MEDITERRANEAN ACTION PLAN (MAP)
REGIONAL MARINE POLLUTION EMERGENCY RESPONSE CENTRE FOR THE MEDITERRANEAN SEA (REMPEC)

Sixteenth Meeting of the Focal Points of the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC)

Sliema, Malta, 13-15 May 2025

REMPEC/WG.61/INF.13
24 January 2025
Original: English only

Agenda Item 8: Reduction of GHG emissions from ships

Study on the Effective Implementation of the 2023 IMO Strategy on Reduction of GHG Emissions from Ships in the Mediterranean region

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REMPEC
Malta, 2025

Note by the Secretariat

This document presents the Study on the Effective Implementation of the 2023 IMO Strategy on Reduction of GHG Emissions from Ships in the Mediterranean region.

Background

1 In July 2023, IMO adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships (hereinafter referred to as the 2023 IMO GHG Strategy) in accordance with the agreed programme of follow-up actions, which now replaces the Initial IMO GHG Strategy. The 2023 IMO GHG Strategy represents a framework for IMO Member States, setting out the future vision for international shipping, the levels of ambition to reduce GHG emissions and guiding principles; and includes candidate mid- and long-term further measures with possible timelines and their impacts on States. It also identifies barriers and supportive measures including capacity building, technical cooperation as well as research and development (R&D).

2 Given the specific characteristics of the Mediterranean region, there are starkly contrasting approaches to decarbonising the maritime industry. Mediterranean coastal States that are EU Member States follow stringent EU legislation, while Mediterranean coastal States that are not EU Member States are not bound by similar mandates. This disparity presents significant challenges in harmonising decarbonisation efforts across the regional shipping sector. Moreover, geopolitical instability further complicates the establishment of a coordinated approach to this transition. Nonetheless, the abundant renewable energy resources of the Mediterranean and its strategic importance as a global trade and energy corridor provide substantial potential for the region to emerge as a leading energy hub. This transformation could drive economic growth through job creation and position the Mediterranean as a pivotal player in the global energy transition.

3 In this context, the Secretariat commissioned Capt. Dr Seyedvahid Vakili and Ass. Prof. Dr Anastasia Christodoulou, to prepare a Study on the Effective Implementation of the 2023 IMO Strategy on Reduction of GHG Emissions from Ships in the Mediterranean region, hereinafter referred to as the Study, in order to support any possible future regulatory or policy action by the Contracting Parties to the Barcelona Convention, in their efforts to mobilise and implement innovative solutions to reduce GHG emissions from ships in selected ports, including through energy efficiency and decarbonisation.

4 The Study evaluates the effective implementation of the 2023 IMO GHG Strategy in the Mediterranean region. Given the absence of a "silver bullet" or a "one-size-fits-all" solution for meeting the IMO's ambitious 2050 goal for net-zero emissions from ships, various measures demonstrate potential for substantial GHG emissions reductions. These measures include the adoption of carbon-neutral fuels and energy efficiency enhancements such as speed reduction and logistics optimisation.

5 Carbon-neutral fuels are expected to contribute approximately 60% towards meeting the IMO's 2050 GHG emissions goal. Energy efficiency measures, including speed reduction, are anticipated to contribute around 30%, while logistics optimisations will account for about 10%. Considering the barriers to using carbon-neutral fuels, improvements in energy efficiency will play a more crucial role around 2035, allowing carbon-neutral fuels to gradually increase their market contribution. After speed reduction, which is a relatively easy measure considering the age of vessels, Wind-assisted Propulsion Systems (WAPS), Energy Saving Devices (ESD), and air lubrication systems are predicted to play significant roles in meeting the 2023 IMO GHG Strategy. Additionally, in short sea shipping, electrification, batteries, fuel cells, and hybrid technologies will contribute more towards transitioning to a zero-emission shipping industry. However, this transition requires sustainable infrastructure and collaboration among various stakeholders.

6 Ports play a significant role in the transition to zero-emission shipping. Special attention should be given to the ship-port interface to expedite this transition. Ports should evolve from being merely cargo hubs to energy hubs by providing sustainable infrastructure, such as alternative fuel bunkering and Onshore Power Systems (OPS), and by implementing appropriate policies such as Just In Time (JIT) arrival and incentive measures. Furthermore, automation, digitalisation, and logistics development may indirectly contribute to shorter ship port stays, thereby aiding in the reduction of emissions at ports.

7 The Study was carried out, pursuant to the Programme of Work and Budget for 2024-2025 of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP), adopted by the Twenty-third Ordinary Meeting of the Contracting Parties to the Barcelona Convention and its Protocols (Portorož, Slovenia, 5-8 December 2023).

8 This activity was financed by the voluntary contribution from the French Ministry for Europe and Foreign Affairs.

9 The Study is presented in the **Appendix** to the present document.

Action requested by the Meeting

10 **The Meeting is invited to take note** of the information provided in the present document.

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Appendix

Study on the Effective Implementation of the 2023 IMO Strategy on Reduction of GHG Emissions from Ships in the Mediterranean region

MEDITERRANEAN ACTION PLAN (MAP)
REGIONAL MARINE POLLUTION EMERGENCY RESPONSE CENTRE FOR THE MEDITERRANEAN SEA (REMPEC)

Preparation of a Study on the Effective Implementation of the 2023 IMO Strategy on Reduction of Greenhouse Gas (GHG) Emissions from Ships in the Mediterranean region

Final Study

Prepared by Capt. Dr Seyedvahid Vakili and Ass. Prof. Dr Anastasia Christodoulou

This activity is financed by the voluntary contribution from the French Ministry for Europe and Foreign Affairs and is implemented by the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC), in cooperation with the International Maritime Organization (IMO).

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List of abbreviations

AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
AIS	Automatic Identification System
CCS	Carbon Capture & Storage
CO_2	Carbon dioxide
CII	Carbon Intensity Indicator
CSI	Clean Shipping Index
CPs	Contracting Parties to the Barcelona Convention
CH_4	Methane
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency for Existing Ships
ESD	Energy Saving Device
ETS	Emissions Trading System
ESI	Environmental Shipping Index
EU	European Union
GA	Green Award
GM	Green Marine
GHG	Greenhouse Gas
GFS	GHG Fuel Standard
HBMCI	Hellenic Bureau for Marine Casualties Investigation
IMO	International Maritime Organization
IoT	Internet of Things
JIT	Just In Time
LNG	Liquefied Natural Gas
MBMs	Market-Based Measures
MoU	Memoranda of Understanding
MMAIP	The Ministry of Maritime Affairs and Insular Policy
MoND	The Ministry of National Defense
NECP	National Energy and Climate Plan
NO_X	Nitrogen Oxides
N_2O	Nitrous Oxide

OCC	Onboard Carbon capture
OCCS	Onboard Carbon Capture Systems
OPS	Onshore Power System
ORC	Organic Rankine Cycle
PM	Particulate Matter
PIDs	Propulsion-enhancing devices
PEMFC	Proton Exchange Membrane Fuel Cells
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
RLF	Renewable and low-carbon fuels
R&D	Research and Development
RTG	Rubber-tired gantry
SEEMP	Ship Energy Efficiency Management Plan
STS	Ship-to-Shore
SOFC	Solid Oxide Fuel Cells
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
SCZONE	Suez Canal Economic Zone
SO_X	Sulphur Oxides
TtW	Tank to Wake
TEN-T	Trans-European Transport Network
TEUs	Twenty-foot Equivalent Units
UGS	Union of Greek Shipowners
VSR	Vessel Speed Reduction
WHR	Waste Heat Recovery
WtW	Well-to-Wake
WAPS	Wind-assisted Propulsion Systems

Executive summary

This study evaluates the effective implementation of the 2023 International Maritime Organization (IMO) Strategy on Reduction of Greenhouse Gas (GHG) Emissions from Ships (hereinafter referred to as the 2023 IMO GHG Strategy) in the Mediterranean region. It begins with a comprehensive review of the relevant IMO's initiatives, an in-depth analysis of the 2023 IMO GHG Strategy and an overview of the recent related EU legislation that has an important direct or indirect impact on the Mediterranean coastal States depending on their exact location. The study also identifies the measures and tools available to expedite the transition towards zero-emission shipping by around 2050. Detailed discussions are supported by a questionnaire distributed among various maritime stakeholders in the Mediterranean region and interviews conducted with experts in the field.

To comply with the 2023 IMO GHG Strategy, the maritime industry aims to define the most effective strategies for achieving net-zero emission shipping by 2050. This necessitates the modernisation of fleets through the adoption of carbon-neutral fuels and green technologies. However, this is a complex task considering the age of vessels and the capacity of shipyards.

Given the absence of a “silver bullet” or a “one-size-fits-all” solution for meeting the IMO’s ambitious 2050 goal for net-zero emissions from ships, various measures demonstrate potential for substantial GHG emissions reductions. These measures include the adoption of carbon-neutral fuels and energy efficiency enhancements such as speed reduction and logistics optimisation.

Carbon-neutral fuels are expected to contribute approximately 60% towards meeting the IMO’s 2050 GHG emissions goal. Energy efficiency measures, including speed reduction, are anticipated to contribute around 30%, while logistics optimisations will account for about 10%. Considering the barriers to using carbon-neutral fuels, improvements in energy efficiency will play a more crucial role around 2035, allowing carbon-neutral fuels to gradually increase their market contribution. After speed reduction, which is a relatively easy measure considering the age of vessels, Wind-assisted Propulsion Systems (WAPS), Energy Saving Devices (ESD), and air lubrication systems are predicted to play significant roles in meeting the 2023 IMO GHG Strategy. Additionally, in short sea shipping, electrification, batteries, fuel cells, and hybrid technologies will contribute more towards transitioning to a zero-emission shipping industry. However, this transition requires sustainable infrastructure and collaboration among various stakeholders.

Ports play a significant role in the transition to zero-emission shipping. Special attention should be given to the ship-port interface to expedite this transition. Ports should evolve from being merely cargo hubs to energy hubs by providing sustainable infrastructure, such as alternative fuel bunkering and Onshore Power Systems (OPS), and by implementing appropriate policies such as Just In Time (JIT) arrival and incentive measures. Furthermore, automation, digitalisation, and logistics development may indirectly contribute to shorter ship port stays, thereby aiding in the reduction of emissions at ports.

Given the specific characteristics of the Mediterranean region, there are starkly contrasting approaches to decarbonising the maritime industry. Mediterranean coastal States that are EU Member States follow stringent EU legislation, while Mediterranean coastal States that are not EU Member States are not bound by similar mandates. This disparity presents significant challenges in harmonising decarbonisation efforts across the regional shipping sector. Moreover, geopolitical instability further complicates the establishment of a coordinated approach to this transition. Nonetheless, the abundant renewable energy resources of the Mediterranean and its strategic importance as a global trade and energy corridor provide substantial potential for the region to emerge as a leading energy hub. This transformation could drive economic growth through job creation and position the Mediterranean as a pivotal player in the global energy transition.

To achieve these goals, a holistic, systematic, and transdisciplinary approach involving collaboration among countries and stakeholders is essential. It is vital for the Mediterranean region to adopt a consistent strategy across all critical infrastructures and foster reciprocal relationships with other regional stakeholders. Establishing partnerships to mitigate investment risks and attract financial investments necessitates comprehensive and harmonised regulations that address the unique challenges and characteristics of the region.

Mediterranean coastal States that are EU Member States, guided by green economy policies and legislation like the EU Emission Trading System (EU ETS), FuelEU Maritime and the Alternative Fuels Infrastructure Directive, are better positioned for decarbonising the maritime industry compared to Mediterranean coastal States that are not EU Member States. However, compliance with EU legislation varies based on national policies. By investing in sustainable port infrastructures, European ports are evolving into energy hubs due to EU legislation, but similar governmental policies are necessary in non-EU ports within the region to expedite the implementation of the 2023 IMO GHG Strategy.

Establishing green corridors between EU ports and non-EU ports, along with supporting investments and technology transfer, can facilitate a harmonious approach to decarbonising the maritime industry and meeting the 2023 IMO GHG Strategy. This initiative offers regional ports the opportunity to adopt innovative measures and green technologies throughout the value chain to achieve zero-emission shipping.

The survey results revealed a lack of awareness about the 2023 IMO GHG Strategy among stakeholders in the Mediterranean region, though there was slightly higher awareness of the EU legislation, particularly among stakeholders in Mediterranean coastal States that are EU Member States. Many stakeholders in the Mediterranean region believe that compliance with the EU legislation will suffice to meet the 2023 IMO GHG Strategy. In light of these findings, it is crucial to focus on capacity building and research and development (R&D) to address uncertainties in regulations and to advance future technologies and carbon-neutral fuels.

Given the critical role of the 2023 IMO GHG Strategy in decarbonising the shipping industry, along with the effectiveness of the EU legislation in expediting the transition to zero-emission shipping, addressing regional discrepancies is imperative. Therefore, it is recommended to undertake a thorough impact assessment on the implementation of both the 2023 IMO GHG Strategy and the EU legislation in the Mediterranean region.

1 Introduction

1.1 Background

Shipping, considered the most energy efficient mode of transport, is responsible for approximately 2.89% of global greenhouse gas (GHG) emissions and contributes to about 15% of global air pollution. Between 2012 and 2018, there was a notable increase of 9.6% in GHG emissions from shipping, which included carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), rising from 977 million tons to 1076 million tons (Figure 1). Notably, CO_2 emissions saw a significant surge of 9.3% during this period, climbing from 962 million tons to 1056 million tons. Consequently, the share of global GHG emissions attributed to shipping rose from 2.76% in 2012 to 2.89% in 2018 (IMO, 2020).

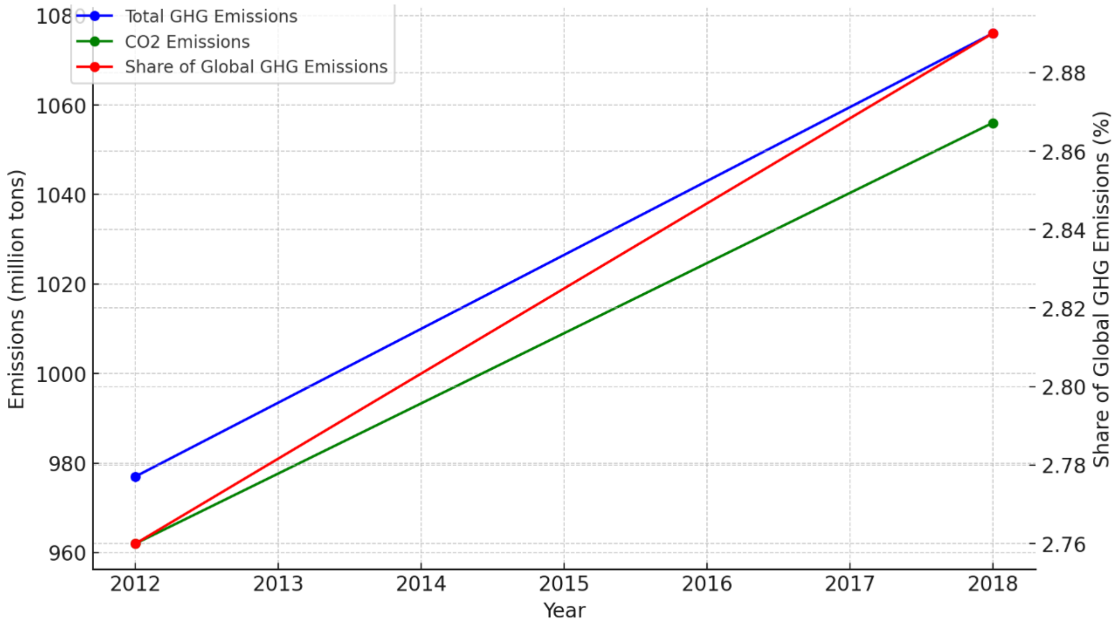


Figure 1. GHG emissions from shipping (2012-2018)
Source: elaboration by Vakili, S. and Christodoulou, A., based on IMO (2020).

In alignment with the goals outlined in the 2015 Paris Agreement, the International Maritime Organization (IMO) has implemented significant measures aimed at reducing the carbon footprint of the maritime industry. In 2018, the IMO introduced its Initial Strategy on Reduction of GHG Emissions from Ships (hereinafter referred to as the Initial IMO GHG Strategy), which aimed to decrease CO_2 emissions per unit of transport work, targeting a minimum reduction of 40% by 2030 and aiming for an even more ambitious 70% reduction by 2050, compared to 2008 levels. Additionally, the Strategy placed a broader emphasis on the overarching objective of reducing the total annual GHG emissions generated by international shipping, with a goal of achieving a substantial 50% reduction by 2050 compared to 2008 levels. However, in 2023, the IMO adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships (hereinafter referred to as the 2023 IMO GHG Strategy), implementing more stringent measures to achieve net-zero emission shipping by or around 2050. While these updated targets may not align perfectly with the 1.5°C temperature target, the commitment to achieving net-zero emissions by around 2050 represents a significant advancement compared to the Initial IMO GHG Strategy established five years prior.

The 2023 IMO GHG Strategy also outlines key milestone objectives for 2030 and 2040 (see Figure 2). By 2030, the aim is to reduce total annual GHG emissions by a minimum of 20% (with an ambitious target of 30%), followed by a more substantial reduction of at least 70% (with a striving goal of 80%) by 2040, all relative to 2008 levels (IMO, 2023). Another pivotal aspect of the 2023 IMO GHG Strategy, essential for achieving these ambitious objectives, is the emphasis on finding sustainable solutions to provide 5% (with an aspirational target of 10%) of the energy utilised by international shipping by 2030 through zero or nearly zero emissions technologies, fuels, and energy sources. Meeting these milestones will require the widespread implementation of robust technical, operational, and economic measures, a process that will take several years to effectively execute (IMO, 2023).

