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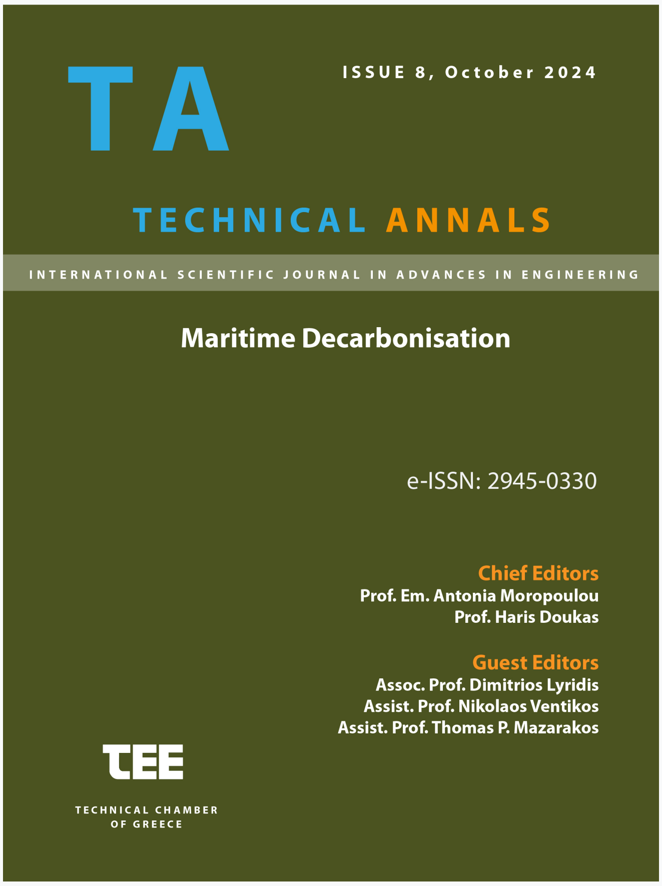

EU Emissions Trading System (ETS): Towards zero carbon maritime transportation and Green Ports

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EU Emissions Trading System (ETS): Towards zero carbon maritime transportation and Green Ports

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Abstract. The European Union Emissions Trading System (EU ETS) is a cornerstone of EU climate policy, aiming to reduce greenhouse gas emissions from various sectors. This article examines the EU ETS with a focus on its potential application to maritime transport.
It will analyze the EU "cap and trade" principle, discussing its effectiveness in reducing emissions across covered sectors. The case study of Greece demonstrates the challenges faced by Member States in implementing the EU ETS, particularly in the maritime sector.
This analysis reveals that while the EU ETS has shown significant emission reductions potential, challenges remain in maintaining market stability and optimizing allocation mechanisms. Future reforms aim to expand coverage, including shipping emissions, increase ambition, and potentially incorporate carbon removals.
This article's aim is to contribute to the ongoing debate on climate policy effectiveness by providing a comprehensive review of the EU ETS regulatory conditions and their implications for emission reductions efforts in the maritime sector.

Keywords: EU ETS, Green Shipping, Green ports

1 Introduction

Climate change mitigation remains one of the most pressing global challenges. The European Union has established various policies to address this issue, with the European Union Emissions Trading System (EU ETS) being one of its cornerstone measures.

The EU ETS was launched in 2005 and has since become the largest cap-and-trade system globally, covering approximately 45% of the EU's greenhouse gas emissions [1]. Its primary objective is to reduce emissions from sectors, such as power generation, manufacturing, civil aviation, and certain industrial processes through market-based mechanisms.

Businesses subject to the EU ETS are required to purchase emission allowances, each corresponding to one unit of CO_2 emissions per ton. The annual reduction of the emissions cap gradually creates a stricter framework, aiming to enhance emissions reductions and achieve climate neutrality by 2050 [2].

The system applies the "cap-and-trade" principle, setting a cap on the emissions that participating installations can produce. This cap decreases annually, gradually increasing the cost of emissions and encouraging businesses to adopt decarbonization solutions. For instance, the annual reduction of the emissions cap by approximately 2.2% strengthens emission reductions to levels required to meet the EU’s intermediate targets, namely a 55% reduction by 2030, and ultimately achieve climate neutrality by 2050 [3].

The EU ETS also addresses the phenomenon of "carbon leakage," which involves the transfer of production to third countries with lower environmental standards to avoid emission costs. The system includes the progressive reduction of free emission allowances and incorporates the Carbon Border Adjustment Mechanism (CBAM). CBAM introduces carbon pricing on certain imported goods, ensuring a level playing field between European and third-country businesses and reinforcing the commitment to climate neutrality within the EU.

This system operates under the authority of the European Commission, and its implementation is overseen by Member State governments. The EU ETS has undergone several phases of expansion and reform since its inception, with Phase III running from 2013 to 2020 [1]. The EU ETS has been extended by the Directive (EU) 2023/959 of 10 May 2023 to maritime transport emissions from all large ships entering EU ports, regardless of the flag they fly, since 1 January 2024, it covers: Carbon dioxide (CO_2), Methane (CH4) as of 2026, and Nitrous oxide (N_20) as of 2026.

The EU has adopted the list of shipping companies and their attributed Member State by 1 February 2024. ETS applies to cargo and passenger ships of or above 5000 gross tonnage (GT) since 2024 and offshore ships of or above 5000 GT from 2027.

