8$ | 0.646 | 0.438 | 0.736 | 0.646 | 0.549 | 0.563 | 0.632 | 0 | 0.250 |
| $C_9$ | 0.847 | 0.590 | 0.771 | 0.771 | 0.722 | 0.646 | 0.771 | 0.750 | 0 |

## Appendix B

We apply The Moment Integrated Solution (THEMIS) Method using the constructs of Table 2 as input. THEMIS is defined as an MCDM method, inspired by moment in physics that takes pairwise comparisons with equilibrium logic in group decision-making, solving comparisons by building a decision matrix consisting of the pairwise comparisons between constructs (Akan et al. 2020). The method starts with goals such as selection, ranking, and others, and continues with the determination of the constructs' hierarchy structure and alternatives. THEMIS comprises the following steps:

*Step 1:* Defining and decomposing the problem. Expanding the goals of the problem considering all factors, goals, and outcomes.

*Step 2:* Building up the hierarchical construct structure and alternatives for the problem.

*Step 3:* The construction of the $n$ constructs is summarized in a $nxn$ pairwise comparison matrix. $C = \left\{ C_j \middle| j = 1, 2, \ldots, n \right\}$ are then defined, to build the constructs and the $nxn$ decision matrix $A$, including comparisons of the constructs form $C$. $A$, as the decision matrix, is shown in Eq. (1). $k$ denotes the number of decisionmakers.

$$A = \left(a_{ij}^k\right)_{nxn} = \begin{bmatrix} a_{11}^k & a_{12}^k & \ldots & a_{1n}^k \\ a_{21}^k & a_{22}^k & \ldots & a_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1}^k & a_{n2}^k & \ldots & a_{nn}^k \end{bmatrix} = \begin{bmatrix} 0 & a_{12}^k & \ldots & a_{1n}^k \\ 1 - a_{12}^k & 0 & \ldots & a_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ 1 - a_{1n}^k & 1 - a_{2n}^k & \ldots & 0 \end{bmatrix} \tag{1}$$

$$\bar{A} = \left(a_{ij}\right)_{nxn} \tag{2}$$

**Table 8** Numbers for linguistic variables in THEMIS

| Intensity of importance | Definition of linguistic variables | |
|---|---|---|
| 0 | E | Equally important |
| 3 | W | Weakly important |
| 5 | S | Strongly more important |
| 7 | V | Very strongly important |
| 9 | A | Absolutely more important |
| 2, 4, 6, 8 | Intermediate values | |

The pairwise comparison matrix requires the explanation of the rules as follows. Homogeneity, which is the pairwise comparison $A$, is significant only if the constructs are comparable. Building up a hierarchy of goals permits the arrangement of elements in a cluster to compare like with like, and reciprocal $n > 2$, $a_{ij} \neq 0$, $a_{ij} = 0$, $a_{ji} = 1 - a_{ij}$ for $\forall i, j, n \in \text{N}$.

*Step 4:* Pairwise comparisons of the $k^{th}$ decisionmaker are calculated as follows. The factors of the pairwise comparisons matrix are found through Eq. (3).

$$a_{ij} = 1 - \frac{1}{\sum_{i=1}^{k} M_i} \sum_{i=1}^{n} \left( dm_i \frac{l_i - l_{\min}}{l_{\max} - l_{\min}} \right), \tag{3}$$

*where* $a_{ij}$ the value of pairwise comparison, $M_i$ the $i^{th}$ decisionmaker, $dm_i$ the $i^{th}$ decisionmaker's opinion on a scale of linguistic variables, $l_i$ the $i^{th}$ value on a scale of linguistic variables, $l_{min}$ the minimum value on a scale of linguistic variables, $l_{max}$ the maximum value on scale of linguistic variables.

The linguistic variables are shown in Table 8. THEMIS is used to aggregate decisionmakers' judgements.

*Step 5:* Eq. (4) is applied for each ($i^{th}$) row of the comparison matrix. The weights for each criterion $m_i$ of each row of $A = [a_{ij}]$ are computed in Eq. (4) as follows.

$$m_i = \frac{1}{n} \sum_{i=1}^{n} a_{ij}^2, \quad i = (1, 2, ..., n) \text{ and } i, n > 0 \ \forall i, n \in \mathbb{N} \tag{4}$$

*where* $m_i$ the value of the $i^{th}$ row, $a_{ij}$ the value of the pairwise comparison, $w_i$ the weight of the $i^{th}$ pairwise comparison construct (in interval [0,1]), $l_i$ the minimum distance to zero in interval [0,1] for weight of $i^{th}$ pairwise comparison criteria.

*Step 6:* The weights of constructs are normalized. The weight of the $i^{th}$ criterion is computed by Eq. (5). Finally, the normalization of the decision matrix and the calculation to acquire the weights of the criteria ($w_1$, $w_2$, ... *and* $w_n$) is carried out.

$$w_k = \frac{m_i}{\sum_{i=1}^{n} m_i}, \quad k = (1, 2, ..., k), \quad i = (1, 2, ..., n) \text{ and } i, k > 0 \ \ \forall i, k \in \mathbb{N} \tag{5}$$

**Abbreviations**

| | |
|---|---|
| AFIR | Alternative fuels ınfrastructure regulation |
| AHP | Analytic hierarchy process |
| AZEC | Asian zero emission community |
| BAA | Broad agency announcement |
| CBAM | Carbon border adjustment mechanism |
| CII | Carbon ıntensity ındex |
| CRP | Carbon reduction program |
| EBRD | European bank for reconstruction and development |
| ECA | Emission control area |
| EEA | European economic area |
| EEDI | Energy efficiency design ındex |
| EEOI | Energy efficiency operational ındex |
| EEXI | Energy efficiency existing ship ındex |
| EGDIP | European green deal ınvestment plan |
| ESI | Environmental ship ındex |
| ETD | Energy taxation directive |

| | |
|---|---|
| ETS | Emissions trading system |
| EU | European union |
| GBM | Goal based measures |
| GHG | Greenhouse gas emissions |
| GO | Guarantees of origin |
| IAPH | International association of ports and harbors |
| IMO | International maritime organization |
| IMRF | International maritime research fund |
| LNG | Liquified natural gas |
| MCDM | Multiple criteria decision making |
| MEPC | Marine environment protection committee (IMO) |
| META | Maritime environmental and technical assistance program |
| NGEU | NextGenerationEU |
| OPS | Onshore power supply |
| PIDP | Port ınfrastructure development program |
| RED | Renewable energy directive |
| SECA | Sulfur emission control area |
| SEIP | Sustainable Europe ınvestment plan |
| TCS | Turkish chamber of shipping |
| TEN-T | Trans-European network-transport |
| THEMIS | The moment ıntegrated solution |
| TURKLIM | Turkish port operators association |

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**Ethics approval and consent to participate**
The preparation of this paper did not involve any animals, humans, human data, human tissue or plants.

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The authors declare that they have no competing interests.

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