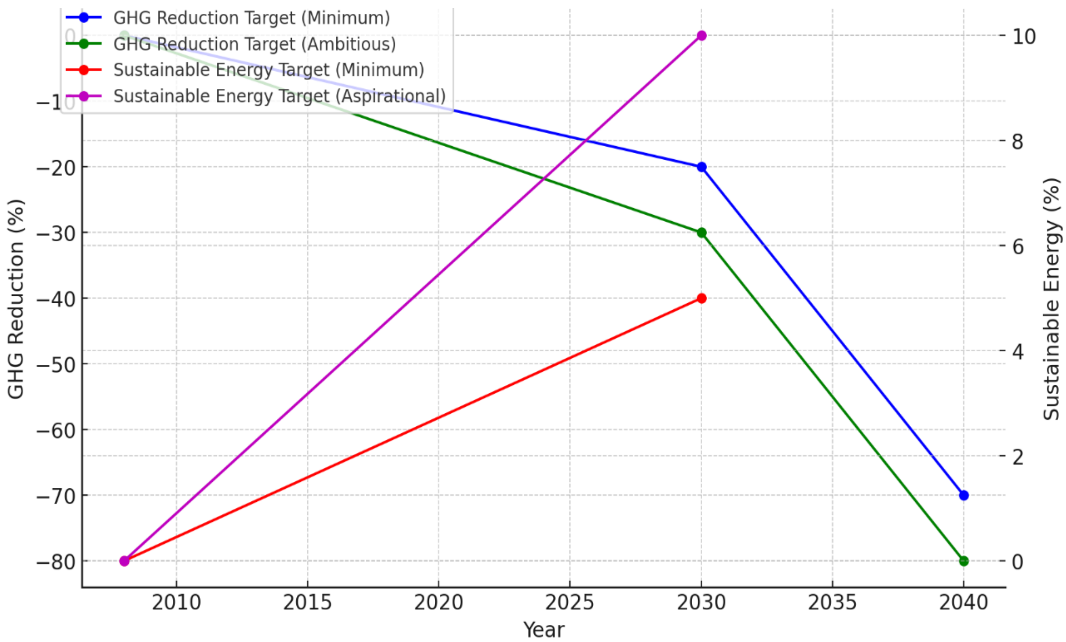


Figure 2. Key milestone objectives of the 2023 IMO GHG Strategy for 2030 and 2040
Source: elaboration by Vakili, S. and Christodoulou, A., based on IMO (2023)

To support the attainment of objectives outlined in the 2023 IMO GHG Strategy, the IMO has introduced a range of **mid-term GHG reduction measures**. The **goal-based marine fuel standard and pricing mechanism** are mid-term GHG reduction measures specified in the 2023 IMO GHG Strategy, adopted in July 2023. Several different proposals of what these measures should entail are currently being considered and these measures, currently in development, include both technical and economic elements. Together, these measures aim to expedite the transition to zero-emission shipping by encouraging the adoption of cleaner energy and more sustainable solutions across the global fleet. Their implementation seeks to ensure a fair and equitable transition for all stakeholders involved.

Considering the mid-term GHG reduction measures, these may include a proposed new Chapter 5 of MARPOL Annex VI containing regulations on the IMO net-zero framework, to include:

- **a goal-based marine fuel standard regulating the phased reduction of the marine fuel's GHG intensity; and**
- **an economic mechanism(s) to incentivise the transition to net-zero (Vakili et al., 2024).**

Considering the challenges and opportunities from the implementation of the 2023 IMO GHG Strategy, this study, conducted on behalf of the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC), aims at assessing the effective implementation of the 2023 IMO GHG Strategy in the Mediterranean region and at making recommendations on any regional policies that may be considered for a more effective implementation of the Strategy within the Mediterranean region, including the adoption of the most appropriate GHG reduction measures. The results of this research offer the opportunity to simplify the global uptake of guidelines and provide crucial insights to a range of maritime stakeholders in the Mediterranean region, including ship owners, shipyards, ports, classification societies, and regulatory authorities.

1.2 Scope of the work

The principal objective of this report is to assess the effective implementation of the 2023 IMO GHG Strategy in the Mediterranean region. The specific objectives of the study include (Figure 3):

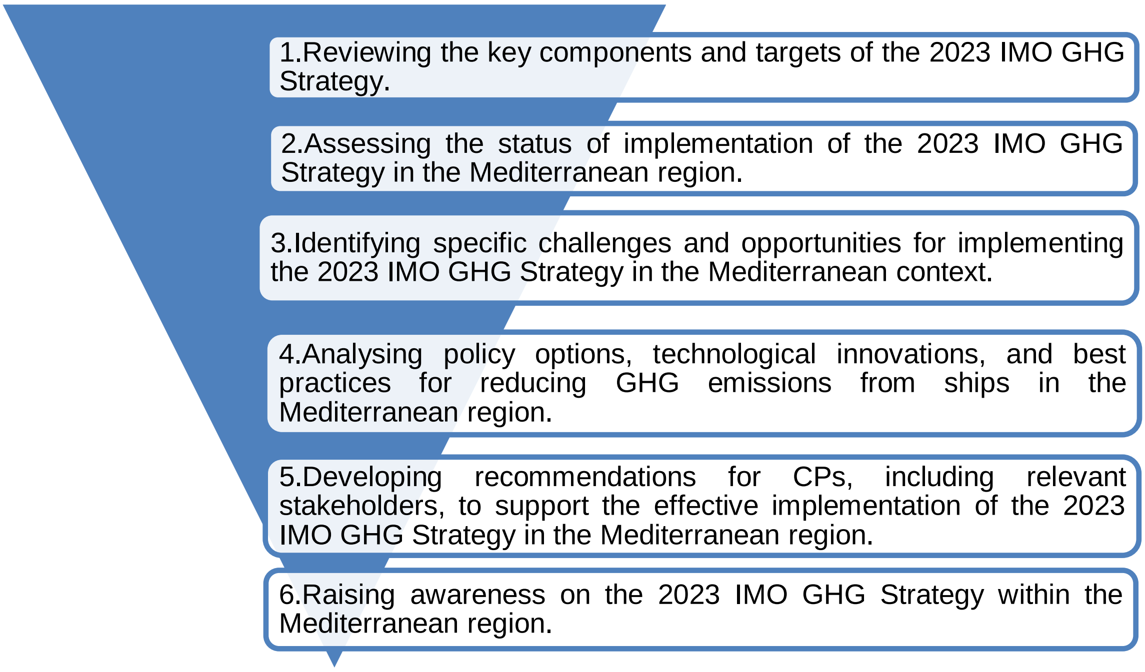


Figure 3. Specific objectives of the current study
Source: Vakili, S. and Christodoulou, A.

2 Methodology

To align with the scope of the study and meet its objectives, the research has been structured into distinct phases:

<u>Phase one: Desk research</u>

This initial phase involves gathering relevant information and data from various stakeholders in the Mediterranean region. A literature review is conducted to assess the actions taken by different stakeholders in the Mediterranean region to comply with the 2023 IMO GHG Strategy. Additionally, both IMO and regional (Europe) strategic goals are reviewed. A comprehensive examination of the decarbonisation efforts within the maritime industry, with a specific focus on the 2023 IMO GHG Strategy, enables the identification of challenges and barriers for the implementation of the Strategy in the Mediterranean region. Data collection is further facilitated by the distribution of questionnaires and conducting interviews with stakeholders, including administrators, shipowners, and port authorities, with the assistance of REMPEC.

<u>Phase two: Data analysis</u>

In this phase, the trends of the shipping industry in aligning with the 2023 IMO GHG Strategy are examined, and best global practices for achieving the goals of the 2023 IMO GHG Strategy are identified.

Phase three: Gap assessment

During this stage, barriers and drivers for the implementation of the 2023 IMO GHG Strategy in the Mediterranean region are identified. Drawing upon the information gathered in phases one and two, this phase aims to pinpoint gaps hindering the successful implementation of the 2023 IMO GHG Strategy.

Phase four: Implementation plan

Following discussions and comparisons of analyses conducted in various phases, this stage involves drawing conclusions, making recommendations, outlining a roadmap, and proposing further actions necessary to facilitate and expedite the implementation of the 2023 IMO GHG Strategy, thereby ensuring a fair and equitable transition to zero-emission shipping in the Mediterranean region (See Figure 4).

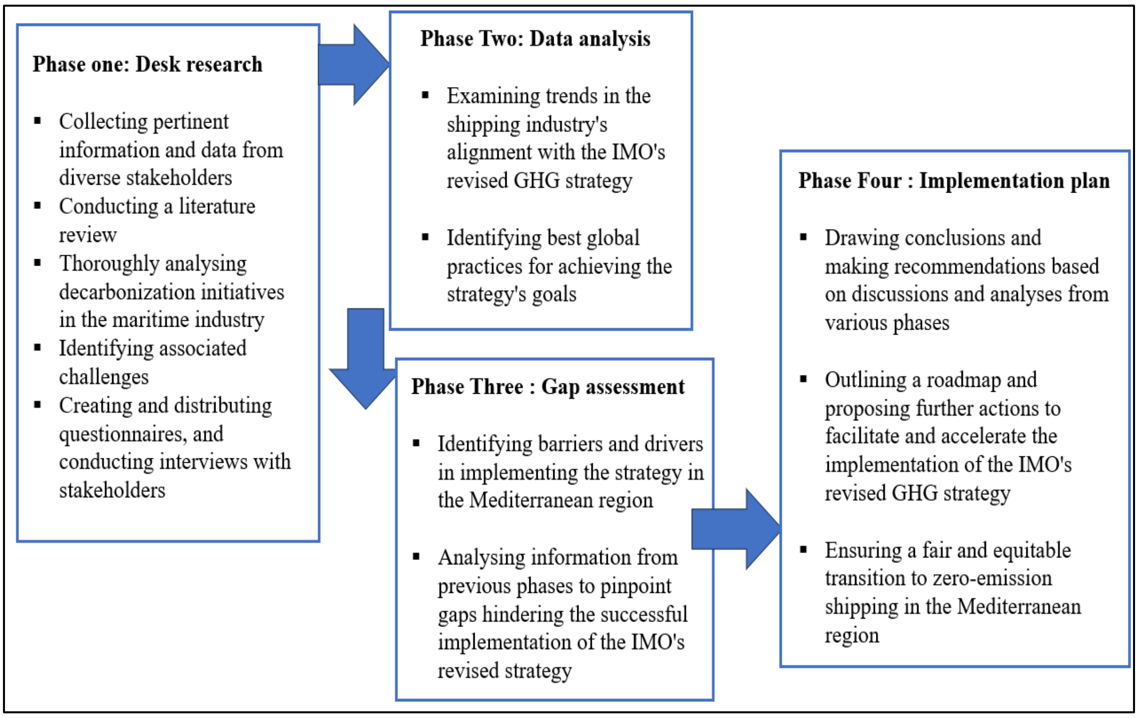


Figure 4. The methodology of the study.
Source: elaboration by Vakili, S. and Christodoulou, A.

3 Literature Review and Best Practices

The 2023 IMO GHG Strategy marks a significant milestone in the decarbonisation journey of the shipping industry. With the ambitious target of achieving net-zero emissions by around 2050, it sends a clear signal to stakeholders in the maritime sector to undertake substantial actions towards more sustainable and environmentally friendly practices.

Recognising the multifaceted challenges in achieving net-zero emission shipping by 2050, it is evident that there is no singular "silver bullet" or universally applicable solution. Embracing a goal-based approach is crucial for decarbonising the shipping industry, with emphasis placed on alternative fuels, carbon capture and storage (CCS), enhancing energy efficiency, and optimising logistics, particularly the ship-port interface.

In light of these considerations, this section offers an overview of the measures aimed at accelerating the decarbonisation of the industry (Figure 5).

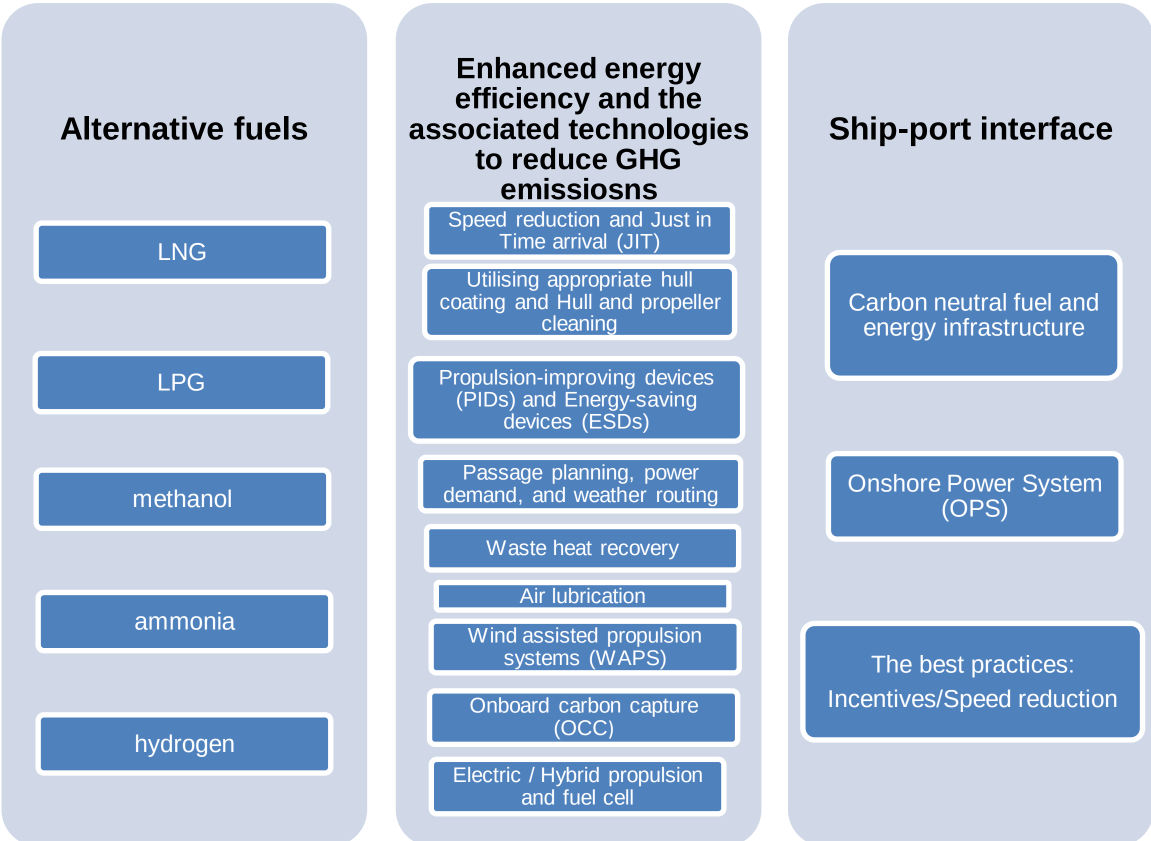


Figure 5. Overview of measures aimed at accelerating shipping decarbonisation. Source: Vakili, S. and Christodoulou, A.

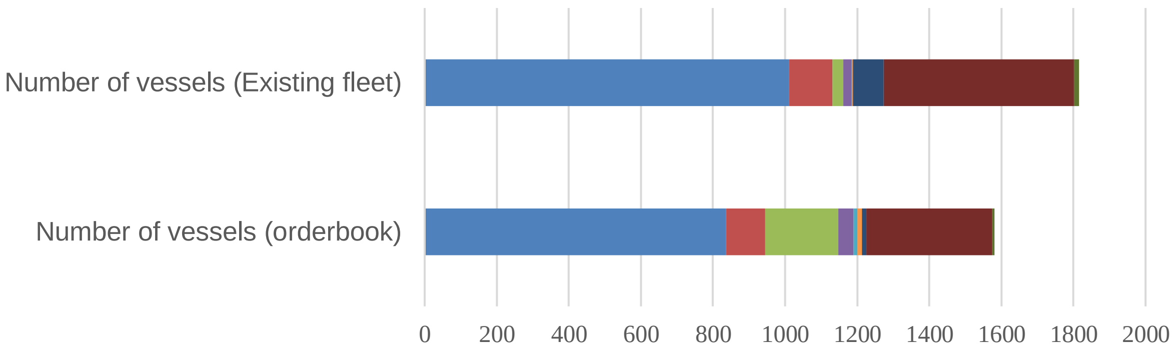
3.1 Alternative fuels

Utilising carbon-neutral fuels plays a pivotal role in aligning with the 2023 IMO GHG Strategy. Projections indicate that by 2050, carbon-neutral fuels could contribute approximately 64% to the industry's decarbonisation efforts (IMO, 2018). However, several challenges hinder the widespread adoption of these fuels, including issues related to availability, cost, inadequate infrastructure, logistical constraints, limited scalability of production, technological maturity in onboard systems and supply infrastructure, as well as considerations regarding ship and engine design, crew training, and safety concerns (Vakili et al., 2024). Therefore, it is predicted that the prominence of carbon-neutral fuels in achieving net-zero emission shipping is expected to rise post-2030 and become dominant beyond 2040 (DNV, 2022; Christodoulou and Cullinane, 2022).

The 2023 IMO GHG Strategy emphasises that by 2030, at least 5% (with aspirations for 10%) of the global maritime transport's energy should originate from sustainable alternative fuels and energy sources. However, the significant demand for carbon-neutral fuel by 2030 (estimated at around 17 million metric tonnes, DNV, 2023), comprising 30% to 40% of global production capacity, coupled with the aforementioned barriers, poses a substantial challenge to meeting these goals. Success in achieving these targets necessitates substantial investment in decarbonisation efforts, the development of essential infrastructure for alternative fuels, and the establishment of zero-emission fuel production at requisite scales.

As documented by Clarkson's research (2023), a mere 50 vessels had committed to alternative fuels in 2020. Yet, this statistic witnessed a remarkable surge, with 224 orders placed in 2021, constituting a remarkable 32% of newbuild tonnage. Of noteworthy significance is the unprecedented record of newbuild orders by tonnage (GT), surpassing 60%, and this positive trajectory continued into the initial half of 2023, registering 216 units (equating to 14.6 million GT) equipped with alternative fuel capabilities, which constitutes 44% of the total ordered GT. This includes 86 ships capable of utilising liquefied natural gas (LNG), encompassing 8.5 million GT (representing 26% of the total orders), 62 vessels with methanol-ready capabilities encompassing 4.3 million GT (equivalent to 13%), alongside 21 ships with LPG capabilities. Additionally, 36 units are slated for battery-hybrid propulsion. The burgeoning market trend towards zero-emission fuel and the growing traction towards flexible fuel choices are evinced by the presence of over 413 LNG-ready vessels within the fleet, with 95 more on the order book. Moreover, 192 vessels are poised for ammonia integration, and 128 for methanol integration, alongside 9 vessels tailored for hydrogen utilisation. While the current contribution of alternative fuels accounts for 3.5% of the fleet and 27% of the order book in terms of tonnage, the focal point is anticipated to pivot towards bunkering and infrastructure technologies in the foreseeable future.