The system covers 50% of emissions from voyages starting or ending outside of the EU (allowing the third country to decide on appropriate action for the remaining share of emissions) and 100% of emissions that occur between two EU ports and when ships are within EU ports.

Emissions resulting from the combustion of sustainable biomass, compliant with the sustainability criteria established by the Renewable Energy Directive, have a CO2 emission factor of zero under the ETS.

According to the EU ETS, shipping companies must surrender (use) their first ETS allowances by 30 September 2025 for emissions reported in 2024.

The share of emissions that must be covered by allowances gradually increases each year starting from 2024. Every year, companies must submit an emissions report for each of the ships under their responsibility and an emissions report at company level (aggregating the ship data to be reported for ETS purposes) and also they have to comply with the MRV (Monitoring, Reporting, and Verification) EU system for emissions, as seen in Figure 1.

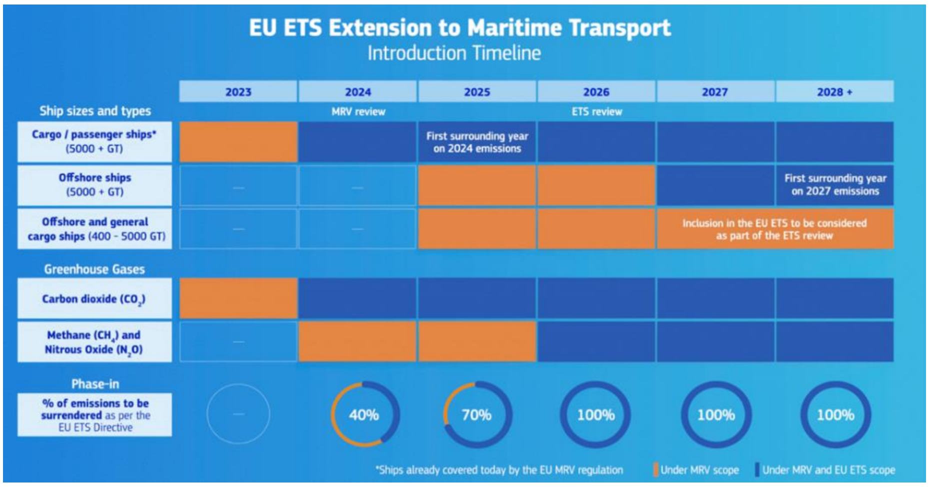

Fig. 1. EU ETS Extension to Maritime Transport [4]

Shipping companies that fail to surrender allowances are liable to an excess emissions penalty of EUR 100 (corrected for inflation) per tonne of CO2 equivalent, and are still liable for the surrender of the required allowances. The names of the penalized companies will be disclosed to the public [5].

In case a shipping company has failed to comply with surrendering its obligations for two or more consecutive reporting periods, and where other enforcement measures have failed to ensure compliance, the concerned EU Member State is required to refuse entry to the ships under the responsibility of the shipping company concerned into any of its ports, until the company fulfils its surrendering obligations [6].

The European Commission will ensure consistency in the way biomass and renewable fuels of non-biological origin (RFNBOs) which includes fuels like renewable hydrogen produced via electrolysis using renewable electricity, and synthetic hydrocarbons such as e-methanol and e-diesel [7] as well as recycled carbon fuels (RCFs) such as carbon captured from industrial emissions or derived from recycled plastics that is converted into synthetic fuels are treated under the different ETS sectors [8].

Emissions resulting from the combustion of sustainable biomass, compliant with the sustainability criteria established by Article 29 of the Renewable Energy Directive (Directive (EU) 2018/2001) [9], have a CO2 emission factor of zero under the ETS.

Within the EU Emissions Trading System (EU ETS), emissions resulting from the burning of specific renewable fuels, particularly Renewable Fuels of Non-Biological Origin (RFNBOs) and Recycled Carbon Fuels (RCFs), may receive a CO_2 emission factor of zero, a method referred to as "zero-rating." In order to be eligible for this zero-rating, these fuels need to comply with particular sustainability and greenhouse gas (GHG) emissions reduction standards stated in the Renewable Energy Directive (RED II). According to this standards RFNBOs and RCFs are required to achieve at least 70% GHG emissions reductions compared to their fossil fuel counterparts over their entire life cycle. This indicates that during their production and use, these fuels must release at least 70% fewer GHGs than conventional fossil fuels [10].

For RFNBOs created with renewable electricity, this electricity needs to be both renewable and "additional." This indicates that the renewable energy utilized must originate from newly established installations that did not exist before, guaranteeing that the creation of RFNBOs does not repurpose existing renewable energy for different applications [11].

RCFs, sourced from waste streams of non-renewable nature, are required to comply with sustainability standards established in the RED II. This entails verifying that the waste materials utilized are inappropriate for material recovery and that their application does not result in adverse environmental effects [12].

It is crucial to understand that the zero-rating is applicable solely if these strict criteria are fulfilled. Should the fuels fail to meet compliance, their emissions are regarded in the same way as those from fossil fuels within the EU ETS [13].

These initiatives seek to encourage the utilization of genuinely sustainable alternative fuels, guaranteeing substantial reduction in GHG emissions and aiding the EU's larger climate objectives.