Projections indicate that achieving a 50% reduction in shipping emissions by 2050 requires a substantial investment of $1.4 trillion (Krantz R, Søgaard K, Smith T, 2020), potentially leading to a 70% to 100% increase in annual fuel costs compared to current levels (UNCTAD, 2023). For context, the average annual investment onboard for new fuels and engine development ranges from $8 billion to $28 billion, with ammonia and methanol necessitating the most significant investments. Notably, the average annual investment in onshore fuel infrastructure surpasses onboard investments by a factor of 3.5, ranging from $28 billion to $90 billion (DNV, 2022). Furthermore, to meet the IMO goals, it is estimated that over 3,500 vessels will need to be built or retrofitted annually to use carbon-neutral fuel until 2050. However, the number of shipyards has decreased by 50% between 2007 and 2022 (Offshore Energy, 2024) (See Figure 6).



	Number of vessels (orderbook)	Number of vessels (Existing fleet)
LNG	837	1011
LPG	107	120
Methanol	203	30
Ethane	43	23
Hydrogen	10	2
Ammonia	13	2
Biofuel	13	85
Battery	348	529
Other	7	13

Figure 6. Alternative fuel uptake in the world fleet in number of ships in operation and on order (April 2024).
Source: Adapted from ABS, 2024; Clarksons Research, 2024.

Table 1. Challenges and Opportunities for using alternative fuels.

Challenges	Opportunities
· **Cost**: Carbon-neutral fuels incur higher costs compared to conventional fuels and require significant investment for retrofitting vessels and building the necessary infrastructure. · **Infrastructure**: There is a shortage of shipyards to build or retrofit vessels for using carbon-neutral fuels. Additionally, sustainable infrastructure to support the scalable production of these fuels is lacking. Ports need to invest in establishing the necessary storage facilities, bunkering stations, and transportation infrastructure to support these vessels. · **Regulatory framework**: There is uncertainty and insufficient regulation in the regulatory environment surrounding carbon-neutral fuel in the maritime domain. · **Safety**: Similar to the regulatory framework, safety concerns arise regarding the use of carbon-neutral fuel in the maritime domain. For example, LNG (as an alternative fuel) requires safety procedures and standards to prevent explosions, while ammonia raises concerns about toxicity and the safety of crew and passengers. · **Technology readiness**: Some carbon-neutral fuel technologies are still in the early stages of development and require further pilot projects to mature the related technologies and make them more cost-effective. · **Global adoption and standardisation**: Given the widespread adoption of carbon-neutral fuels, appropriate collaboration and cooperation among various stakeholders are crucial. Standardisation of fuel specifications, bunkering procedures, and safety protocols is essential to facilitate global trade and operations.	· **Emissions Reduction**: By transitioning to carbon-neutral fuel, the maritime industry can align with the goals of the Paris Agreement. Carbon-neutral fuels have the potential to significantly reduce GHG emissions and air pollutants, thereby mitigating the industry's negative impact on society and improving air quality in port cities. · **Compliance with Regulations**: With environmental regulations becoming more stringent, the use of carbon-neutral fuel offers an opportunity for compliance with these regulations. · **Energy Security**: Diversifying energy sources in the maritime sector reduces dependency on conventional fuels, thus decreasing vulnerability to price volatility and geopolitical instability in the energy market. Investing in various fuel types enhances energy efficiency and resilience. · **Market Opportunities**: As the industry transitions towards zero-emission practices, there is a growing market demand for carbon-neutral fuel. This presents opportunities for beneficial investments in production, distribution, and infrastructure development for carbon-neutral fuels. · **Regional Development**: Significant investment in the production, distribution, and infrastructure of carbon-neutral fuels can spur economic development and job creation in regions involved in these activities. · **Reputation and Brand**: Investing in and deploying carbon-neutral fuel to achieve zero-emission shipping can enhance the reputation of shipping companies, ports, and operators. Demonstrating a commitment to sustainability through the use of carbon-neutral fuels can differentiate companies from their competitors and serve as a competitive advantage.

· **Training**: Training is essential due to the widespread adoption of carbon-neutral fuels in the maritime domain, representing a new paradigm for both seafarers and bunker stations in ports.	· **Collaboration and Partnerships**: Transitioning to a zero-emission industry and adopting carbon-neutral fuels require collaboration among stakeholders at various levels. This presents an opportunity for partnerships and knowledge sharing to drive innovation, technology development, and deployment, thereby accelerating the transition to zero-emission shipping.

3.2 Enhanced energy efficiency and the associated technologies to reduce GHG emissions

Given the diverse barriers linked to the adoption of carbon-neutral fuels, enhancing energy efficiency stands out as a key element in fulfilling the 2023 IMO GHG Strategy. Projections indicate that roughly 32% of emissions reductions by 2050 will rely on energy efficiency enhancements, with speed reduction alone accounting for approximately 23% of the total reduction needed to meet the targets of the 2023 IMO GHG Strategy (DNV, 2022). Measures such as weather routing, appropriate hull coating, hull and propeller cleaning, energy-saving devices (ESDs), propulsion-enhancing devices (PIDs), air lubrication, and waste heat recovery (WHR) are among the strategies that can bolster energy efficiency.

3.2.1 Speed reduction and Just In Time arrival (JIT)

Examining the interdisciplinary challenges inherent in the adoption of carbon-neutral fuels within the maritime sector, it becomes evident that speed reduction emerges as a pivotal strategy for achieving decarbonisation goals. Projections suggest that speed reduction could contribute up to 23% towards meeting the targets of the 2023 IMO GHG Strategy by 2050 (Vakili et al., 2024). This significance can be attributed to the cube law relationship between power and speed, wherein fuel consumption experiences a notable reduction. When combined with JIT practices, which minimise port stays, the benefits of speed reduction are further amplified. Consequently, implementing speed reduction not only yields cost savings by curbing operational expenses (given that fuel constitutes approximately 60% of a ship's operational costs) but also diminishes the carbon footprint of vessels.

However, it is crucial to recognise that the economic advantages from speed reduction are not uniformly distributed across the maritime value chain. While shipowners stand to benefit from fuel savings, the reduction in a vessel's annual cargo capacity translates to decreased revenue. This may prompt owners to compensate for the lost capacity by introducing additional vessels to their fleets (Vakili et al., 2023). Moreover, prolonging voyages can escalate opportunity costs for cargo owners, potentially incentivising modal shifts to road, rail, or air transport modes. Such shifts, in turn, could result in higher air emissions and environmental impacts (APEC, 2019).

Taking the above into consideration, incorporating effective practices and policies like JIT and implementing a fair cost and benefit-sharing framework among stakeholders can mitigate traffic capacity limitations and ensure an equitable distribution of costs and benefits (Vakili et al., 2024). The synergistic integration of speed reduction and JIT has the potential to slash both fuel consumption and GHG emissions by 14% to 23% (Aroca et al., 2020).

Referring to the 2023 IMO GHG Strategy and the requirements of the Carbon Intensity Indicator (CII), projections indicate that under the current CII system and with a significant portion of the fleet aged over 15 years (approximately 30%), around 30% of existing vessels—including tankers, bulk carriers, and container ships—are likely to receive D or E ratings based on CII assessments. Considering the barriers in implications of retrofitting for carbon-neutral fuel or investing in green technologies, the adoption of speed reduction emerges as a strategic approach to enhance the overall efficiency of the fleet (Vakili et al., 2024).

Table 2. Challenges and Opportunities for implementing speed reduction and JIT arrivals.

Challenges	Opportunities
· **Economic Considerations**: While speed reduction offers fuel savings and economic advantages for shipowners, it also results in longer voyage times and increased associated costs, including those related to crew, insurance, maintenance, and wages. Furthermore, these benefits are not uniformly distributed among stakeholders. · **Introduction of Additional Vessels and Modal Shift**: Compensating for reduced transport capacity due to speed reduction may necessitate the introduction of additional vessels to the fleet, potentially leading to heightened air emissions. Moreover, market demands may prompt a shift to more polluting modes of transportation due to extended voyage times. · **Operational Efficiency**: Speed reduction can disrupt shipping schedules and logistics within the maritime industry's value chain, thereby diminishing overall system efficiency. · **Competition and Market Pressures**: Prolonged voyages resulting from speed reduction may erode market competitiveness and trigger modal shifts. · **Regulatory Compliance, Enforcement, and Monitoring**: Ensuring compliance with speed reduction initiatives requires investment in monitoring and reporting systems, as well as adjustments to vessels for sustained speed reduction. · **Stakeholder Alignment**: Achieving meaningful outcomes from speed reduction necessitates collaboration and cooperation among various stakeholders, including shipowners, charterers, ports,	· **Fuel Savings and Emissions Reduction**: Utilising the cube law principle, slow steaming offers significant potential for reducing fuel consumption, resulting in lower levels of GHG emissions such as carbon dioxide (CO_2), sulphur oxides (SO_X), and nitrogen oxides (NO_X). · **Compliance with Regulations**: Given the age of fleets, CII requirements, and interdisciplinary barriers in adopting carbon-neutral fuels, slow steaming presents a readily available means to meet environmental regulations in the maritime industry. · **Reduced Operational Costs**: With fuel costs being a significant portion of operational expenses, slow steaming fuel-saving potential directly translates to reduced operational costs for shipowners. · **Enhanced Safety**: Slowing down high-speed vessels improves safety by affording seafarers more time to react to hazards like adverse weather conditions, maritime traffic, and navigational challenges, thereby mitigating the risk of accidents. · **Noise Reduction and collisions with marine mammals**: Slowing vessel speeds reduces cavitation, thereby minimising underwater radiation noise and its adverse effects on marine species. Additionally, it decreases the likelihood of collisions with marine mammals, such as whales.

regulatory bodies, and cargo owners, to balance the benefits among all parties. · **<u>Technical Limitations</u>**: Some vessels may lack optimal fuel efficiency at lower speeds due to their engine design constraints.	

3.2.2 Utilising appropriate hull coating, and hull and propeller leaning

Hull and propeller fouling can result from physical damage or the use of unsuitable coatings, leading to the formation of biofouling. The extent of biofouling is influenced by factors such as vessel speed, trading area, and activity level. Biofouling increases resistance, thereby raising fuel consumption (Speranza et al., 2019). Employing appropriate hull coatings and regular cleaning of the vessel's hull and propeller can enhance efficiency by 7-10% (IMO, 2011).

Implementing an anti-fouling system and associated management protocols for selecting appropriate coatings and surface treatments can significantly mitigate biofouling formation, reduce resistance, and decrease fuel consumption. Furthermore, it aids in preventing the spread of invasive aquatic species (MEPC 80, 2023).

3.2.3 Propulsion-improving devices (PIDs) and Energy-saving devices (ESDs)

Innovative technological measures encompass a range of solutions, including propeller ducts, twisted rudders, gate rudders, bulbous bows, propeller cap turbines, pre-swirl stators, Mewis ducts, and propeller boss caps. These technologies, contingent upon vessel type and size, exhibit the capacity to enhance energy efficiency by a notable margin, ranging from 1.5% to 21% (Chang et al., 2019; Heinke & Hellwig-Rieck, 2011; Heinke & Lübke, 2014; Mizzi et al., 2017; Wärtsilä, 2022). Considering both the potential for energy efficiency enhancement and the relatively low capital investment and short payback period associated with these technologies, they have gained popularity within the maritime fleet. Approximately 6,400 vessels, accounting for 28% of the total fleet tonnage, have implemented various types of these technologies (Clarkson, 2023).

3.2.4 Passage planning, power demand, and weather routing

Efficient passage planning entails the appraisal, planning, execution, and monitoring of maritime routes, thereby not only bolstering the safety of vessels, crew, and cargo but also optimising energy utilisation. Leveraging oceanic and local currents, as well as tidal flows, enables vessels to mitigate engine loads, thereby concomitantly reducing fuel consumption and emissions (Vakili et al., 2021). Additionally, the strategic deployment of weather routing methodologies enhances both safety and efficiency by circumventing adverse weather conditions and charting courses that account for environmental factors such as currents and wind patterns. This approach holds the potential to augment energy efficiency by up to 5% (IAMU, 2014). In addition, the integration of weather routing with WAPS can further amplify energy efficiency. Research indicates that the synergistic combination of passage planning with cutting-edge technologies such as rotor sails yields the most substantial benefits, followed by suction wings, and to a lesser extent, wing sails (Dupuy et al., 2023).

3.2.5 Waste heat recovery (WHR)

Utilising heat technology spans diverse sectors, including its integration into maritime vessels to capture wasted heat from combustion engines, thus bolstering energy efficiency (Pesyridis et al., 2023). Customising WHR systems according to vessel dimensions, classification, and fuel composition can result in efficiency enhancements of up to 12% (Singh and Pedersen, 2016; Tillig et al., 2015). Additionally, blending this technology with permanent slow steaming and wind hybrid systems can generate supplementary savings ranging from 1 to 3% (Faber et al., 2012). Moreover, coupling the technology with fuel cells can elevate overall system efficiency.

Among the array of WHR methodologies, the Organic Rankine Cycle WHR system emerges as particularly noteworthy for its ability to leverage low-temperature heat for power generation. In contrast to the conventional Rankine Cycle, which relies on water as the primary working fluid and demands a substantially higher temperature heat source (Song and Gu, 2015; Loni et al., 2021), the ORC WHR system presents a promising avenue for efficient energy reclamation.

3.2.6 Air lubrication

The air lubrication system represents an innovative approach aimed at mitigating the frictional resistance experienced by a ship's hull through the generation of minuscule bubbles (Lloyd et al., 2020). This technology finds application in both newly constructed vessels and retrofit installations. While investigations involving 250 ships already equipped with this technology by 2030 (DNV, 2023) affirm its adaptability across vessels of varying sizes and types, its efficacy and economic viability are anticipated to be more pronounced in larger vessels. Scaled model experiments suggest that the adoption of this technology holds the potential to improve energy efficiency by 4-15% and reduce underwater radiated noise from commercial vessels by more than 10 dB (RINA, 2023; Vakili et al., 2024). Refer to Figure 6 for a comprehensive overview of the air lubrication system's performance across different vessel sizes and types.

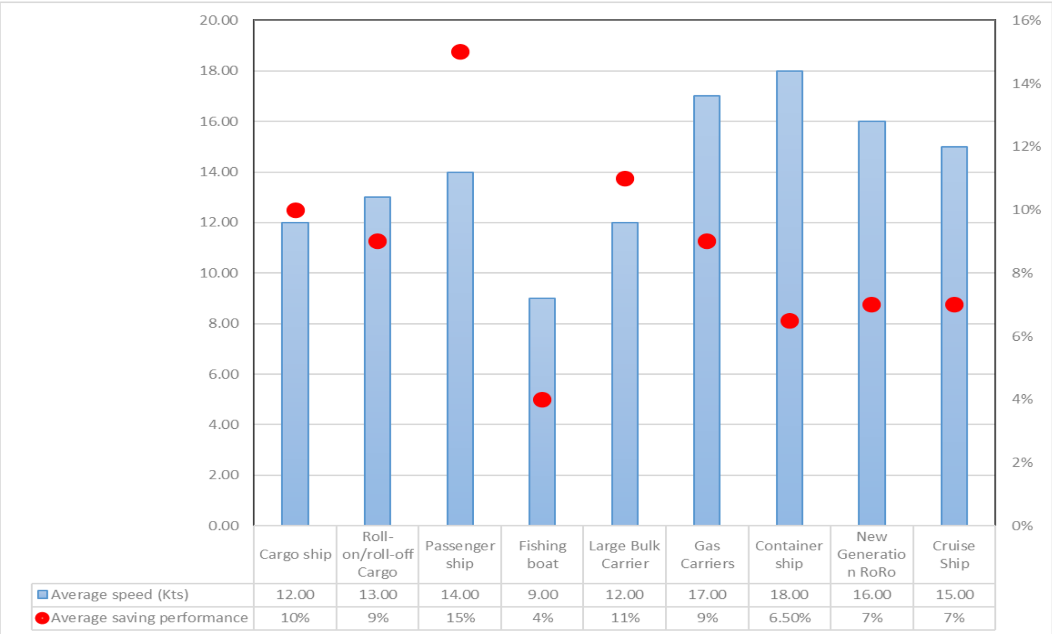


Figure 7. The air lubrication system performance.
Source: Adopted from (Kumagai et al., 2015; Silverstream, 2023).

3.2.7 Wind assisted propulsion systems (WAPS)

Using wind as an assistance propulsion system can improve energy efficiency of vessels and play an important role in meeting the 2023 IMO GHG Strategy in compliance with the Energy Efficiency Existing Index (EEXI), the Energy Efficiency Design Index (EEDI), and the CII (Vakili et al., 2024). There are different types of wind-assisted propulsion systems, including soft sails, hard sails, Flettner rotors, suction wings, kites, turbines, and hull forms, that have been implemented across some vessels, showcasing advancements in energy efficiency. Although the Fourth IMO GHG Study 2020 projected 1.66% contribution of wind power to the decarbonisation of the shipping by 2050, overlooking to evolving the technology maturity, trends of the market, ongoing projects, reduction of associated cost, and implementation of stricter environmental regulations, the projection shows that the Technogym plays a more important role in achieving the goal of the 2023 IMO GHG Strategy by 2050 (IMO, 2020; Vakili et al., 2024).

The Technogym has seen utilisation across 28 large vessels (DNV, 2023), signalling potential for broader adoption among smaller vessels such as ferries and fishing boats, with reported fuel reduction improvements ranging from 9% to 25% (DNV, 2023). Integration with weather routing and speed reduction strategies can further enhance these savings. The variability in fuel savings potential is contingent upon several factors including vessel speed, hull design, type of technology employed, machinery configuration, prevailing weather conditions, and seasonal fluctuations.

Although the initial capital outlay for implementing this technology is substantial and often cited as a primary barrier to its widespread deployment, ongoing technological evolution and maturity are anticipated to lead to cost reductions. Additionally, there is a growing interest among financial institutions to support and invest in this technology, which could contribute to cost alleviation. The payback period is heavily influenced by factors such as the type of technology utilised, prevailing fuel prices, vessel speed, and route characteristics (MEPC 81, 2024). With reference to increasingly stringent environmental regulations such as carbon pricing initiatives (IMO's Market Based Measures (MBMs) and EU ETS), as well as the widening gap between conventional and carbon-neutral fuels, it is anticipated that the payback period for this technology will shorten in the foreseeable future.