The regulatory framework of the EU ETS is complex and multifaceted. It includes provisions related to coverage, allocation methods, monitoring and reporting requirements, and key sector specific rules. Understanding these regulatory conditions is crucial for assessing the system's effectiveness and identifying areas for improvement. The negative impact of the implementation of the EU ETS in shipping is that purchasing allowances adds operational costs and the positive one is the incentive for Clean Technologies as the ETS encourages adoption of low-carbon solutions like LNG, electric vessels (such us Yara Birkeland: This Norwegian container ship is one of the world's first fully electric and autonomous cargo vessels. Equipped with a 7 MWh battery powered by hydroelectric energy, it can carry approximately 120 and aims to eliminate the need for 40,000 diesel truck journeys annually [14] and in Netherlands the Alphenaar, an electric inland shipping vessel utilizing swappable battery packs that allows for continuous operation with minimal downtime, as depleted batteries can be quickly replaced with charged ones [15]) and energy efficiency measures such as Air Lubrication Systems [16] that enhance fuel efficiency by generating a layer of air bubbles that lessens the friction between the ship's hull and the water, Wind-Driven Assistance [17] that contemporary sail innovations, like rigid sails or kites, can capture wind energy to enhance engine power, thus lowering fuel usage and Ship Energy Efficiency Management Plan (SEEMP) [18] that creates a framework for enhancing ship's energy efficiency in a financially viable way.

On spring of 2025 the International Maritime Organization (IOM) will adopt a new regulation for cutting GHG emissions from ships according to its new net-zero framework.

This article aims to provide a comprehensive overview of the EU ETS regulatory framework, focusing on its progressive application to maritime transport. We will examine the system's design principles, implementation mechanisms, and ongoing efforts to enhance its impact, particularly in the shipping sector.

2 Analysis of Greece's Implementation of the EU Emissions Trading System (ETS)

2.1 Overview of Greece's Participation in the EU ETS

Greece, as an EU member state is bound by the EU ETS, which is a cornerstone of the EU's climate policy, aiming to reduce greenhouse gas emissions (GHG) from various sectors, including energy-intensive industries, and aviation. 2024 is the first year of application of the EU ETS to the maritime transport.

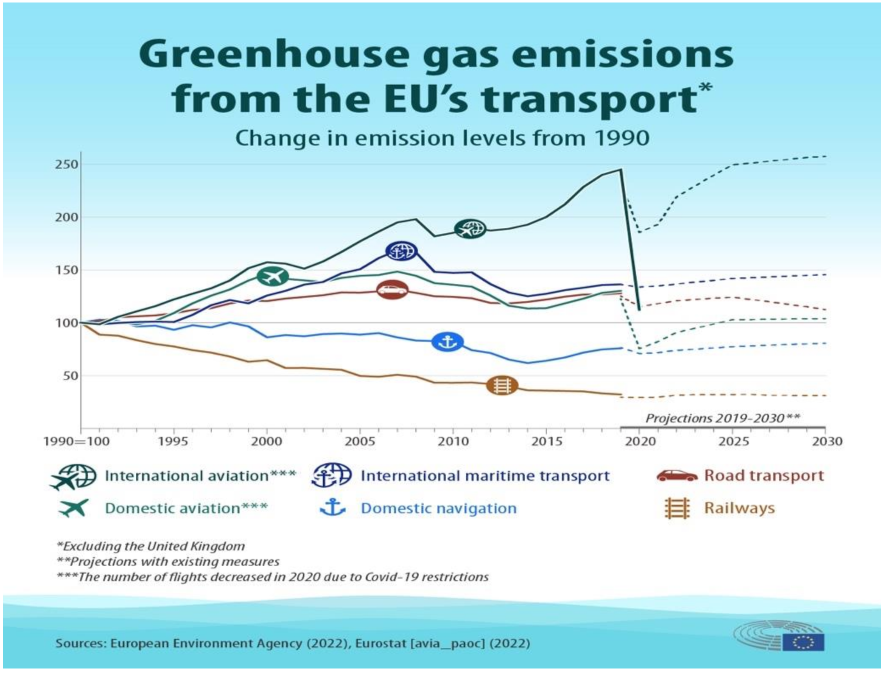

Fig. 2. This report provides comprehensive data on CO_2 emissions from both aviation and shipping sectors. It includes projections and historical data up to 2023, offering insights into emission trends and future scenarios. [19]

2.2 Challenges in Implementing the EU ETS in Greece

Although Greece is involved in the European Union Emissions Trading System (EU ETS), it encounters numerous challenges in efficiently executing and overseeing the system. These difficulties arise from economic, administrative, and financial limitations, along with worries regarding the competitiveness of essential sectors.

Economic Crisis Impact

The extended economic turmoil in Greece has significantly impacted the nation's regulatory system and environmental strategies. The economic decline, combined with austerity policies, has decreased investment in green initiatives from both the public and private sectors. Financial limitations have resulted in reduced enforcement of environmental regulations, particularly those linked to the EU ETS.

Studies indicate that in times of economic uncertainty, adherence to emissions trading rules often decreases, as businesses and governments focus on immediate financial survival rather than sustained environmental obligations [20]. Moreover, Greece's dependence on fossil fuel sectors has rendered the shift to low-carbon energy sources slower and more difficult [21].

Administrative Burden

The integration of the shipping industry into the EU ETS has imposed considerable administrative challenges on Greek shipping firms. Considering that Greece possesses one of the world's largest shipping sectors, with a significant share of its fleet managed by small and medium-sized enterprises (SMEs), adherence to EU ETS regulations necessitates comprehensive documentation, emissions tracking, and reporting [22].