Table 3. Challenges and Opportunities for using WAPS.

Challenges	Opportunities
· **<u>Design and Integration</u>**: The integration of technology into various vessel types and propulsion systems is a multifaceted endeavour demanding meticulous engineering. Ensuring the seamless integration of wind propulsion systems while maintaining cargo capacity and stability necessitates innovative design approaches. · **<u>Variable Wind Conditions</u>**: Forecasting wind direction, intensity, and consistency presents a formidable challenge,	· **<u>Elimination of Onshore Infrastructure Requirements</u>**: Wind-assisted propulsion does not necessitate specific infrastructure at ports, reducing the logistical and financial burdens associated with supporting new technology installations. · **<u>Reduced Environmental Risk</u>**: Unlike fossil fuel-based systems, wind propulsion carries no risk of oil spills or associated environmental contamination, making it a

complicating the optimisation of wind utilisation. Overcoming this hurdle requires the implementation of suitable control systems to adapt to fluctuating conditions effectively. · **<u>Space Constraints</u>**: Implementing wind propulsion technology necessitates ample space aboard vessels. Limitations in deck space pose challenges to the adoption of this technology, highlighting the importance of addressing spatial constraints. · **<u>Operational Limitations</u>**: WAPS may not be viable under all operational circumstances. For instance, during manoeuvres, periods of low wind, or in rough seas, conventional propulsion systems become indispensable for vessel manoeuvrability and safety. · **<u>Cost and Investment</u>**: The initial investment in installing wind-assisted propulsion systems can be substantial. The viability of such an investment hinge on variables like fuel prices, regulatory incentives, and the operational profile of the vessel. Owners and operators should carefully assess these factors against potential fuel savings and long-term benefits. · **<u>Regulatory and Certification</u>**: The deployment of new propulsion systems necessitates compliance with maritime regulations and certification standards, introducing additional layers of complexity and regulatory hurdles. · **<u>Crew Training and Acceptance</u>**: Successful deployment of this technology relies on comprehensive training for personnel to ensure its safe and effective utilisation. Overcoming resistance and inertia among crew members towards adopting new technologies is crucial for the seamless integration and operation of these systems.	cleaner alternative with minimal ecological impact. · **<u>Enhanced Safety</u>**: Wind-assisted systems significantly reduce the risk related to fuel handling, such as contamination, explosions, and fires, thus improving overall safety aboard ships. · **<u>Regulatory Compliance</u>**: Wind-assisted propulsion enhances the efficiency of shipping operations and can promote in complying with international regulations, including the 2023 IMO GHG Strategy. These systems help improve key performance indicators such as the EEXI, EEDI, and CII. · **<u>Simplified Training Requirements</u>**: Operating wind-assisted systems generally requires less specialised training compared to more complex new technologies, facilitating easier adoption and integration into existing crew training programs. · **<u>Operational Cost Savings</u>**: By reducing dependency on fuel, ships equipped with wind-assisted propulsion can achieve cost savings over time, particularly in scenarios of rising fuel prices. · **<u>Public and Market Acceptance</u>**: As global awareness and demand for sustainable practices increase, ships utilising clean technologies such as wind-assisted propulsion are likely to be viewed more favourably by cargo owners, regulators, and environmentally conscious consumers. · **<u>Flexibility and Retrofitting Potential</u>**: Wind-assisted systems can be designed to complement existing propulsion mechanisms and are adaptable for retrofitting, making them suitable for both new builds and existing vessels without extensive modifications.

3.2.8 Electric / hybrid propulsion and fuel cell

In the maritime market, systems adaptable to various sizes and types of vessels are increasingly available. As the shipping industry transitions towards net-zero emissions, the adoption of fuel cells, batteries, and hybrid technologies, especially in short sea shipping, is becoming popular. These technologies enhance energy efficiency and emission reduction, aligning closely with the IMO's objectives for GHG reduction. According to a report by the Marine Battery Forum (2023), there are currently 589 operational battery-powered vessels, with an additional 171 on order. The implementation of these technologies is facilitated by increasingly stringent regulations and a significant reduction in the cost of lithium-ion battery packs—from $273/kWh in 2016 to an anticipated $73/kWh by 2030 (Kortsari et al., 2022). However, the operational efficacy and environmental benefits of these systems depend heavily on the availability of sustainable infrastructure, such as OPS, and the source of the electricity provided (Vakili and Ölçer, 2023)

Fuel cells, as an innovative technology, offer substantial potential for reducing emissions from maritime fleets. Despite their high initial costs, fuel cells are increasingly utilised for auxiliary, hybrid, and low-power applications and especially in short sea shipping (ITF, 2018). Various types of fuel cells, including proton exchange membrane fuel cells (PEMFC) in both low and high temperature variants, and solid oxide fuel cells (SOFC), demonstrate fuel efficiencies ranging from 50-60%. When integrated with WHR systems, their efficiency can be enhanced to as much as 85% (Elkafas et al., 2022). The extent to which these technologies can reduce emissions largely depends on the type of fuel used. For instance, hydrogen-powered fuel cells can decrease emissions by up to 91.4% throughout their lifecycle (Madsen et al., 2020).

Table 4. Challenges and Opportunities for using hybrid system.

Challenges	Opportunities
· **Energy Density**: The lower energy density of batteries, relative to conventional fuels, restricts their suitability primarily to short sea shipping applications. · **Charging Infrastructure for Batteries**: Essential for supporting battery-powered vessels is the development of sustainable port infrastructure, such as OPS. The absence of such infrastructure at many seaports poses a significant barrier to the broader adoption of this technology. · **Battery Lifespan and Performance**: The harsh maritime environment, characterised by exposure to sea salt, vibrations, and temperature fluctuations, can impair battery performance and reduce their lifespan, ultimately affecting the reliability of hybrid systems. · **Fuel Infrastructure for Fuel Cells**: The adoption of fuel cell technology in the maritime sector heavily depends on the availability of carbon-neutral fuelling infrastructures, such as those for hydrogen and ammonia. The current lack of such infrastructure is a primary obstacle. · **Durability and Maintenance of Fuel Cells**: Fuel cells entail high initial costs, and their maintenance is both complex and costly, which poses a challenge for their widespread implementation in maritime applications. · **Cost of Fuel Cell Technologies**: Despite a decline in costs, the deployment of fuel cell technology remains expensive when compared to conventional systems, partly due to the use of precious metals such as platinum in fuel cell catalysts. The cost-effectiveness of these technologies is also influenced by fluctuating energy prices. · **Safety**: Batteries and fuel cells introduce specific safety risks, including chemical leaks and fires. Developing and implementing stringent safety regulations to	· **Reduction in Emissions**: Both battery/hybrid systems and fuel cell technology have the potential to significantly reduce GHG emissions and other air pollutants, aligning with the 2023 IMO GHG Strategy. The extent of emission reductions will, however, depend on the energy sources utilised within the national grid, as determined through a comprehensive well-to-wake analysis. · **Energy Efficiency**: Hybrid systems enhance operational efficiency by optimising power usage and reducing fuel consumption, while fuel cells convert chemical energy directly into electrical energy, potentially improving energy efficiency by up to 60%. · **Regulatory Compliance**: Given the increasingly stringent environmental regulations and the 2023 IMO GHG Strategy, vessels equipped with these technologies can achieve compliance more readily. Furthermore, these ships may benefit from incentive measures at ports due to their environmentally friendly performance. · **Energy Security**: Deploying battery and fuel cell technologies diversifies energy sources, enhancing energy security by reducing reliance on volatile fossil fuels. · **Quiet and Smooth Operations**: Battery/hybrid systems and fuel cells operate more quietly and smoothly compared to conventional engines, minimising both air and underwater noise. This is particularly beneficial when vessels operate in environmentally sensitive areas. · **Brand and Reputation**: Early adoption of these technologies can enhance a company's brand and reputation by demonstrating commitment to sustainable shipping. This proactive approach can also provide a competitive advantage in the

mitigate these risks is crucial, though it presents an additional barrier to adoption. · **Lack of Awareness and Expertise**: There is a critical need for training among crew and port staff regarding the handling, maintenance, and emergency procedures associated with new energy technologies to ensure safe and effective operation. · **Technological Immaturity**: Fuel cell technology, while promising, is still in early stage of development for the domain. The immaturity leads to technical challenges, limited operational data, and reluctance to stakeholders to adopt and invest in the technology until their reliability and effectiveness are more established.	increasingly environmentally conscious maritime market. · **Economic Boost and Job Creation**: The industry's transition towards zero-emission shipping and the adoption of new technologies can drive the development of required sustainable infrastructure, such as OPS and carbon-neutral fuel facilities. This development is likely to stimulate economic growth and create new job opportunities. · **Technological Immaturity**: Fuel cell technology, while promising, is still in early stage of development for the domain. The immaturity leads to technical challenges, limited operational data, and reluctance to stakeholders to adopt and invest in the technology until their reliability and effectiveness are more established.

3.2.9 Onboard carbon capture (OCC)

Considering the interdisciplinary challenges in deploying carbon neutral fuel, Onboard Carbon Capture (OCC) can be an appropriate technology for short to medium term in decarbonisation of the shipping industry, particularly in the realm of deep-sea shipping. Onboard carbon capture presents itself as a dual-purpose solution, contributing to maritime decarbonisation for both new and existing vessels. While fully comprehensive, full-scale carbon capture systems are yet to be fully realised and are still being piloted, significant progress is being made, with the IMO tasking and is expected to increase in the next decade.

Table 5. Challenges and Opportunities for using Onboard Carbon Capture Systems (OCCS).

Challenges	Opportunities
· **Technical Complexity and Space Constraints**: Integrating carbon capture technology into various ship types is complex and requires substantial space. This poses significant challenges for smaller vessels and retrofitting existing ships. · **Increased Energy Consumption**: The deployment of carbon capture technology significantly increases energy usage, potentially reducing a vessel's overall efficiency. This heightened energy demand may diminish the technology's effectiveness in reducing emissions. · **High Capital and Operational Costs**: Due to the immature state of the technology, both the capital investment and operational costs	· **Reduction in GHG Emissions**: OCC technology can significantly reduce CO_2 emissions from maritime vessels, aiding the transition towards zero-emission shipping and aligning with the 2023 IMO GHG Strategy. · **Compliance with Environmental Regulations**: Given the tightening of environmental regulations globally, the adoption of OCC technology enables compliance with these evolving standards, supporting the maritime industry's environmental accountability. · **Market Differentiation and Competitive Advantage**: Early adopters of carbon capture technology can distinguish

associated with onboard carbon capture systems are high. · **<u>Regulatory Uncertainty</u>**: The absence of specific maritime regulations for onboard carbon capture creates uncertainty. This lack of clarity can deter shipowners and operators from investing in the technology. · **<u>Storage and Logistics of Captured CO_2</u>**: Managing the safe storage, offloading, and utilisation of captured CO_2, both onboard ships and at ports, presents logistical challenges and necessitates additional investment and regulatory frameworks. · **<u>Impact on Ship Stability and Safety</u>**: The integration of carbon capture equipment requires meticulous planning and design to ensure the safety and stability of vessels, considering the added weight and altered system configurations. · **<u>Market Readiness and Technological Development</u>**: The market for OCCS is still in development. The limited availability of tailored technology for maritime applications can hinder deployment and increase costs. · **<u>Technological Immaturity</u>**: Although promising, OCCS technology is in its early stages of development within the maritime sector. This immaturity leads to technical challenges, limited operational data, and a reluctance among stakeholders to adopt and invest in the technology until its reliability and effectiveness are more thoroughly verified.	themselves in the marketplace, potentially securing a competitive advantage over peers that delay the integration of these sustainable technologies. · **<u>Potential for Carbon Credits and Preparedness for Future Regulations</u>**: Implementing OCC technology allows companies to prepare for regulations such as the Emissions Trading System (ETS) and the IMO's Market-Based Measures (MBM). Proactive adoption facilitates the refinement and smooth integration of the technology, circumventing hasty implementations in reaction to regulatory shifts. · **<u>Innovation and Technology Leadership</u>**: Investment in carbon capture technology encourages innovation within the company and across the maritime industry. This strategic focus positions a company as a leader in technological advancement, enhancing its appeal for partnerships, investment, and skilled talent. · **<u>Potential for New Business Opportunities</u>**: The development and deployment of carbon capture technology open avenues for new business ventures, including partnerships with tech providers, participation in joint industry projects, and expansion into new services cantered on carbon management and storage.

3.3 Ship-port interface

Ports are crucial in the maritime sector, and their management along with zero-emission strategies are generally divided into three areas: the ship-port interface, port operations, and the port-city interface (Vakili & Ölçer, 2023). Given the scope of this study, the analysis is specifically concentrated on the ship-port interface, examining the policies and measures that support compliance with the 2023 IMO GHG Strategy.

3.3.1 Carbon neutral fuel and energy infrastructure

Decarbonising shipping, particularly through the use of sustainable energy sources and zero-emission fuels, necessitates enhanced energy and logistical capabilities. This endeavour often requires forming strategic collaborations across various stakeholders within the industry's value chain, emphasising the crucial role of ports. The IMO, in MEPC 323 (74), emphasised the critical role of ports in decarbonisation efforts. It outlined the necessity for ports to provide infrastructure for bunkering clean fuels, OPS sourced preferably from renewable energy, facilitate 'just in time' arrivals, and implement an incentivisation schedule, all of which gain increased importance under the 2023 IMO GHG Strategy.

Effective policies at the ship-port interface are essential to comply with the 2023 IMO GHG Strategy. Ports act as vital nodes in maritime logistics, enabling not just the transfer of cargo but also the provision of infrastructure for carbon-neutral fuels and clean energy sources. This transformation of the role of ports from traditional cargo hubs to comprehensive energy hubs is instrumental in reducing emissions from vessels, both during their time in port and throughout their operational life cycle (Vakili et al., 2023a).

According to DNV (2023), there are 172 operational LNG bunkering ports, with plans for an additional 94, and 122 ports are equipped with methanol storage facilities. Moreover, out of 2,376 vessels that have shore power connections, 888 are involved in domestic shipping (Clarkson, 2024). According to Sea-LNG (2019), LNG was already available at five Mediterranean ports in France and Spain (including Port of Barcelona) since 2019 while fifteen other Mediterranean ports, including Marseilles, had plans for the development of such infrastructure from the middle of 2019. LNG bunkering infrastructure is available at the Port of Marseilles-Fos since 2022 (Offshore Energy, 2023) and at the Port of Valencia since 2020 (Port of Valencia, 2021). LNG bunkering services are also available at the Port of Algeciras since the beginning of 2024 which marks an important milestone for the port authority that can now provide environmentally friendly solutions to the LNG-powered vessels visiting the port (GreenPort, 2024). Additionally, Egypt is proceeding with plans for LNG bunkering operation at Suez Canal by 2025 at the latest given one of the key advantages of Egypt as an LNG bunkering location that derives from the country's natural gas resources and liquefaction facilities that place it in a unique and competitive position towards the key LNG bunkering hubs of the world (The Maritime Executive, 2022). Despite considerable advancements in providing clean energy to vessels, the rate and extent of development need to be accelerated to achieve the IMO's ambitious 2030 and 2050 targets, calling for increased investment and more rapid implementation efforts.

To align with the 2023 IMO GHG Strategy, approximately 17 million metric tons (30-40%) of carbon-neutral fuel is needed. Producing this quantity of fuel within the set timeframe necessitates significant investment in port infrastructure. According to Krantz, Søgaard, and Smith (2020), achieving a 50% reduction in shipping emissions by 2050 will require a substantial investment of $1.4 trillion, with about 85% of this directed towards land-based infrastructure, including renewable energy generation and fuel synthesis (World Bank, 2021). Notably, DNV (2022) reports that the average annual investment in onshore fuel infrastructure to meet decarbonisation by 2050, ranges from $28 billion to $90 billion, which is 3.5 times higher than the investments made onboard.

3.3.2 Onshore Power System (OPS)

Although the technology promises significant potential of reduction of emissions from vessels at ports, it encounters various challenges that can impede its adoption across maritime ports. Firstly, the infrastructure costs are substantial, as establishing shore power requires significant investments in both the port and the vessels, including upgrades to the electrical grid. Compatibility and international standardisation issues also pose hurdles, as vessels have varying power needs and connection mechanisms. Additionally, the layout and design of many existing ports may not support easy integration of shore power systems, necessitating extensive modifications.

Operational complexities arise from coordinating the arrival and departure of ships while managing shore power connections, requiring efficient procedures and thorough staff training. The source and availability of electricity are crucial; OPS's environmental benefits are diminished if the grid relies on non-renewable energy sources, and reliability of power supply is essential. Retrofitting vessels to enable shore power connections can be a time-consuming and costly process.

Regulatory compliance with international and local standards introduces further complexity, and the lack of global standardisation complicates operations for vessels visiting multiple ports. Space constraints in ports may limit the installation of necessary equipment. Public perception and acceptance are critical to advancing shore power initiatives, necessitating targeted education and awareness campaigns. Lastly, safety concerns, particularly regarding static electricity risks associated with high voltage operations in tankers carrying flammable cargo, should be managed. Together, these barriers highlight the multifaceted challenges in broader implementation of OPS (Bakar et al., 2023; Ballini and Bozzo, 2015; Christodoulou and Cullinane, 2021a; Spengler and Tovar, 2021; Vakili and Ballini, 2023, Vakili & Ölçer, 2023a; Zis, 2019).

3.3.3 The best practices

As vital stakeholders in the maritime domain, ports actively explore a range of policies and innovative strategies to mitigate the environmental impacts of shipping within their areas of control. Notable among these initiatives is the adoption of measures such as incentive schedules and slow steaming within port limits. These strategies are widely recognised as effective means to significantly reduce the carbon footprint of the shipping industry in port areas. To maximise the benefits of these practices, cross-sector collaboration and the sharing of insights and best practices across various industrial sectors are crucial.

- **Incentives**

Incentive schedules in ports play a crucial role in promoting the decarbonisation of ships by encouraging the adoption of cleaner technologies and more sustainable practices. Such policies are instrumental in accelerating the transition to environmentally sustainable maritime operations, thereby reducing the ecological footprint of vessels (Christodoulou et al., 2019). The efficacy of these incentive schedules hinges on their thoughtful design and implementation, as well as on broad-based industry engagement and collaboration with these initiatives. Effective programs strike a balance between the imperative to foster sustainability and the practical and economic realities of the shipping industry. Although these incentives may offer significant benefits to liner vessels, such as ferries, passenger, and container ships, they may confer less economic advantage to other types of vessels, highlighting a need for wider adaptation (Becqué et al., 2017).

In response to the urgent need to mitigate maritime environmental impacts, various incentive schemes have been established, targeting different emissions and operational facets within the shipping industry. The Clean Shipping Index (CSI) and the Environmental Shipping Index (ESI) are two notable initiatives focused on reducing emissions such as NO_X, SO_X, CO_2, and particulate matter (PM) (CSI, 2021; ESI, 2021). These indices provide benchmarks that incentivise ports, shippers, and charterers to embrace cleaner shipping practices by rewarding vessels that meet or surpass specific environmental performance standards. Conversely, the Green Award (GA) adopts a more comprehensive approach by not only prioritising air emissions but also integrating criteria related to safety, security, and service quality into its evaluation framework. This inclusive scheme appeals to a diverse group including ports, financial companies, and maritime service providers, all of whom are keen to promote higher environmental and operational standards (GA, 2021). Similarly, the Green Marine

Environmental Program (GM) broadens its scope to address additional environmental challenges such as noise, water pollution, and waste management, thereby engaging a wider array of stakeholders, including ships themselves and financial backers (GM, 2021). Collectively, these incentive schemes underscore the complex approach required to address environmental challenges in the maritime sector, facilitating a collaborative effort among various entities to cultivate a sustainable shipping environment.

- **Slow steaming**

The Vessel Speed Reduction (VSR) program is an environmental initiative implemented by many ports worldwide to minimise the ecological impact of shipping operations. Ports setting speed limits for vessels approaching or leaving the port. These limits are often enforced within a certain distance from the port or in designated areas known to be habitats for endangered marine species. Compliance with these speed limits is usually monitored via AIS (Automatic Identification System) tracking.

Lowering vessel speeds in ports through the VSR program has a multiplicity of environmental benefits. By decreasing engine power output, ship speeds directly impact the reduction of emissions such as NO_X, SO_X and PM. This reduction is critical for enhancing air quality, especially in port cities where air pollution can pose serious health risks to residents. Moreover, the implementation of slower speeds improves fuel efficiency, consequently lowering CO_2 emissions and supporting global efforts to combat climate change. Additionally, the VSR program helps protect marine life by reducing underwater noise and diminishing the likelihood of high-speed collisions with marine species, such as whales, which are particularly susceptible to disturbances and injuries from fast-moving vessels (Vakili et al., 2021).

To encourage compliance with VSR policies, ports typically offer a range of incentives to shipping companies. These incentives include reductions in port fees, prioritised services, and public recognition that can bolster a company's reputation for corporate social responsibility (OECD, 2018). The Green Flag Program of the Port of Long Beach consists of an indicative example of such initiatives encouraging vessel operators to reduce their speed to 12 knots or less within 40 nautical miles of Point Fermin, near the harbour entrance (Port of Long Beach, 2024). Operators who comply with the program at least 90 percent of the time throughout the year are eligible for dockage rate reductions. The program has been highly successful, with over 90 percent of incoming vessels participating. Despite the advantages of the VSR program, its success requires careful planning and collaboration among various stakeholders, including shipping companies, port authorities, and cargo owners. Additionally, it is crucial to strike an appropriate balance between economic, environmental, and social factors and the efficiency of operations. This balancing act is essential to ensure that implementing such measures does not lead to a loss of competitiveness with neighbouring ports.

4 Policies and Regulations

4.1 IMO Global GHG Fuel Standard (GFS) and GHG pricing

It has been agreed that the 2023 IMO GHG Strategy works on GHG fuel standard and GHG pricing as technical and economic measures; however, the debates on range of preferences of the parameters for the mid-term measures are still continued. At present there are progressive discussions to achieve an agreement on how to convert the ambitions and objectives of the 2023 IMO GHG Strategy to specific and detailed regulations by Spring 2025.

To achieve the objectives of the 2023 IMO GHG Strategy — specifically, securing at least 5%, and ideally 10%, of international shipping's energy from zero or near-zero GHG emission technologies by 2030, aiming for a 20% reduction, potentially reaching 30% in Well to Wake (WtW) GHG emissions by that date, aspiring to a 70% reduction with the possibility of reaching 80% by 2040, and targeting a complete 100% reduction by around 2050, all relative to the

2008 baseline — the implementation of both technical measures such as the GFS and economic measures including GHG pricing, is essential. These strategies collectively expedite the energy transition in shipping, motivating the worldwide fleet to embrace low-carbon and zero-carbon solutions and thus facilitating a fair and equitable transition.

In support of the IMO's mid-term GHG reduction strategies, a goal-based marine fuel standard, the GFS, has been considered. The primary objective of the GFS is to systematically reduce the GHG intensity of marine fuels. The approach is designed to promote a gradual transition to zero-emission fuels by reducing GHG emissions from marine fuels, without introducing barriers or restrictions on transportation activities.

The GFS operates as a goal-based mechanism, which does not prescribe specific fuel types for the decarbonisation of shipping but rather supports a variety of fuels and energy blends to achieve the IMO's ambitious targets. The implementation of the GFS is poised to spur investments in alternative fuels such as methanol, ammonia, hydrogen, synthetic fuels, and sustainable biofuels, as well as the necessary logistics infrastructure. This is expected to drive increased demand for these fuels within the maritime sector. However, given the short timeline to 2030 and the extended period required to establish such infrastructure, significant production and availability of carbon-neutral fuels are anticipated to materialise post-2030 (DNV, 2023).

The GFS mandates that ships of specific size thresholds (either 400 GT or 5,000 GT) utilise fuels or energy sources considering their WtW GHG intensity—measured as GHG emissions mass per unit of energy (g CO_2e/MJ)—within specified limits. According to the 2023 IMO GHG Strategy, which aims for a 70-80% reduction in total GHG emissions by 2040 from the industry, the GHG emission intensity per unit of transport work (g CO_2e per tonne-nm) should decrease by approximately 86%to 91% (UMAS, 2024).

During the 16th session of the ISWG-GHG, various parameters that could define the GFS and GHG pricing mechanisms were discussed, highlighting a range of opinions on several specific aspects:

- Whether the GFS should assess emissions based on WtW or Tank to Wake (TtW).
- Whether GHG intensity should be measured for each individual ship or averaged across the fleet.
- The intended outcomes of integrating GHG pricing within the GFS:
    - Implementing GHG pricing solely as a component of the GFS's flexibility mechanisms, akin to a credit or emissions trading system.
    - Introducing dual GHG pricing mechanisms, which would include both a GFS with credit trading and a universal GHG pricing strategy on emissions, such as a levy.
    - Simplifying the GFS to exclude credit trading but combining it with a global GHG emissions price, such as a levy.
    - The allocation and use of revenues generated from GHG pricing. Although all options generate revenues, there are differing views on how these funds should be utilised and distributed (UMAS, 2024).

Considering the outcomes of the comprehensive impact assessment conducted on the 2023 IMO GHG Strategy, the IMO Member States are better equipped to understand the implications of each mechanism and the associated concerns, thereby facilitating a more informed approach to adopting the regulations.

Coming to GHG pricing and the adoption of a MBM for the maritime industry, the MBMs mostly discussed revolve around the implementation of a global carbon tax (or levy) on fuel use and CO_2 emissions trading (Psaraftis et al., 2021; Christodoulou et al., 2021a). The potential introduction of a MBM for shipping has long been discussed within the IMO, but it was not until the adoption of the 2023 IMO GHG Strategy that the need for GHG pricing for the achievement of shipping decarbonisation was recognised.

At first place, the First IMO GHG Study in 2000 recommended exploring a global levy on marine fuel or a maritime ETS to reduce GHG emissions from shipping (IMO, 2000). However, it was not until 2010 that IMO Member States were asked to propose suitable MBMs. Various proposals were submitted, primarily focusing on global levies on marine bunker fuels and shipping emissions or different forms of ETS (Psaraftis et al. 2021). Norway, the UK, France, and Denmark were strong proponents of an ETS, with support from Japan and the US. Norway proposed a global ETS with annual emissions caps and tradable allowances. The UK's similar proposal differed in cap determination and allowance allocation. France's proposal elaborated on the auctioning mechanism. Germany's METS was another cost-efficient ETS proposal aligned with those from Norway and France. These MBMs were evaluated by the Expert Group on the Feasibility Study and Impact Assessment. Despite significant progress, the IMO suspended MBM discussions indefinitely in 2013.

MBMs regained attention with the adoption of the Initial IMO GHG Strategy in 2018, aiming to reduce shipping GHG emissions by 50% by 2050, ultimately aiming for zero emissions by the end of the century. The Initial IMO GHG Strategy included short-term, mid-term, and long-term measures, with MBMs planned for the mid-term (2023-2030). Finally, the 2023 IMO GHG Strategy actively works on the development of a GHG fuel standard and GHG pricing as technical and economic measures are considered critical for the achievement of its targets.

4.2 European Green Deal

In relation to GHG pricing and the economic mechanism(s) that could incentivise the transition to net-zero, as part of the mid-term GHG reduction measures under the 2023 IMO GHG Strategy, there are two main economic mechanisms that are discussed for the shipping industry: a global levy on marine bunkers and an ETS.

In principle, ETSs are economic mechanisms that involve the setting of an annual cap on the total CO_2 emissions of the industry sectors that are mandated to participate within the system. Participant companies can then buy or sell rights to emit (as incorporated within the emissions allowances which are granted to each industry player), depending on their industrial output and their ability to improve their energy efficiency and reduce their carbon footprint (Christodoulou and Cullinane, 2024). In this way, 'cleaner' operations are rewarded with these companies having the ability to sell their surplus emissions allowances to industry counterparts that find it more cost-efficient to buy allowances than to invest in reducing their emissions.

Although there is no adoption of such a measure at global level yet, the EU has already proceeded with the inclusion of shipping in the EU ETS since the beginning of 2024. The EU-ETS is a regional MBM that regulates GHG emissions from many industrial sectors, namely the forest industry, steel and metal industry, cement and stone, energy sector, refineries and aviation. Since 2005, the scope and allowances allocation methodology of the EU-ETS have been periodically revised and updated under certain trading periods. Aviation was included in the EU-ETS in 2012 (during the third trading period), as a semi-parallel system, mainly due to the different allocation methodology that is based on transport work (tonne-km) (Directive 2008/101/EC). During the first phase of the inclusion of aviation in the EU-ETS, 82% of emission allowances were allocated for free, a percentage that has been constantly reducing over the years.

In December 2019, the European Green Deal was adopted - the EU comprehensive roadmap to tackle climate change and achieve carbon neutrality by 2050 - that embodies a wide-ranging set of policies and aspires to facilitate the transition towards a sustainable, low-carbon future by addressing key areas such as energy, industry, transportation, and agriculture. The European Green Deal sets two critical targets for GHG reduction:

- A 2030 deadline to reduce emissions by 55% compared to a 1990 baseline.
- A 2050 deadline for carbon neutrality.

Following the adoption of the European Green Deal, the EU Fit for 55 legislative package is a landmark legislative proposal introduced by the European Commission in July 2021, representing a comprehensive set of measures aimed at significantly reducing the European Union's GHG emissions by 55% by 2030. The EU Fit for 55 legislative package encompasses several significant measures directly impacting the shipping industry as part of the broader efforts to reduce GHG emissions and achieve climate targets and includes ten proposals, three of which are directly related to shipping (Figure 8).

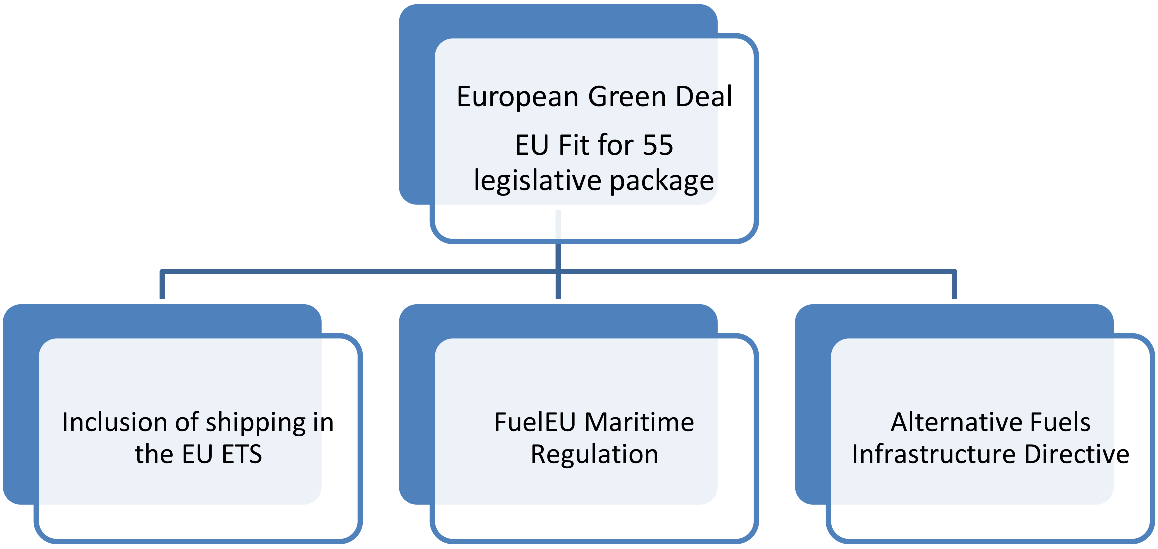


Figure 8. EU legislation and policy directly relevant to shipping.
Source: Vakili, S. and Christodoulou, A.

4.2.1 Inclusion of shipping in the EU ETS

The EU Fit for 55 legislative package extends the existing ETS to shipping. The emission trading system aims to reduce the total volume of GHG emitted over time and is implemented through a "cap and trade" mechanism, meaning that every registered emitter should buy allowances corresponding to their emissions through an auction system. Participants can only emit up to the amount covered by their allowances. If they do not have enough to cover their needs, they can purchase additional allowances. The cap is reduced on an annual basis. The reduction linear factor for GHG emissions allowances will be -4.3 % from 2024 to 2027 and -4.4 % from 2028.

All ships larger than 5,000 GT regardless of flag that are engaged in internal European Economic Area (EEA) voyages, incoming voyages from the last non-EEA port to the first EEA port of call, and outgoing voyages from an EEA port to the next non-EEA port of call, are departing from an EU port or arriving at an EU port, fall under the scope of the EU Monitoring, Reporting and Verification Regulation (2015/757) (EU MRV) and have already begun collecting GHG emissions since 2018. EU MRV regulation requires shipowners and operators to annually monitor, report and verify data on each ship's CO_2 emissions, fuel consumption, distance travelled, time spent at sea and cargo carried. This data is then published annually by EMSA, with the first data available for the year 2018 published 2019-07-01.

The geographical scope of the system covers 100% of internal EEA voyages, 50% of incoming voyages from non-EEA to EEA ports and outgoing voyages from EEA to non-EEA ports. The phase-in period will start from January 1st, 2024, with:

- 40% of the verified emissions covered in 2024
- 70% of the verified emissions covered in 2025
- 100% of the verified emissions covered in 2026.

The penalty for excess emissions will be €100 per metric ton equivalent emitted. Moreover, the operator remains under the obligation to purchase the corresponding quantity of allowances for emitted emissions. In case of persistent non-compliance for two or more consecutive reporting periods:

- expulsion orders may be issued at the port of entry in case of non-compliance
- flag detention order until the shipping company fulfils its obligations (for ships flying the flag of an EU Member State within a port in that Member State).

There are certain exemptions for the adoption of the Directive. Until December 31, 2030, ships with ice-class IA or IA super, or equivalent, may surrender 5% fewer allowances. Additionally, some emissions are excluded on voyages by passenger and Ro-pax:

- between an EU port on an island with fewer than 200,000 permanent residents where there is no road or rail link with the mainland and a port of the same State, and from their activities within a port;
- when performed as part of a transnational public service contract or obligation between two EU ports, and from their activities within a port;
- between an EU port located in an outermost region and a port of the same State, and from their activities within a port.

Table 6. Challenges and Opportunities for implementing EU ETS.

Challenges	Opportunities
● **Carbon leakage**: in the case of the inclusion of shipping in a regional ETS, shipping companies may have greater motivation to register all or some of their vessels elsewhere or even engage in maritime trades in other geographical regions in preference to the EU, to avoid compliance with the regional ETS system or, alternatively, decide to use neighbouring ports outside of the geographical coverage of the ETS. Transport & Environment (2020) analysed the additional costs for re-routing vessels away from EU ports. According to their findings, ships would only deviate if it is in a ship's financial interest to avoid the ETS and this would only happen if compliance costs were more expensive than the sum of all the extra costs involved in the deviation to an alternative port. Based on their calculation for a representative model vessel, vessels approaching EU ports would only proceed with a deviation from their route if the price per emission allowance unit would be	● **Sector-dedicated fund**: The fund aims to "improve the energy efficiency of ships and support investment in innovative technologies and infrastructure to decarbonise maritime transport, including in short sea shipping and ports, and the deployment of sustainable alternative fuels and zero-emission propulsion technologies." For example, compensate for the ongoing current investments in cleaner fuels (e.g., hydrogen and ammonia) that are not only more expensive per unit of energy than conventional alternatives, but also require some initial investment for their deployment (e.g., engine conversion). A fund that would promote climate adaptation and mitigation within the maritime sector through R&D of green technologies and technical support to least developed and developing countries for the introduction of these technologies. A regional ETS for shipping would support the effective

123 euros or above. On the other hand, Psaraftis and Lagouvardou (2022) estimated that much lower prices per emission allowance unit could lead to potential deviations from EU ports to neighbouring ports. ● The European Commission has announced that containerships sailing from a non-EU port to discharge cargo at an EU port by the way of Tanger Med or East Port Said will pay for 50% of emissions. Directive (EU) 2023/959[1] sets out an exclusion from the definition of 'port of call' of stops of containerships in a neighbouring container transhipment port. For a port to be identified as a neighbouring container transhipment port, it needs to meet several criteria: a) the port's share of transhipment of containers should exceed 65% of the total container traffic of that port during the most recent 12-month period for which relevant data is available, b) the port should be located outside the EU but less than 300 nautical miles from a port under the jurisdiction of an EU Member State. ● An ETS allows the price of emission allowances to be determined by the market forces creating an increased uncertainty to shipping companies (already operating under highly volatile market conditions) (Flodén et al., 2024). ● In the case where shipping companies merely attempt to pass on their additional CO_2 costs to shippers and passengers, the threat of a modal shift from shipping to land-based modes of transport due to the increased cost of maritime services is mainly relevant only to short-sea shipping. In contrast to deep-sea shipping that, in many cases, has no substitutes and is characterised by a highly inelastic demand, the high elasticity of demand that characterises short-sea shipping services means that their customers could easily turn to alternative modes of transport (Christodoulou and Cullinane, 2024). Any resulting modal shift from shipping to road transport would lie in contradiction to the achievement of climate neutrality in Europe, notwithstanding the greater generation of other negative externalities of road transport related to safety and congestion.	implementation of the FuelEU Maritime Regulation that requires all vessels of 5,000 gross tonnage and above to gradually reduce their carbon content of marine fuel starting from 2025. ● Shipping companies need to develop a long-term sustainability strategy to maintain their competitiveness through investments. The cost-effectiveness of the different abatement options for the reduction of CO_2 emissions from shipping will rationally equal the emission allowance price, as ship operators will seek to minimise the additional cost from CO_2 emissions. ● investments in carbon neutral technology: As shipping companies will face increased operational costs from having to pay for CO_2 emissions allowances, they will seek to reduce their costs, either by adjusting their operational practices (e.g., utilising slow steaming) in the short term or by retrofitting new technologies on their vessels or renewing their fleet in the longer-term. ● Reward the 'first movers'—the companies that have been proactive and have already reduced their carbon footprint—by offering them the opportunity to sell their surplus emissions allowances to those companies with lesser environmental credentials and this will contribute to generating additional revenues.