This heightened bureaucracy raises operational expenses and presents difficulties for smaller companies that do not have the required resources to handle compliance efficiently. The European Commission has recognized these challenges, stating that high administrative expenses can impede effective execution [23].

Financial Implications

Adhering to the EU ETS poses significant financial difficulties for Greek companies, particularly within the maritime industry. The need to buy emission allowances has raised operating expenses, which could, in turn, be transferred to consumers via increased shipping fees [24].

A report from the International Maritime Organization (IMO) indicates that shipping in Greece may experience a general rise in expenses, especially for routes that depend significantly on fossil fuels [25]. Moreover, small and medium-sized shipping companies, which are the cornerstone of the Greek maritime industry, frequently face challenges with liquidity and capital access, making adherence to the EU ETS an extra financial burden [21].

Competitiveness Concerns

The inclusion of the shipping sector in the EU ETS has raised worries regarding the competitiveness of Greek shipping firms, both on a national and global scale. Greek companies vie with non-EU shipping firms that are not bound by the same emissions rules, which could put them at a disadvantage [26].

This concern has been highlighted by industry advocates and legislators, who claim that companies in the EU might forfeit market share to rivals with more lenient environmental regulations [27]. Furthermore, increased operating expenses might prompt certain Greek companies to think about registering their ships in non-EU nations to sidestep compliance requirements, which could weaken the efficacy of the EU ETS [22].

The effective execution of the EU ETS in Greece encounters major obstacles, such as economic instability, bureaucratic challenges, financial limitations, and competitive tensions. Although the system seeks to lower carbon emissions and encourage sustainability, its success hinges on Greece's capacity to tackle these issues via specific policy initiatives, financial assistance for impacted sectors, and efficient administrative procedures.

2.3 Impact on Greek Shipping Industry

The incorporation of the shipping industry into the European Union Emissions Trading System (EU ETS) has significantly impacted Greece's maritime sector. Given that the nation maintains one of the largest merchant fleets globally, the regulatory modifications affect not just major companies but also the numerous small and medium-sized enterprises (SMEs) that are fundamental to Greek shipping. A number of significant obstacles have arisen:

Liability Distribution

A major issue in implementing the EU ETS in shipping is the equitable distribution of responsibility for Emission Allowances (EU-As). Historically, shipowners have shouldered operational expenses, but the EU ETS adds new challenges, since fuel usage and emissions are primarily influenced by operational choices made by charterers [28]. This has resulted in the necessity for updated contractual agreements that specify cost-sharing methods. To tackle these issues, the Baltic and International Maritime Council (BIMCO) launched the ETS-Emissions Trading Scheme Allowances Clause for Time Charterparties [29]. This provision outlines how the expenses of compliance ought to be allocated between shipowners and charterers, promoting transparency and avoiding contract disputes. Nevertheless, certain industry participants contend that additional adjustments are necessary to cater to various shipping models, including tramp shipping, where operational control frequently changes hands between parties [30].

Charter Party Considerations

The incorporation of shipping into the EU ETS has greatly influenced charter party agreements. Charterers are now more frequently expected to consider vessel emissions in their commercial and operational assessments [31]. Specifically, time charter contracts need to clearly outline which party is accountable for buying EUAs and the process for emissions reporting. This has resulted in higher legal and administrative expenses, especially for Greek shipping firms competing in global markets [32]. Moreover, considering emissions as a factor in charter negotiations affects the freight market. Vessels that produce lower emissions intensity might appeal more to charterers, potentially putting older Greek ships at a disadvantage if they do not comply with strict efficiency standards yet [33]. This change puts pressure on Greek shipowners to invest in more environmentally friendly technologies, like LNG-powered ships or carbon capture systems, which necessitate substantial financial investment [34].

SME Vulnerability

Small and medium enterprises (SMEs), representing a substantial segment of the Greek maritime sector, encounter specific challenges in adjusting to the EU ETS. In contrast to bigger shipping companies, SMEs frequently do not possess the financial and administrative capabilities needed to establish intricate monitoring, reporting, and verification (MRV) systems [35]. The obligation to comply, encompassing the acquisition of allowances, monitoring emissions, and revising operational processes, is becoming a considerable financial burden for smaller operators [36]. Moreover, SMEs might face difficulties in negotiating equitable charter party terms, since larger charterers or shipowners could possess more power to transfer expenses. This may result in diminished profitability or potentially exiting the market for certain smaller Greek shipping companies, especially those working in fiercely competitive shortsea shipping routes [37]. The European Community Shipowners' Associations (ECSA) has cautioned that, in the absence of specific financial aid or exemptions, smaller maritime businesses may be unfairly affected by the new regulations [38].

The inclusion of shipping in the EU ETS poses major challenges for the Greek maritime sector, especially regarding liability allocation, contractual intricacies, and the resilience of SMEs. Although regulatory frameworks like BIMCO's charter party clauses offer some guidance, additional improvements are necessary to guarantee equitable burden sharing. Moreover, policymakers ought to explore financial aid programs or gradual implementation plans to assist Greek SMEs in shifting towards a low carbon shipping industry. In the absence of these measures, Greek shipping firms -particularly smaller ones- could struggle to remain competitive amid the changing regulatory environment.