[1] Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system.

4.2.2 FuelEU Maritime Regulation

FuelEU Maritime Regulation 2023/1805 entered into force on 12 October 2023 and will apply from 1 January 2025. It promotes the use of renewable and low-carbon fuels and speeds up large-scale production. Ideally, renewable, and low-carbon fuels (RLF) should represent 86-88% of the international maritime transportation fuel mix by 2050 to contribute to the EU targets. FuelEU Maritime aims to drive demand and mitigate competition between operators and ports during the fuel transition. The regulation's two key targets areas are:

- Mandatory use of OPS or other technologies offering equivalent environmental benefits at berth in an EU port for calls lasting more than two hours
- GHG intensity limits on energy used onboard a ship.

From 2025, FuelEU Maritime will include ships of 5,000 GT and above, regardless of their flag. In future, and pending reviews, the regulation's scope may be increased to include more vessels. As for voyages, FuelEU maritime applies to:

- 100% of energy used for voyages between two EU ports (or EEA) of call and at berth
- 50% of energy used for voyages between an EU port (or EEA) and an extra-EU destination.

Transhipment is also covered under FuelEU Maritime if:

- It occurs within a zone of 300 nautical miles.
- The share of transhipment containers exceeds 65% of total container traffic at the relevant port.

FuelEU Maritime will apply to 50% of the energy used between the extra-EU port of origin or destination and the EU port (or EEA) in question. The annual reduction targets will become more ambitious up to 2050 to reflect developments in low-carbon fuel technology and availability (Figure 9).

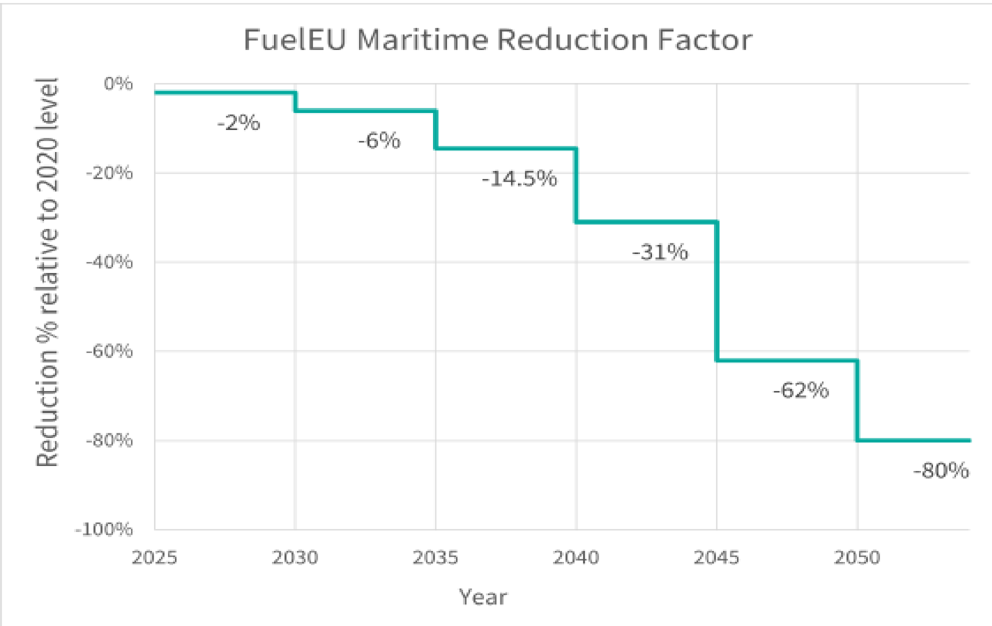


Figure 9. Reduction in GHG intensity of energy used on board from 2020 levels (%). Source: Lloyds Register.

The following cases of energy use will be exempt up until 31 December 2029:

- Passenger ships providing transportation services between ports of call under the jurisdiction of the same EU Member State when one port of call is located on an island with fewer than 200,000 permanents residents.
- Energy used between two ports of call-in outermost regions, and the energy used during their stay in port.
- Passenger ships operating before this regulation comes into force, on specific routes between their mainland ports of call and ports of call under their jurisdiction located in an island or the cities of Ceuta and Melilla.
- Ice-classed ships and ships sailing in ice will also benefit from a reduction factor in the GHG intensity of energy used onboard until 31 December 2034.

The use of OPS at berth will apply as follows:

- Container and passenger ships at quayside in TEN-T core and comprehensive network ports from 2030
- Container and passenger ships at quayside in all EU ports (or EEA) where the quay is equipped from 2035.

There are three exemptions from the mandatory use of OPS:

- In unscheduled port calls, for emergency, safety and lifesaving reasons, which will have to be certified by the administering body of that port.
- Before 2035, if OPS is unavailable or incompatible in a port of call.
- Ships staying at port for less than two hours.

It is not a simple task to forecast how the shipping industry will react in order to comply with the FuelEU Maritime Initiative, since the decision to invest in alternative fuels is multi-dimensional (Christodoulou and Cullinane, 2022). It will most probably move towards the 'less radical' options, at least in the short term. However, renewable fuels will be the only effective solution for meeting the required reductions in GHG energy intensity beyond 2040, with levels reaching as high as 80% in 2050 compared to 2020. The decarbonisation of maritime transport through investments in renewable fuels will be initiated through the Initiative, but it will probably take place later on; probably after 2040. Time will obviously be needed for the shipping industry to introduce renewable fuels via new buildings designed to run on them and the retrofitting of existing vessels.

4.2.3 Alternative Fuels Infrastructure Regulation (AFIR)

The Alternative Fuels Infrastructure Regulation (AFIR)[2] entered into force on 12 October 2023 to ensure that EU Member States adopt appropriate GHG reduction measures of equal ambition and the adoption of RLF is not constrained by a lack of recharging and refuelling infrastructure. The AFIR will work hand in hand with the FuelEU Maritime Regulation and the Trans-European Transport Network (TEN-T). These three measures are essential to trigger the development of policies for the rollout of alternative fuels infrastructure in Mediterranean coastal States that are EU Member States.

In 2016, the Alternative Fuels Infrastructure Directive (AFID)[3], the predecessor of the AFIR, had already required EU Member States to create and provide National Policy Frameworks

[2] Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU.
[3] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure.

(NPFs) to the EU Commission, which should outline national objectives for implementing RLF infrastructure, including both maritime and inland LNG infrastructure.

With the AFIR, the main EU ports (TEN-T ports) are required to provide a minimum shore-side electricity supply for seagoing container ships and seagoing passenger ships over 5,000 GT as of January 2030, while designated ports should provide an appropriate number of refuelling points for liquified methane by January 2025. AFIR will indirectly benefit ship operators as it will assist them in meeting the FuelEU requirements. The inclusion of provisions for both OPS and RLF infrastructure will prove useful in achieving this objective.

5 Case studies

The Mediterranean Sea, covering an area of 2.5 million km², is a pivotal maritime hub that connects the Atlantic Ocean with the Red Sea and the Indian Ocean through the Suez Canal. This strategic connection facilitates a more direct shipping route between Europe and Asia, considerably reducing transit times compared to the alternative route around the Cape of Good Hope. Over the decade from 2010 to 2019, maritime trade to and from Mediterranean coastal States increased significantly by 284 million tonnes (González, 2022). The Suez Canal plays a critical role in global trade, managing the annual movement of vast amounts of cargo. Its strategic position not only underscores its global significance but also brings to light environmental and operational challenges stemming from intense maritime traffic and related emissions.

The Mediterranean region is uniquely encircled by many countries that differ greatly in cultural, economic, and social aspects. This diversity makes it challenging to achieve consensus and implement uniform policy measures on issues like maritime emissions, where different priorities and capabilities exist. Furthermore, the region contends with competing land uses such as tourism, agriculture, and transport, which also shape its environmental policies and practices.

Given the diverse number of states within the region and the limited timeline of the Study, it was not feasible to thoroughly review and evaluate the efforts of each Contracting Party to the Barcelona Convention (CP) to comply with the 2023 IMO GHG Strategy. Therefore, case studies from different continents were selected to obtain a broader perspective on the CPs' compliance. It is important to clarify that the selection of these case studies does not diminish or overlook the significant roles other CPs play in regional maritime transportation. These case studies are based on publicly available information from reliable websites and all relevant references are cited in the text and included in the list of references. Additionally, a questionnaire that assessed the awareness of the 2023 IMO GHG Strategy and identified related drivers and barriers was developed and distributed among all CPs to the Barcelona Convention, which provided further information. This case study approach aims to garner more detailed insights into how various CPs are addressing the challenges and requirements of the 2023 IMO GHG Strategy.

5.1 Egypt

Egypt is endowed with 37 ports, with ten situated on the Mediterranean Sea and the remainder on the Red Sea. Among these, the principal ports — Damietta, Alexandria, East Port Said, El Dekheila, Sokhna, Adabia, and West Port Said — are notable for their significant cargo throughput, which amounted to approximately 154.5 million tons in 2018 (Maritime Transport Sector, 2019; Mohamed Hussein, K. N., 2021). The Suez Canal plays a critical role not only in the global economy but also significantly impacts Egypt's economy. Key ports such as East and West Port Said, Damietta, Alexandria, and El Dekheila are frequented by major shipping lines, including MSC, Maersk, and CMA CGM, as depicted in Figure 10.

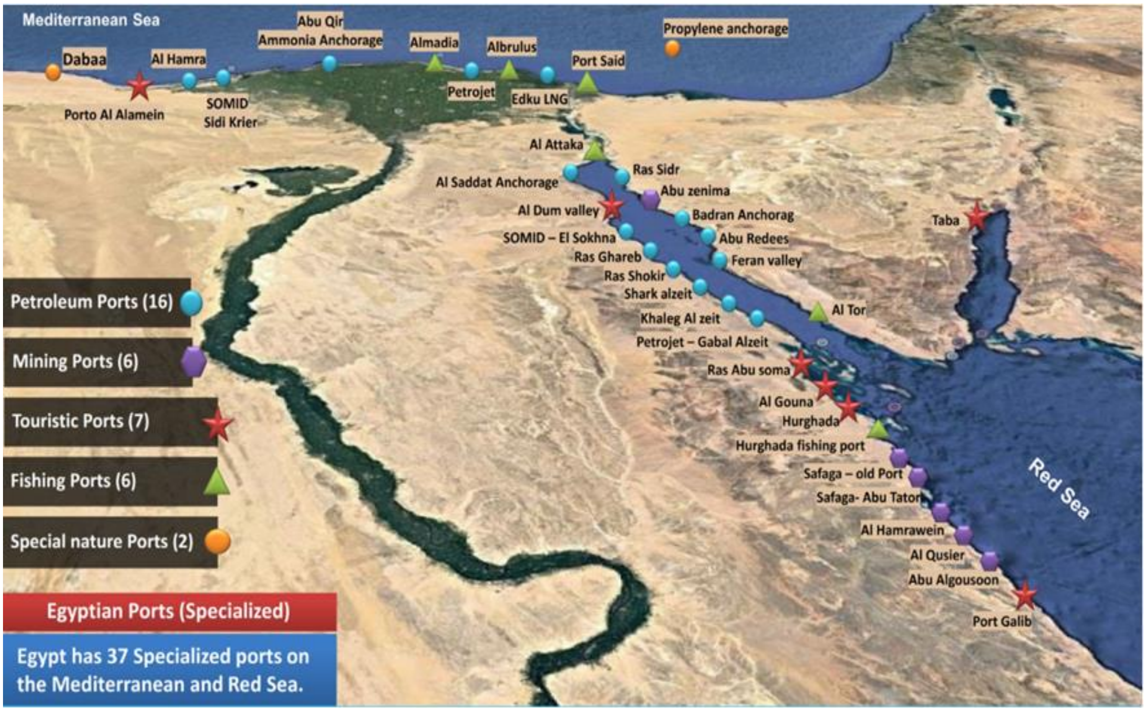


Figure 10. Specialised Ports Archives in Egypt. Source: Adopted from mts.gov.eg.

Recognising the potential benefits of transitioning to zero-emission shipping, Egyptian ports are considering significant upgrades as part of a national plan to promote international maritime connectivity and improve the infrastructure to support sustainable shipping practices. For example, the construction of a transshipment terminal by Hapag-Lloyd at Damietta aims to enhance the capacity and efficiency of Egypt's maritime logistics and includes the implementation of technologies and systems that align with global sustainability goals (Ship Technology, 2023; Xinhuanet, 2021).

Egypt boasts a promising energy mix that includes renewable sources, green hydrogen, and hydrocarbon resources (Egypt Oil and Gas, 2024). Given its abundant solar irradiance and high wind speeds, the country is uniquely positioned to significantly expand its renewable energy sector. This includes untapped opportunities to enhance the production of green fuels such as green hydrogen and green ammonia in the future. Currently, Egypt's renewable energy generation comprises 18% solar energy, 60% hydro power, and 22% from wind. With the implementation of the El-Dabaa Project, it is anticipated that the contribution of wind energy to the nation’s electricity production could increase to 30% by 2050 (Egypt Oil and Gas, 2024).

In light of this potential, Egypt is making substantial investments to further develop its capacity for producing green hydrogen and green ammonia, aligning with global sustainability goals and energy diversification strategies. Egypt has set ambitious targets, aiming to increase its annual production from 3.2 million tons to 9.2 million by 2040. This initiative positions Egypt to become a significant player on the global stage, with plans to establish itself as a regional centre for green hydrogen production by 2026, and a global hub by 2030.

Moreover, Egypt has made significant strides in integrating renewable energy technologies, evidenced by the establishment of the first green hydrogen facility in Africa. This facility boasts a capacity to produce 15,000 tons of green hydrogen and 90,000 tons of green ammonia annually. Notably, in 2023, this project facilitated the export of the world's first green ammonia shipment to India, marking a significant milestone in global green energy trade.

Taking into account the trend in the maritime market towards carbon-neutral fuels and the pivotal role of Egyptian ports and the Suez Canal in global maritime transportation, there exists a significant opportunity for Egyptian ports to invest in the production of carbon-neutral fuels and to act as energy hubs within the maritime logistics domain. The Suez Canal Economic Zone (SCZONE) has dedicated substantial resources to developing the necessary infrastructure for the production of carbon-neutral fuels. In this context, the SCZONE, the Petroleum Technical Office, and Scatec ASA have entered into a MoU that facilitates Scatec's involvement in ship bunkering operations with green fuels at East Port Said, representing an investment of $1 billion (Magli, 2023).

Furthermore, the Gulf of Suez is home to a project aimed at producing 183 tons per day of green hydrogen and 1,000 tons per day of green ammonia, with an investment of $1 billion. This initiative is part of a broader effort to develop sustainable maritime fuel options across Egypt's ports. This strategic development positioned Egypt to welcome the first Green Fuel Container Ship in Africa and the Middle East on 23 August 2023 at East Port Said, where it bunkered with 500 tons of green methanol.

Considering additional measures to enhance the ship-port interface and reduce air emissions from ships at ports, detailed information remains limited. International companies operating terminals in Egypt's major ports have set ambitious goals to decrease their carbon footprint across scopes 1 to 3, achieving notable reductions in their overall emissions portfolio. Their strategies focusing on automation, digitalisation, and logistics development may indirectly contribute to shorter ship port stays, thereby aiding in the reduction of emissions at ports.

As an example, the Alexandria International Container Terminal, operated by Hutchison Ports, has set a robust goal to achieve zero-emission shipping by 2050. This target is supported by an ambitious net-zero strategic roadmap (Hutchison Ports Sustainability Report, 2023). While the port aims to achieve zero emissions by reducing emissions in Scopes 1, 2, and 3, through increased use of renewable energy, reducing fossil fuel use, sourcing cleaner electricity, and utilising battery-powered vehicles and equipment, it currently lacks specific initiatives to lower ship emissions at the port through enhanced ship-port interface strategies. However, future plans include considering the establishment of a green corridor and implementing incentive measures, which are expected to reduce emissions related to ship-port interfaces.

In summary, Egypt's capacity to generate electricity from renewable sources presents a unique opportunity for ports to offer OPS from clean energy sources, which could significantly reduce emissions from the shipping industry. However, achieving this requires substantial investment and consideration of both ship-port and ship-city interfaces. It is crucial that the capacity of the national grid is increased, and the existing grid is modernised to support these initiatives (Vakili and Ölcer, 2023). Collaboration among various stakeholders at both horizontal and vertical levels is essential.

Given the strategic positioning of Egyptian ports within the maritime domain, coupled with the country's shift towards producing carbon-neutral fuels, a unique opportunity emerges for establishing Green Corridors with other ports. Such an initiative would not only expedite the transition to zero-emission shipping but also attract investments in zero-emission technologies, aiding in the achievement of the IMO’s ambitious goals. Given that many ports are located in populated urban areas, reducing emissions will not only improve air quality but also enhance the well-being of the community.

5.2 Greece

Greece is a leading maritime nation, with its shipping industry and tourism being the most vital sectors of its economy. For many years, Greece has held the top global position for the number of merchant ships owned by its nationals. Greek owners have a strong presence in the tanker and bulk carrier sectors, which handle the majority of global trade (UGS, 2024). Even during the COVID-19 pandemic, starting from 2019, the capacity increased by 7.4% (Figure 11). Greek shipowners continually invest in new, energy-efficient ships and environmentally friendly equipment with more than 27.6% of the Greek-owned fleet's tonnage (in terms of dwt) meeting the global EEDI standards (UGS, 2024).

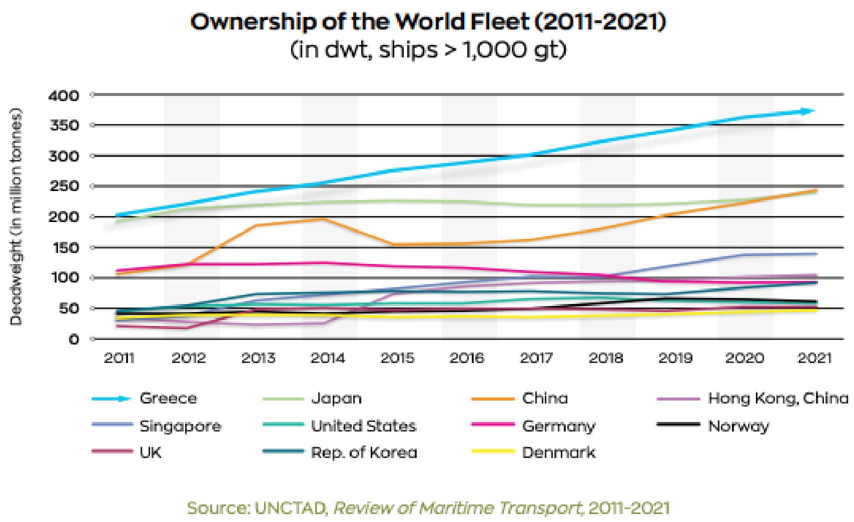


Figure 11. Ownership of the world fleet (2011-2021).

With regards to the 2023 IMO GHG Strategy and the net-zero target for around 2050, it was welcomed by the Union of Greek Shipowners (UGS) that confirmed its commitment to decarbonisation of the sector and its strong support to the goals of the 2023 IMO GHG Strategy. The UGS emphasises that safe and effective alternative drop-in fuels are crucial for enabling the existing fleet to meet the revised decarbonisation targets, especially given the short timeline to the 2030 checkpoint, while maintaining global trade operations. The availability and distribution of these fuels and technologies will largely depend on external stakeholders such as fuel producers, suppliers, engine manufacturers, shipyards, and ports. The UGS also underscores the necessity for the IMO to ensure a safe transition to alternative fuels and technologies for ships and their crews. Additionally, the UGS calls for the urgent adoption of a levy-based economic measure for GHG emissions, alongside a simple, goal-based fuel standard as proposed by the industry. This approach is essential to reduce the cost gap between conventional and low-carbon fuels, ensuring their availability and use (UGS, 2023).

At national level, Greece is committed to the implementation of the IMO regulations and conventions with this commitment being threefold as ‘the Hellenic Republic shall meet efficiently its responsibilities **as a flag, port and coastal state** by taking action for the effective implementation of the relevant international mandatory instruments… In doing so, Greece shall maintain a proactive maritime administration ensuring that all laws, regulations and recommendations are implemented and enforced effectively, thus guaranteeing that flag, port and coastal state obligations are fully met’ (YNAPN, 2021).

With regards to the energy and climate policies of Greece, these are aligned to the European Green Deal that aims to achieve net-zero emissions by 2050, while ensuring energy security and economic competitiveness (IEA, 2023). The National Energy and Climate Plan (NECP) of 2019 and the National Climate Law of May 2022 set specific targets for reducing GHG emissions by 55% by 2030, 80% by 2040, and reaching net-zero by 2050.

Coming to the Greek port sector, the country has numerous ports, essential to the country's economy and the broader European transport network. Major ports such as Piraeus, Thessaloniki, Patras, Igoumenitsa and Heraklion are crucial for both passenger and freight transport. Some Greek ports form part of the TEN-T that is a fundamental aspect of the EU transport policy, designed to enhance connectivity and support economic growth across Europe. In Greece, the ports that are part of the TEN-T network and have an enhanced strategic significance are:

- **Port of Piraeus**: One of the largest ports in the Mediterranean, Piraeus is a major gateway for trade between Europe and Asia. As a key node in the TEN-T network, it provides extensive cargo handling and passenger services.
- **Port of Thessaloniki**: A critical hub in the TEN-T network, Thessaloniki serves the Balkans and southeastern Europe. It handles a substantial volume of container traffic and is crucial for regional trade and logistics.
- **Port of Patras and Port of Igoumenitsa**: Both located on Greece's western coast, they are vital for passenger and freight transport to and from Italy and other parts of Western Europe. As part of the TEN-T network, they ensure efficient maritime connections.
- **Port of Heraklion**: Situated on the island of Crete, Heraklion supports both tourism and cargo operations. As a TEN-T network port, it plays an important role in linking the Aegean Sea with broader European routes.

Under the EU Fit for 55 legislative package, the TEN-T ports are considered as proactive with many regulations becoming mandatory for these ports before the rest of the EU ports. As an example, the provision of OPS in core TEN-T ports under the FuelEU Maritime is becoming mandatory from 2030 while the rest of the EU ports have 5 more years to comply with the regulation.

The Port of Piraeus is one of the Mediterranean's most significant ports and a crucial maritime hub for Greece. Located near Athens, it acts as a major gateway for trade between Europe and Asia, handling a substantial volume of container traffic, cargo, and passenger services. It serves as a key node in the TEN-T, enhancing its strategic importance and connectivity within Europe. Moreover, Piraeus is a leading cruise port, drawing millions of tourists annually and serving as a starting point for numerous Mediterranean cruises. Its state-of-the-art facilities and efficient operations make it a preferred destination for global shipping lines, reinforcing its status as a key logistics and transportation centre. Continued investments in infrastructure and modernisation efforts are boosting the port's capacity and efficiency, ensuring its competitiveness on the global stage. The Port of Piraeus is essential not only to Greece's maritime industry but also to regional and international trade networks.

The Port of Piraeus is actively embracing the energy transition as part of Greece's broader commitment to sustainability and reducing carbon emissions. Central to this transition is the adoption of green technologies and renewable energy sources to power port operations. Key initiatives include the installation of solar panels and other renewable energy systems to generate clean electricity, reducing reliance on fossil fuels. The port is also upgrading its infrastructure to support the use of alternative fuels, such as LNG, for ships and port equipment, significantly lowering emissions from maritime activities. Energy efficiency measures are being implemented across the port, including the modernisation of buildings and facilities to reduce energy consumption. The port is investing in electric vehicles and equipment, further minimising its carbon footprint. Additionally, the Port of Piraeus is exploring smart grid technologies and energy management systems to optimise energy use and integrate renewable energy more effectively. These efforts align with the European Green Deal and Greece's National Energy and Climate Plan (NECP), positioning Piraeus as a leader in sustainable port operations and contributing to the overall energy transition of the maritime industry. By adopting these innovative practices and technologies, the Port of Piraeus aims to enhance its environmental performance, support Greece's climate goals, and maintain its competitiveness as a major global maritime hub.

5.3 Spain

Spain boasts an extensive network of ports that play a crucial role in the country's economy, trade, and tourism. With its strategic location along the Mediterranean Sea and the Atlantic Ocean, Spain's ports serve as vital gateways for international trade between Europe, Africa, and the Americas. Spanish ports that form part of the TEN-T are (Figure 12):

- **Port of Algeciras**: Located in the south of Spain, the Port of Algeciras is one of the busiest ports in the Mediterranean and Europe. It serves as a major transshipment hub, handling a significant volume of container traffic. Its strategic position at the crossroads of major shipping routes makes it a pivotal point for global trade.
- **Port of Valencia**: The Port of Valencia is the largest container port in Spain and the fifth busiest in Europe. It plays a critical role in the Spanish economy, facilitating extensive trade with Asia, the Americas, and the Mediterranean region. The port is known for its advanced logistics and efficient operations.
- **Port of Barcelona**: As one of Spain's most important ports, the Port of Barcelona handles a diverse range of cargo, including containers, vehicles, and bulk commodities. It is also a major cruise port, attracting millions of tourists each year. The port is renowned for its modern facilities and connectivity.
- **Port of Bilbao**: Situated on the northern coast, the Port of Bilbao is a key entry point for goods coming into Spain from the Atlantic. It handles a variety of cargo types, including bulk, breakbulk, and containerised goods. The port is also noted for its role in the energy sector, particularly in handling LNG.
- **Port of Cartagena**: This port on the southeastern coast of Spain specialises in handling liquid bulk commodities, particularly petroleum products. It is also an important naval base and has facilities for handling general cargo and containers.

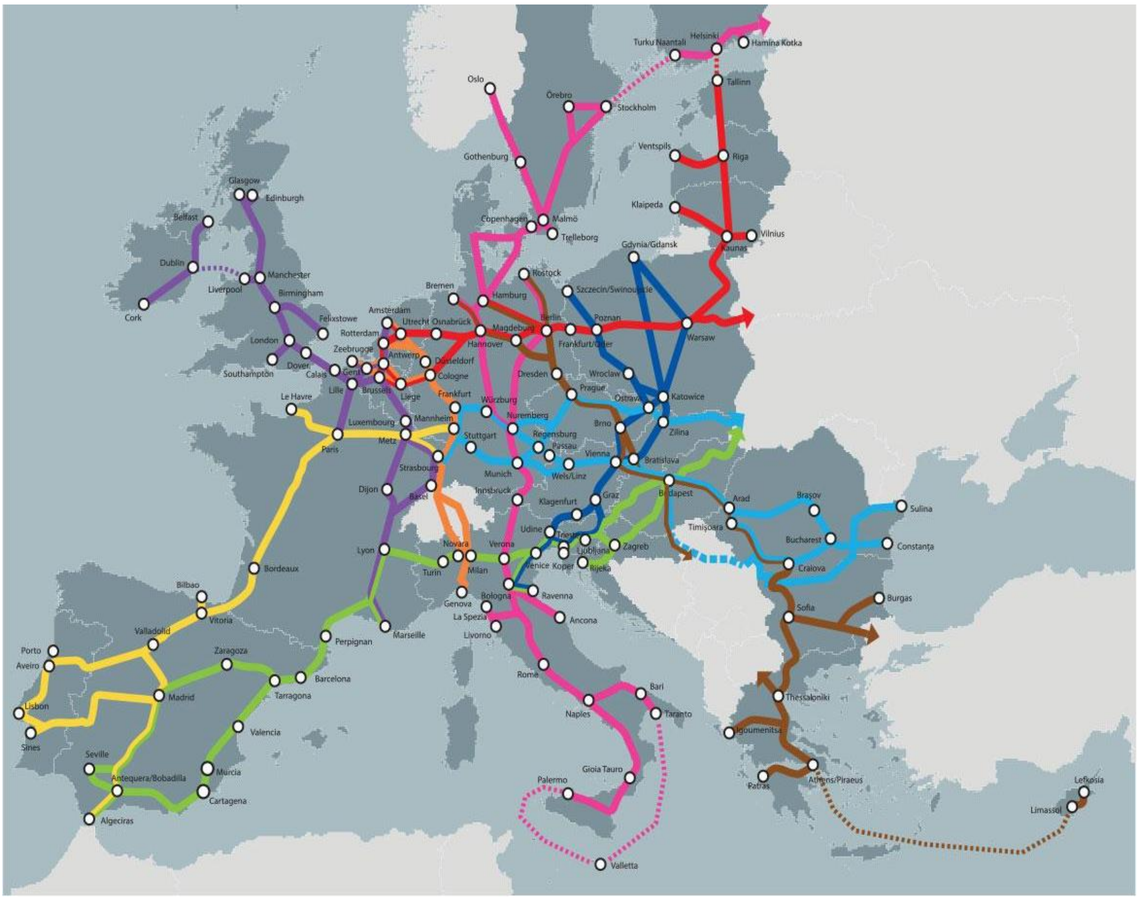


Figure 12. TEN-T.

Spanish ports are increasingly focusing on sustainability and environmental protection. Initiatives include the adoption of green technologies, such as OPS to reduce emissions from ships while docked, and investments in renewable energy sources. Ports like Valencia and Barcelona are leading the way in implementing measures to reduce their carbon footprint and promote sustainable maritime practices. Ongoing investments in port infrastructure aim to enhance capacity, efficiency, and connectivity. Major projects include the expansion of container terminals, modernisation of facilities, and improvements in digital infrastructure to support smart port operations. These developments are designed to ensure that Spain's ports remain competitive in the global maritime industry and continue to drive economic growth. Overall, Spain's ports are vital hubs for trade and tourism, playing a key role in the country's economic development and integration into the global economy. Their strategic initiatives and continuous improvements position them as leaders in the maritime sector.

More specifically, the Port Authority of Valencia, in accordance with the European Green Deal policies, has developed a strategy to significantly reduce GHG emissions from port activities. This strategy focuses on implementing findings from various innovation projects that emphasise energy efficiency, climate impact reduction, the circular economy, and the transition to clean fuels and renewable energy sources. The project focuses on six key areas within the port sector value chain to achieve zero emissions, surpassing mere decarbonisation by also targeting reductions in local air pollutants, such as PM and other harmful pollutants. The strategy includes:

.1 **Renewable Energy**: Developing a mix of wind, photovoltaic, and wave energy, along with intelligent management systems, to ensure renewable energy generation and efficient energy distribution, considering Valencia's climatic conditions.

.2 **Hydrogen Technologies**: Implementing hydrogen production, storage, and distribution to promote green hydrogen. Green hydrogen is recognised as essential for decarbonising the European economy, and Spain has already included it in its national plans with the Renewable Hydrogen Roadmap. The strategy includes specific 2030 targets for using hydrogen as a port fuel.

.3 **Intelligent Energy and Traffic Management**: Optimising systems for managing freight and passenger traffic to reduce inefficiencies and environmental impact.

.4 **Decarbonisation of Port Operations**: Introducing circular economy practices and eco-efficient infrastructures, along with pilot projects for hydrogen-powered and electric terminal machinery to reduce emissions. This includes analysing port operations, their environmental impacts, and proposing solutions like hydrogen pilot boats, onshore power supply systems for ships, and hydrogen and electric terminal machinery.

.5 **Road Transport Decarbonisation**: Deploying a fleet of zero-emission trucks and supporting supply facilities to extend decarbonisation efforts beyond the port area.

.6 **Improvement of Rail Transport**: Enhancing rail transport usage in ports to further reduce emissions.

These initiatives are designed to ensure the Port of Valencia achieves zero emissions while maintaining efficient port operations and addressing environmental impacts comprehensively.

5.4 Türkiye

Due to its strategic location, Türkiye serves as a crucial gateway linking the Black Sea with the Mediterranean Sea. Among the Mediterranean costal States that are not EU Member States, Türkiye boasts the strongest economic ties with the EU, ranking as its sixth-largest trading partner. The Turkish maritime transport system is integral in transporting goods to the EU and is influenced by both the 2023 IMO GHG Strategy and the EU maritime legislation. As the EU strives to be the first carbon-neutral continent by 2050, it has integrated maritime transportation into this ambition. Regulations such as the EU ETS and FuelEU Maritime impact all nations with shipping operations in Europe, including Türkiye.

Türkiye has set a target for achieving net-zero emissions in the maritime sector by 2053, as announced by the Ministry of Environment, Urbanisation, and Climate Change in 2021. Considering the role of the Turkish maritime transportation in its economic as well as the integration with the EU and the associated emissions with the Turkish maritime transportation, the transition to greener and cleaner technologies and operations becomes more important. Therefore, the sector carefully follows the developments in the EU and in IMO, and it leads to an increasing number of carbon neutral maritime businesses in the country such as adaptation of green transformation projects.

Taking all the above into consideration, shipowners invest in green technologies and using carbon neutral fuels in new-build ships and some major Turkish ports are actively planning investments in sustainable infrastructure. This includes the development of facilities for cleaner and carbon-neutral fuels, as well as onshore power stations to support environmental sustainability initiatives. However, considering the timeline with meeting the 2023 IMO GHG Strategy, the transition should be taken faster.

Türkiye's action towards adopting carbon-neutral fuels in the maritime sector aligns with broader European and global efforts to reduce GHG emissions such as the 2023 IMO GHG Strategy, the FuelEU Maritime Regulation and the EU ETS. This national initiative from Türkiye's side enhances the adoption of regulations that encourage the use of renewable and low-carbon fuels in maritime transport. The integration of carbon-neutral fuels in Türkiye's maritime industry is part of its larger strategy to adapt to sustainable energy sources and reduce dependency on traditional fossil fuels like coal, oil, and natural gas.

In its recent National Energy Plan for 2035, Türkiye has committed to a significant expansion and diversification of its renewable energy portfolio, emphasising solar and wind power (Climate action tracker, 2023; Enerdata, 2023). Considering the potential of the country to harness renewable energy sources, the Turkish Ministry of Energy and Natural Resources has unveiled Türkiye's National Hydrogen Strategy and Roadmap. Projections suggest that the demand for green hydrogen in Türkiye could exceed 1-1.5 million tons by 2030 and could rise to 2-2.5 million tons by 2050. This anticipated growth in green hydrogen demand offers substantial opportunities for the creation of innovative business models in this rapidly expanding sector.