2.4 Future Outlook and Technological Impact

As the EU continues to refine its climate policies, including the EU ETS, Greece faces ongoing challenges:

I. Technological Innovation:

Encouraging investment in cleaner technologies and alternative fuels may become crucial for maintaining competitiveness in the maritime sector [38]. Technological innovation plays a crucial role in the Greek maritime industry's adaptation to the EU ETS and its quest for sustainability, considering that Greek Maritime lies among the top worldwide. Shipowners should focus on alternative strategic technologies to maintain competitiveness and comply with emerging regulations. Several cutting-edge technologies emerge as promising solutions for enhancing efficiency and sustainability in maritime operations.

II. Alternative Fuels and Energy-Efficient Propulsion Systems:

a. The transition towards cleaner (green) fuels is indeed gaining momentum in the maritime sector [39]
b. Hydrogen fuel cells and ammonia-based propulsion systems show great promise for reducing greenhouse gas emissions [39]
c. These alternative fuels offer significant advantages over traditional fossil fuels, potentially reducing emissions by up to 90% compared to conventional diesel engines [39]
d. However, hydrogen has very low energy density, requiring large storage volumes, which may prevent its use in international deep-sea shipping [39].
e. Other promising alternative fuels include LNG, LPG, methanol, and biofuels [39]

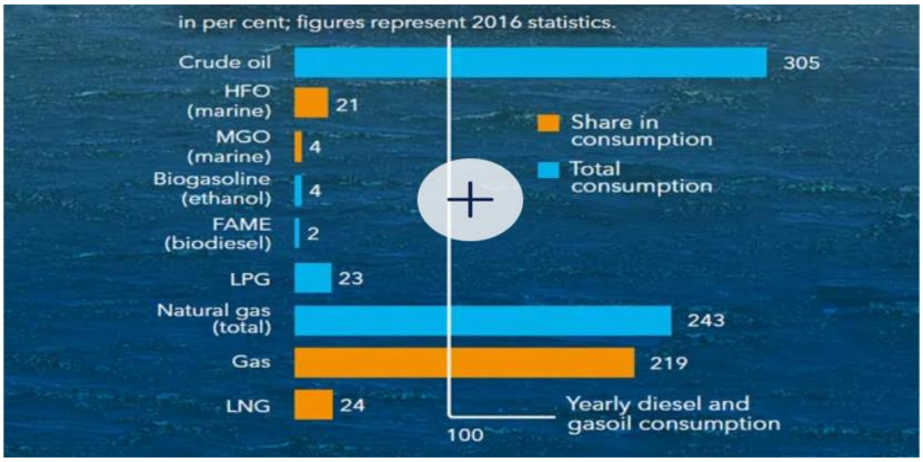

Fig. 2. Yearly Energy Consumption in Relation to Diesel and Gasoil Consumption [9]

III. Digital Twin Technology:

While not explicitly mentioned in the search results, digital twin technology is a recognized advancement in the maritime industry for simulating vessel operations and predicting maintenance needs [39].

IV. Smart Shipping Infrastructure:

a. The concept of smart shipping infrastructure is supported by the Joint Research Centre's publication on "Artificial Intelligence for Maritime Safety and Efficiency" [40].
b. This includes the creation of intelligent (green) ports and terminals equipped with AI-driven systems for efficient cargo handling and processing [40].

V. Autonomous and Semi-Autonomous Vessels:

a. Fully autonomous ships are still in development, but semi-autonomous systems are already being implemented in various aspects of maritime operations [39].
b. These systems can assist human operators in navigating challenging conditions and optimizing routes for better fuel efficiency [39].

VI. Advanced Materials and Lightweight Structures:

While not explicitly mentioned in the search results, advancements in materials science are leading to the development of lighter, stronger materials for shipbuilding [39].

VII. Carbon Capture and Utilization:

This technology is not specifically addressed in the search results provided, so further research would be needed to validate its feasibility and effectiveness in the maritime sector.

It's important to note that while these technologies show promise, their implementation faces various challenges, including regulatory hurdles, cost considerations, and the need for significant investment in research and development. The maritime industry is rapidly evolving, and the success of these technologies will depend on continued innovation and collaboration between industry leaders, researchers, and regulatory bodies.

By embracing these technological innovations, Greek shipowners can not only comply with stringent regulations but also enhance operational efficiency, reduce costs, and contribute to a more sustainable maritime sector. However, it's essential to note that while technology offers significant benefits, human expertise remains vital in the complex world of maritime operations.

The successful integration of these technologies into Greek maritime operations will require careful planning, significant investment in research and development, and a willingness to adapt business models. As the maritime industry continues to evolve, Greek shipping companies that embrace these technological advancements will be well-positioned to compete in an increasingly regulated and environmentally conscious global market.

VIII. Hydrodynamic Improvements for Energy Efficiency

Hydrodynamic improvements play a crucial role in decreasing fuel usage and minimizing emissions in maritime transport, in line with the EU ETS and IMO decarbonization objectives [40].

Hull Optimization: Utilizing advanced computational fluid dynamics (CFD) and biomimetic coatings decreases drag resistance, enhancing efficiency by up to 10% [41].

Energy-Saving Devices (ESDs): Fins, ducts, and pre-swirl stators improve propulsion efficiency by 5-8%, providing affordable retrofitting solutions [42].

Wind-Assisted Propulsion: Rotor sails, wing sails, and kite propulsion reduce engine load, achieving up to 30% fuel savings on suitable routes [43].

Air Lubrication Technology (ALT): Air cavity systems lower hull friction, enhancing fuel efficiency by 10-15% [44].

Economic & Compliance Advantages: These advancements lower EU ETS compliance expenses, improve operational efficiency, and promote long-term sustainability [45].

With the rise of carbon pricing, it is vital for ship-ping firms to invest in hydrodynamic enhancements to stay competitive and meet emissions regulations [46].

2.5 International Cooperation

As the EU continues to refine its climate policies, including the EU ETS, Greece faces ongoing challenges Collaboration between EU member states and non-EU countries will become increasingly important as global shipping regulations evolve. This cooperation is crucial for several reasons:

a. Harmonization of standards: International cooperation can lead to the development of consistent regulations across different jurisdictions, reducing confusion and compliance costs for shipping companies operating globally [47]. The International Maritime Organization (IMO) has been working alongside the EU to align carbon reduction targets with global frameworks, ensuring that regulations such as the EU ETS do not conflict with international maritime laws [48].

b. Knowledge sharing: Countries can exchange best practices and technological innovations in addressing common challenges in maritime regulation [49]. For instance, the European Maritime Safety Agency (EMSA) collaborates with international bodies to promote digitalization in emissions monitoring, which enhances transparency and efficiency in compliance procedures[4]. Greece has actively participated in forums organized by EMSA to adapt global best practices to the specific needs of its shipping sector [50].
c. Addressing global challenges: Issues like climate change and pollution affect both EU and non-EU countries. Collaborative efforts can lead to more effective solutions to these global problems [51]. The United Nations Framework Convention on Climate Change (UNFCCC) has emphasized the need for multilateral agreements in shipping emissions reductions to prevent regulatory fragmentation [52]. Additionally, the International Chamber of Shipping (ICS) has been advocating for a market-based approach to carbon pricing that aligns with both EU and global maritime policies [53].
d. Trade facilitation: Consistent regulations across borders can streamline international trade, benefiting both EU and non-EU economies [54]. The World Trade Organization (WTO) has acknowledged that fragmented environmental regulations could create trade barriers, emphasizing the need for harmonized policies [55]. For Greece, whose shipping sector heavily depends on international trade, regulatory consistency is essential for maintaining competitiveness [56].
e. Enforcement coordination: International cooperation can strengthen enforcement mechanisms, making it harder for companies to exploit loopholes in different jurisdictions [57]. The European Commission and the IMO have been working on mechanisms to ensure that vessels switching between EU and non-EU jurisdictions are held to the same emissions standards [58]. In addition, Greece has participated in regional enforcement initiatives, such as the Mediterranean Emissions Control Area (ECA), which aims to improve emissions monitoring and compliance verification [59].

2.6 Adaptation Strategies

As the EU continues Greek authorities will need to develop effective strategies to help SMEs adapt to the new regulatory environment while minimizing economic impacts. Some key strategies could include [48]:

a. Gradual implementation: Introduce new regulations gradually, giving SMEs time to adjust their operations and invest in necessary technologies [60]. A phased approach to emissions trading schemes has been recommended by industry experts to allow businesses, particularly in the maritime sector, to transition smoothly without excessive financial burden [61].
b. Training programs: Offer workshops, online courses, and consulting services to educate SMEs about the new regulations and compliance methods [62].
c. Financial incentives: Provide subsidies or tax breaks to encourage SMEs to invest in compliance-related technologies and processes [63]. The European

Commission has proposed using part of the revenues generated from EUA auctions to support maritime decarbonization initiatives [64]. Greece could leverage EU funding mechanisms, such as the Innovation Fund, to assist SMEs in making necessary technological upgrades [65].

d. Regulatory flexibility: Allow for temporary exemptions or simplified compliance procedures for smaller companies facing particular challenges [66].
e. Industry-specific guidance: Develop tailored guidelines for different segments of the maritime industry, recognizing that SMEs in different sectors may face unique challenges [67]. The International Maritime Organization (IMO) has emphasized the importance of sector-specific adaptation strategies to ensure that regulations account for operational realities [68].
f. Partnerships and collaborations: Facilitate partnerships between larger companies and SMEs to share resources and knowledge in complying with regulations [69]. Such cooperative models have been successful in other industries, where large corporations mentor SMEs in adopting best practices [70]. The Hellenic Chamber of Shipping has also promoted cross-sector collaboration to enhance compliance capabilities [71].
g. Delegation of responsibilities: Encourage shipowners to delegate EU ETS responsibility to the Document of Compliance (DOC) holder, typically the technical manager, who already handles MRV reporting. This can simplify compliance and leverage existing expertise within the organization [72].
h. Pragmatic approach to EUA acquisition: Advise against speculative buying of EUAs due to market volatility. Instead, recommend buying as needed based on operational requirements rather than market movements [73].
i. Simplified contractual structures: Suggest making settlements in EUAs rather than cash to eliminate market price volatility risks. Also, recommend keeping EU ETS terms in charter parties clear and simple [74].
j. Data management focus: Emphasize the critical importance of effective data management to avoid non-compliance and financial penalties. Ensure digital compatibility, including comprehensive APIs and detailed voyage/time-based analytics [75].
k. Selecting appropriate data partners: Stress the need to select data providers that understand the nuances between EU ETS rules and MRV frameworks, while also having advanced digital capabilities [76].

2.7 Data Management Solutions

The development and adoption of digital solutions for EU ETS compliance, may become increasingly important for Greek shipping companies. These solutions offer several benefits [48]:

a. Automation of complex processes: Digital tools can streamline tasks like tracking, accounting, and allocating EUAs, reducing human error and saving time [77].
b. Standardization: These systems ensure consistent data handling across different companies and vessels, facilitating easier audits and comparisons [78].

c. Real-time monitoring: Advanced digital platforms allow for continuous tracking of emissions and EUA holdings, enabling prompt action when needed [79].
d. Compliance management: Integrated systems can handle multiple regulatory requirements simultaneously, ensuring comprehensive coverage of all necessary aspects of EU ETS compliance [80].
e. Cost reduction: By automating many processes, these solutions can help reduce operational costs associated with manual record-keeping and reporting [81].
f. Improved transparency: Digital platforms provide clear insights into company performance, making it easier to demonstrate compliance to authorities and stakeholders [82].
g. Scalability: As regulations evolve, digital solutions can more easily accommodate changes and new requirements compared to manual systems [83].
h. Data analytics: Advanced tools can provide valuable insights on emission patterns, helping companies identify areas for improvement in their operations [84].

By embracing these data management solutions and implementing effective adaptation strategies, Greek shipping companies can better navigate the complexities of EU ETS compliance while positioning themselves for future regulatory challenges in the maritime sector. International cooperation will also play a crucial role in shaping global standards and addressing shared environmental concerns.

2.8 Impact of Shore Connection on EU ETS

Shore connection technology, which allows ships to connect to onshore power while docked, has profound implications for the EU ETS in the shipping sector. This innovative approach to reducing emissions during port stays is poised to significantly alter the landscape of maritime emissions control and compliance [85].

a. Reduced Emissions:

When ships connect to shore power, they can avoid using their onboard generators, resulting in a dramatic decrease in CO2 emissions during port stays. This reduction in emissions directly impacts the amount of allowances a ship needs to surrender under the EU ETS system, potentially lowering compliance costs for shipping companies [86].

b. Compliance Cost Reduction:

By reducing emissions during port stays, shipping companies can lower their overall compliance costs under the EU ETS. This is particularly beneficial as the cap on allowances is reduced over time, increasing the value of each allowance. The cost savings from reduced emissions can be reinvested in more efficient technologies or sustainable practices, creating a virtuous cycle of environmental improvement and economic benefit [87].

c. Carbon Neutrality Goals:

Shore connection technology aligns perfectly with the EU's ambitious goal of achieving carbon neutrality by 2050.It provides a tangible, immediate solution for shipping companies to reduce their carbon footprint and contribute to climate objectives. The visible reduction in emissions during port stays can serve as a powerful demonstration of the effectiveness of shore connection technology, potentially accelerating its adoption across the industry [88].

d. *Regulatory Alignment:*

The inclusion of maritime emissions in the EU ETS since January 2024 creates a direct link between shore connection usage and compliance. Shipping companies that implement shore connection technology may find it easier to meet EU ETS requirements, potentially simplifying their compliance processes. This alignment of technology with regulation encourages a culture of compliance and sustainability within the shipping industry [89].

e. *Market Incentives:*

The inclusion of maritime emissions in the overall ETS cap creates market incentives for energy efficiency and low-carbon solutions. This includes the use of shore connection technology during port stays, potentially driving innovation in this area. Companies that invest in shore connection technology may gain a competitive advantage in the form of lower compliance costs and improved public perception [90].

f. *Phased Implementation:*

The initial phase-in period (2025-2027) allows shipping companies time to adapt and implement technologies like shore connection before full compliance. This gradual approach helps mitigate potential disruptions to the shipping industry while encouraging long-term sustainability. It also provides an opportunity for companies to assess the economic viability of shore connection technology and plan for wider implementation [91].

g. *Reporting and Verification:*

Shipping companies will need to report emissions from both voyages and port stays under the revised MRV Maritime Regulation.This increased transparency can help identify opportunities for further emission reductions through shore connection. Advanced digital platforms for shore connection can seamlessly integrate with reporting systems, streamlining the process and reducing errors [92].

h. *Infrastructure Development:*

As shore connection becomes more prevalent, there may be pressure to develop more widespread shore connection infrastructure at ports across Europe. This could lead to significant investments in green infrastructure, creating jobs and stimulating local economies. The development of shore connection facilities might also drive innovation in renewable energy technologies, potentially benefiting other industries beyond shipping [93].

i. *Cost-Benefit Analysis:*

Shipping companies will need to conduct thorough cost-benefit analyses to determine when shore connection technology becomes economically viable compared to traditional power generation. Factors influencing this decision will include the frequency of port calls, the size of the ship, and the cost of shore connection facilities versus the savings from reduced emissions. As the technology improves and economies of scale are achieved, the cost-benefit ratio is likely to shift in favor of shore connection [94].

j. *Industry-wide Impact:*

The success of shore connection technology in reducing emissions could set a precedent for other sectors within the EU ETS. It may inspire similar approaches in other industries, potentially leading to a broader transformation in how we manage and reduce emissions across various sectors of the economy. The shipping industry's experience with shore connection could inform policy decisions and technological innovations in other areas of environmental regulation [95].

k. *Job Creation and Skills Development:*

The increased demand for shore connection technology could lead to job creation in manufacturing, installation, and maintenance of these systems. There may be a need for specialized training programs to equip workers with the skills required to install, operate, and maintain shore connection facilities [96].

l. *Environmental Awareness:*

The visible reduction in emissions during port stays can raise awareness among passengers, crew members, and port workers about the environmental impact of shipping and the importance of sustainable practices in the context of circular economy with the view to reducing the environmental, climate and energy footprint of maritime transport and promote the concept of circular ports. This increased awareness could lead to broader cultural shifts in the shipping industry, encouraging further innovation in sustainable technologies [97].

m. *International Cooperation:*

The success of shore connection technology in reducing emissions could spur international cooperation, as other countries may seek to emulate this approach. This could lead to harmonization of standards across different regions, simplifying compliance for shipping companies operating globally [98].

n. *Research and Development:*

The implementation of shore connection technology may drive further research into more efficient and sustainable power generation systems for ships. This could lead to breakthroughs in battery technology, hybrid systems, or even entirely new concepts for powering marine vessels [99].

o. *Public Perception and Brand Image:*

Shipping companies that adopt shore connection technology may see improvements in their public image and brand reputation, attracting environmentally-conscious customers and investors. This positive publicity could create a competitive advantage in the market, especially for companies operating in environmentally sensitive areas [100].

By embracing shore connection technology, both in marine and Maritime (either in Low Voltage distribution networks or Medium Voltage networks), shipping companies can not only contribute to climate goals but also potentially reduce their compliance costs under the EU ETS. However, the widespread adoption of this technology will depend on factors such as infrastructure availability, cost-effectiveness, and regulatory support. As the industry moves towards a more sustainable future, shore connection technology stands out as a crucial tool in the fight against climate change, offering tangible benefits for both the environment and the bottom line of shipping companies. It goes without saying that shore connection will deploy its full added value only if RES are used to electrically power the ships while at port.

3 Conclusions

The implementation of the EU ETS in Greece reveals considerable challenges and prospects, especially for the nation's crucial maritime industry. The economic downturn, regulatory challenges, and financial consequences have hindered effective implementation, while the extension of the EU ETS to shipping has heightened worries about competitiveness, particularly for small and medium-sized enterprises (SMEs).

The integration of shipping into the EU ETS has fundamentally transformed the Greek maritime scene. Concerns regarding the distribution of emission permits and the inclusion of environmental adherence in charter party contracts highlight the increasing significance of sustainability in both operational and commercial decision-making. SMEs, being crucial contributors to Greek shipping, are significantly impacted because of their restricted resources, highlighting the necessity for customized support systems.

Technological advancement stands out as a key element for adaptation and progress within the EU ETS framework. Progress in alternative fuels, energy-efficient propulsion systems, digital twin technology, smart shipping infrastructure, and autonomous ships offers exciting opportunities for improving efficiency and sustainability. Nonetheless, the effective implementation of these solutions necessitates addressing substantial challenges, such as elevated investment expenses, regulatory obstacles, and the requirement for cooperation among industry participants.

Through strategic investments in cleaner technologies and innovative methods, Greek shipowners can not only adhere to changing regulations but also gain a competitive edge in the international marketplace. The shift towards more sustainable operations should involve strong research and development efforts, thorough business strategies, and a thoughtful incorporation of human skills in tandem with technological progress.

The progressive implementation of the EU ETS emphasizes a complex challenge for Greece, particularly in the maritime industry, while also reinforcing the significance of innovation, global cooperation, and strategic adjustments. Greece's maritime sector, heavily impacted by regulatory growth, experiences considerable pressure to align operations with environmental compliance requirements, while preserving competitiveness, especially for small and medium-sized enterprises (SMEs).

Global collaboration stands out as a fundamental element in tackling these issues. Through the promotion of unified standards, the encouragement of knowledge sharing, and the coordination of enforcement actions, collaboration between EU and non-EU nations can simplify compliance challenges and enhance trade, while tackling worldwide environmental issues. These collaborations can establish steady frameworks that serve the interests of all parties involved in the shipping sector.

Strategies for adaptation are equally important. Phased regulatory rollout, specific financial incentives, and customized training initiatives for SMEs can alleviate the economic effects of the EU ETS while promoting adherence. Encouraging the adoption of digital tools for tracking emissions and managing data boosts transparency and lowers operational expenses, allowing businesses to efficiently meet changing regulatory requirements.

Technological innovations, such as the implementation of shore connection systems, are crucial instruments for attaining compliance and lowering emissions. These systems not only reduce carbon emissions while at ports, but also support wider EU goals for achieving carbon neutrality. The incorporation of these technologies relies significantly on the advancement of infrastructure, cost efficiency, and regulatory support, all of which necessitate strong investment and global collaboration.

Moving forward, the maritime industry needs to adopt a dual strategy of innovation and cooperation to manage the challenges posed by the EU ETS. Investments in alternative energy sources, intelligent shipping infrastructure, and sophisticated data management systems will be crucial for sustaining operational efficiency and achieving sustainability objectives. Concurrently, international collaborations and synchronized initiatives will facilitate the harmonization of regulations and policies across nations, fostering an environment conducive to adherence and expansion.

In a nutshell, the EU ETS represents both a challenge and a chance for Greece's maritime industry. By adopting sustainable methods and utilizing technological advancements, including AI, Greek shipping firms can effectively manage regulatory challenges, improve operational efficiency, and play a role in creating a more sustainable future for the international maritime sector by promoting, as frontrunners, ESG and circular entrepreneurship, while improving their competitiveness worldwide while significantly contributing to environmental sustainability and efforts to combat climate change.

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