The strategic document outlines ambitious targets for the production of green hydrogen, alongside plans to foster local manufacturing through incentive programs. This detailed strategic framework identifies hydrogen and ammonia production for widespread industrial use, with a particular emphasis on the transportation sector. The strategy intends to leverage excess production for global trade, with a specific focus on the renewable ammonia market. Such initiatives position renewable ammonia as a viable fuel alternative for maritime shipping. Recognising the primary challenge of high production costs, Türkiye has set ambitious targets to expand its hydrogen production capabilities to 2 GW by 2030, 5 GW by 2035, and 70 GW by 2053. The cost objectives are defined at $2.40 per kilogram by 2035, decreasing to below $1.20 per kilogram by 2053, in alignment with Türkiye's goal of achieving net-zero emissions by that year. Meanwhile, key stakeholders in the Turkish energy market are exploring the possibilities and addressing the challenges associated with green hydrogen. It is predicted that Türkiye will produce 500 tons of green hydrogen per year (Fuelcell work, 2023) (See Figure 13).

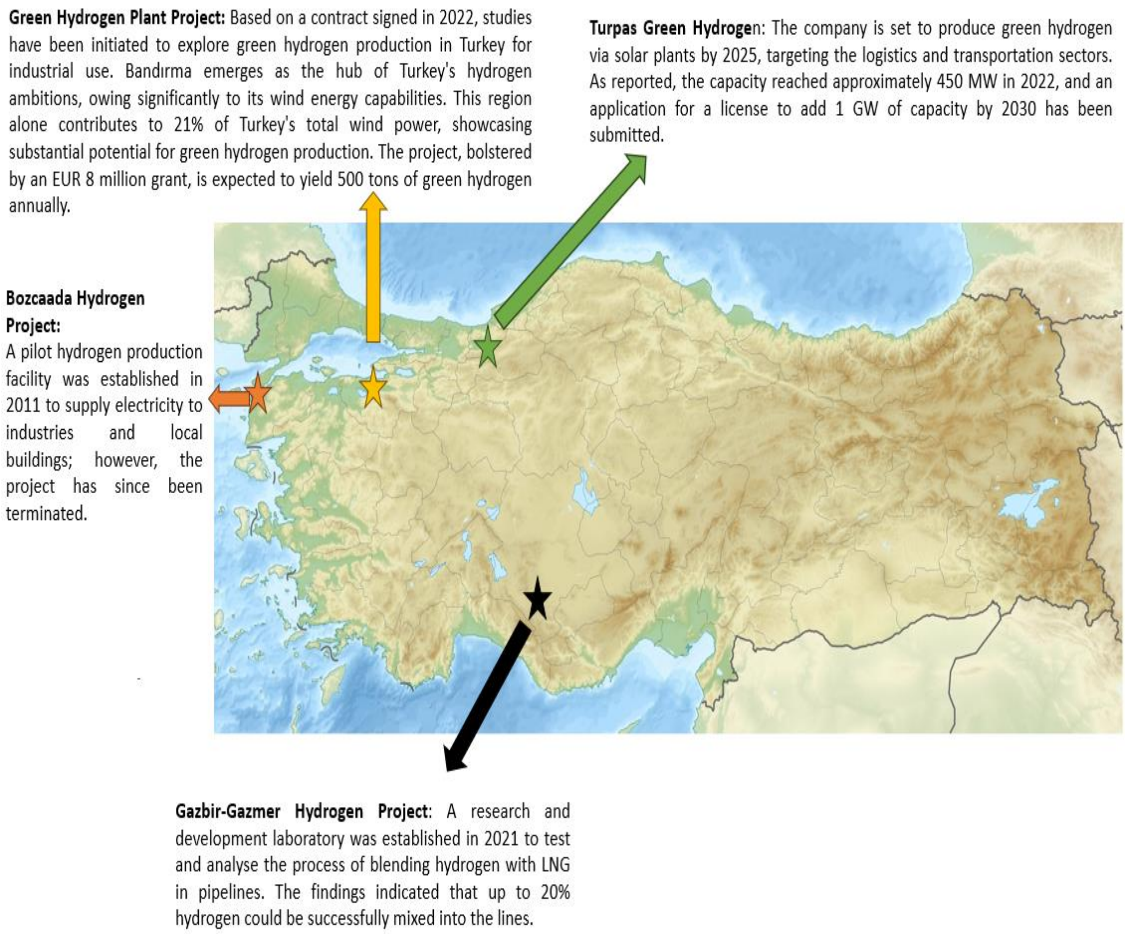


Figure 13. Hydrogen production in Türkiye. Source: (Adapted from: Fuel cell work, 2023).

Under the Green Port Certification guidelines, it is advised that each port install at least one OPS facility. However, due to the voluntary nature of this recommendation, Turkish ports currently lack such systems. Numerous studies have been conducted on the implementation of OPS at Turkish ports affirming both the environmental and economic advantages of these projects, yet implementation has not proceeded (Peksen, 2013; Kılıç et al., 2020). Asyaport, among other Turkish ports, is in the process of acquiring such a system, but no operational facility exists to date (ASYAPORT, 2024). Given its strategy to adopt carbon-neutral fuels like hydrogen and its significant investment in renewable energy resources, there is a substantial opportunity to advance these technologies at ports in Türkiye. Implementing these measures would not only reduce emissions at the ship-port interface but also support the development of green port initiatives across the nation. However, realising this potential requires substantial investments and careful consideration of both ship-port and ship-city interfaces. It is essential to increase the capacity of the national grid and modernise existing infrastructure to support these green initiatives (Vakili and Ölcer, 2023; 2023a). Collaboration among various stakeholders is crucial for success.

6 Interviews and Survey

6.1 Interviews

Interviews were conducted with a diverse group of experts in the Mediterranean region. These interviews aimed to collect data and gather insights regarding the 2023 IMO GHG Strategy, EU legislation, appropriate measures to meet the goals, and associated barriers. The target group was focused on top experts in the region. In total, approximately 7 hours of online interviews were conducted with various stakeholders, including academia, shipowners, and port operators, from Egypt, Italy, Spain, and Türkiye.

The majority of the interviewees support the IMO's initiatives in decarbonising the maritime industry and believe that the 2023 IMO GHG Strategy is a significant step towards achieving zero-emission shipping by mid-century. However, they noted that appropriate regulations are still lacking to determine how to achieve this goal and the objectives that derive from the 2023 IMO GHG Strategy, namely:

- Net-zero GHG emissions by or around 2050.
- A reduction in total annual emissions by at least 20%, striving for 30%, by 2030, and by at least 70%, striving for 80%, by 2040, compared to 2008 levels.
- Ensuring that zero or near-zero emissions technologies, fuels, and energy sources account for at least 5%, with a goal of reaching 10%, of the energy used by international shipping by 2030.

Notably, many interviewees insisted that **carbon neutral fuels play a crucial role** in meeting the goals of the 2023 IMO GHG Strategy and the level of success in overcoming the associated challenges can strongly affect meeting the goals. Considering the associated barriers in access to the carbon neutral fuels, they believe that there will be a limitation of access to carbon neutral fuels by 2030 and these fuels will become more widely available by 2035 and will uptake after 2040.

Considering the above, the majority of the interviewees were optimistic about achieving the goals within the specified timelines, with the exception of the 2040 checkpoint. They believe that the 2030 goals are achievable in the short term through energy efficiency improvements and existing technologies. However, meeting the 2040 goal of a 70% reduction, striving for an 80% reduction in total annual GHG emissions by 2040, requires around 90% reduction in GHG intensity. This necessitates the widespread availability of carbon-neutral fuels. Given the barriers and the required investment in infrastructure, the interviewees are sceptical about the availability of such fuel for the maritime domain. Another highlighted challenge is that current ships need to be equipped with carbon-neutral fuel technologies to meet these goals by 2040, which is not the case. The existence of an ageing fleet further complicates achieving the 2040 target. Therefore, they emphasised the need for continuous improvement in energy efficiency. Meanwhile, they believed that 2050 goals are achievable due to the availability of carbon neutral fuels by that time. Ammonia and hydrogen were raised as the most dominant sources of energy by 2050 and biofuel and methanol have been considered as the short to medium source of alternative fuels. Indeed, electric battery powered vessels were highlighted as the solution for short sea shipping if appropriate infrastructure such as OPS is provided in ports.

On the other hand, some interviewees expressed concerns about relying solely on carbon-neutral fuels for decarbonisation and delaying further actions. They highlighted the uncertainties in selecting the best type of fuel and the lack of sufficient and clear regulations for transitioning to zero-emission shipping. *"Until the last few years, everyone claimed that LNG* *was the solution. However, with the changing IMO policies and the introduction of more ambitious goals, LNG is no longer considered viable,"* noted one interviewee. *"Shipowners and investors need appropriate and consistent policies to make informed investments. Shipping is a long-term investment, and regulatory bodies must provide a clear roadmap and regulations to mitigate investment risks."*

Another interviewee pointed out, *"Everyone is thinking that by around 2040, a magic solution—carbon-neutral fuel—will emerge and solve all the problems. This is not the case, and other measures must be considered."* They emphasised the importance of energy efficiency and technologies such as WAPS, air lubrication, and fuel cells.

Interviewees highlighted several barriers to achieving zero-emission shipping, including high capital costs, lack of appropriate regulations, associated uncertainties, immaturity of technologies, and high investment risks. Interestingly, one interviewer, a leading expert in the field, offered an additional perspective on these barriers. While acknowledging the mentioned challenges, he noted that some stakeholders tend to oversimplify the required actions for achieving zero-emission shipping. He emphasised the complexity of the shipping industry and the necessity of a holistic approach that considers various perspectives to overcome these barriers. Additionally, he stressed the importance of raising awareness, promoting a paradigm shift, and changing lifestyles and trade models to effectively tackle climate change. *"For decarbonisation, developed countries and less developed and developing ones must adopt different approaches and perspectives,"* he stated. *"Developed countries should support others in various aspects, such as technical assistance, economic aid, capacity building, and human resource development."* Additionally, he highlighted that human factors have been underestimated compared to other disciplines in the transition to zero-emission shipping, warranting further attention. In terms of capacity building, training, competency improvement, and leadership development should be prioritised to facilitate this transition effectively.

In regard to the Mediterranean region, the majority of interviewees emphasised the specific characteristics of the area that impact the transition to zero-emission shipping. They noted that the economic and policy disparities between the Mediterranean coastal States that are EU Member States and those that are not EU Member States pose challenges to adopting a unified approach to achieving zero-emission shipping in the region. Additionally, some interviewees highlighted geopolitical instability in the Mediterranean region or adjacent regions, such as in the Black Sea, which hinders efforts to establish a harmonised approach to zero-emission shipping transition.

While acknowledging the renewable energy resources of the region and their potential to serve as a green energy hub, interviewees stressed the importance of resolving geopolitical issues to attract investors and stimulate economic growth through the creation of jobs. Others emphasised the strategic significance of the region as a global trade and energy corridor, advocating for its potential to become an energy hub and a key player in energy transition. However, they emphasised that addressing geopolitical instability and adopting a harmonised approach to decarbonisation in the maritime industry are essential prerequisites for realising this potential.

While a few individuals believed that the EU legislation could positively impact the decarbonisation of the maritime industry, the majority held the view that the EU should adopt a similar approach to the IMO. *"The EU needs to follow the lead of the IMO rather than pursuing separate actions. It is understandable that the IMO may have a slower approach to achieving zero-emission shipping compared to the EU, but this is inherent to the nature of the organisation, which comprises many countries with diverse political and economic backgrounds,"* emphasised one interviewee. Others expressed concerns that the EU ETS could impact the market, potentially leading some shipping lines to avoid EU ports and shift to less energy-efficient road transportation.

A few interviewees pointed out that shipowners are still awaiting clearer guidance on the implementation of regulations, as ambiguities persist in certain areas. Regarding uncertainties surrounding regulations and future technologies aimed at meeting the goals of the 2023 IMO GHG Strategy, some shipping companies are opting to pay penalties until they have more certainty, and only then invest in the necessary technology. Their rationale is that while penalties represent short-term costs, investing in technology requires long-term planning and careful decision-making to avoid further losses.

Considering the above, uncertainties impose significant costs on shipowners. For example, based on one interviewee's calculations in 2020, Turkish shipowners were projected to pay $200 million to comply with the EU ETS, a figure expected to rise to around $250 million, a 25% increase since 2020, attributed to geopolitical issues in the region.

The majority of the interviewees placed significant emphasis on the role of ports in achieving the 2023 IMO GHG Strategy. They assert that ports need to prioritise improving energy efficiency in the short term and support decarbonisation efforts within the shipping industry by enhancing energy efficiency at the ship-port interface. Additionally, interviewees highlighted the potential of improving energy efficiency, automation, digitalisation, and the use of artificial intelligence to reduce ship-port stays, thereby decreasing shipping emissions within ports. The role of OPS as an effective measure for reducing emissions from ships while at port was also underscored. However, associated barriers such as high capital costs, technological demands, limited space at ports, electricity costs, energy sources, and the potential strain on the national grid were identified as challenges.

Furthermore, interviewees stressed the importance of long-term sustainability by establishing sustainable bunkering infrastructure and transitioning to energy hubs. They emphasised that ports failing to consider this transition risk losing competitiveness in the market. Conversely, a few interviewees expressed less optimism about the role of ports in shipping decarbonisation in the absence of appropriate regulations. They highlighted the importance of government policies in guiding ports to act as energy hubs in the maritime domain. *"Ports can play a crucial role if the appropriate policies are in place. They adhere to national regulations and policies; thus, if there are decarbonisation initiatives in place, ports will also contribute. While European ports are transitioning to energy hubs due to EU directives, similar initiatives are lacking in non-EU ports in the region. Therefore, everything hinges on government policies,"* as emphasised by one of the interviewees.

6.2 Survey

To better understand aspects related to awareness of stakeholders within the Mediterranean region, a questionnaire was designed and distributed among various stakeholders. The target groups considered were various active stakeholders in the maritime domain in the region, including shipowners, port operators, seafarers, ship operators, regulator bodies, international organisations, regional organisations, local communities, research and education sections, technology providers, as well energy and fuel providers. Considering the limitation of time, in addition to the list of REMPEC Focal Points provided by the Secretariat (REMPEC), a questionnaire was circulated to top experts in the topic in order to receive fruitful feedback and inputs from their side. In other words, the weight and quality of responses have been considered rather than the number of the responses.

The questionnaire was divided into 5 sections, as follow:

A. Stakeholders' background
B. Familiarisation with the 2023 IMO GHG Strategy
C. The role of ports in meeting the goals of the 2023 IMO GHG Strategy by 2030 and 2050
D. EU legislation and policy, and
E. Mediterranean context.

A. Stakeholders' background

A total of 19 responses were received from stakeholders. The majority of participants were from Egypt, the European Union, and Libya, each contributing 15.8% (3 responses). Albania and Malta each had 2 participants (10.5%), making significant contributions to the questionnaire. Cyprus, Italy, and Türkiye each contributed 5.3% (1 response) (Figure 14).

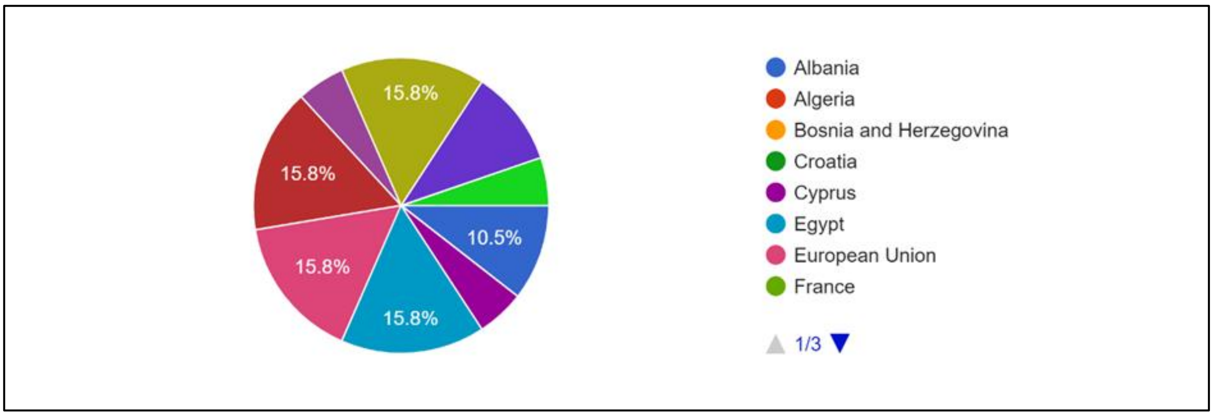


Figure 14. Contributors to the survey.

Shipowners had the highest contribution to the questionnaire, with 6 respondents (31.6%). Following them, regulators and policymakers contributed 21.1% (4 responses), and research and academia centres contributed 15.8% (3 responses). Port operators and regional organisations each had 2 respondents (10.5%). Finally, only one ship operator and one local community member responded (5.3%) (Figure 15). The majority of respondents were at senior or mid-level in their careers, comprising 52.6% and 36.8% of the participants, respectively, while 10.5% were at the junior level (Figure 16).

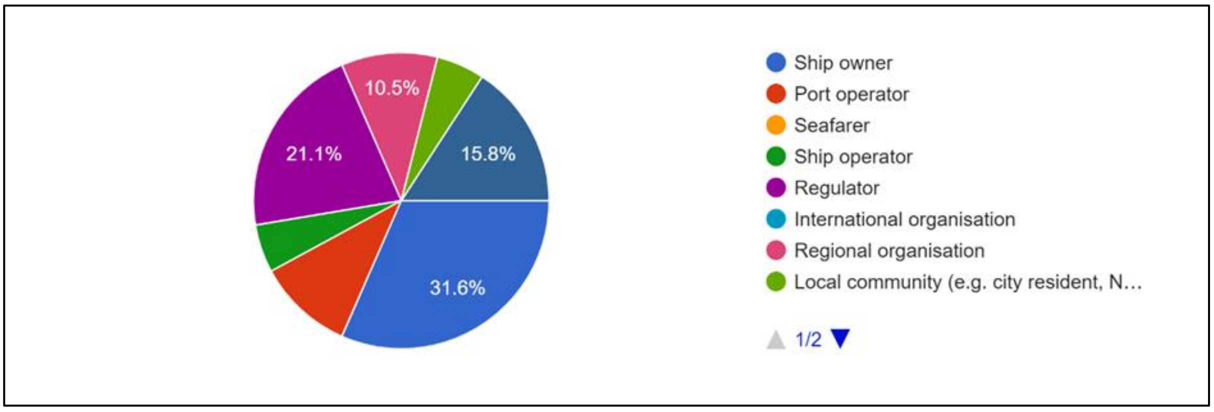


Figure 15. Role of contributors to the survey.

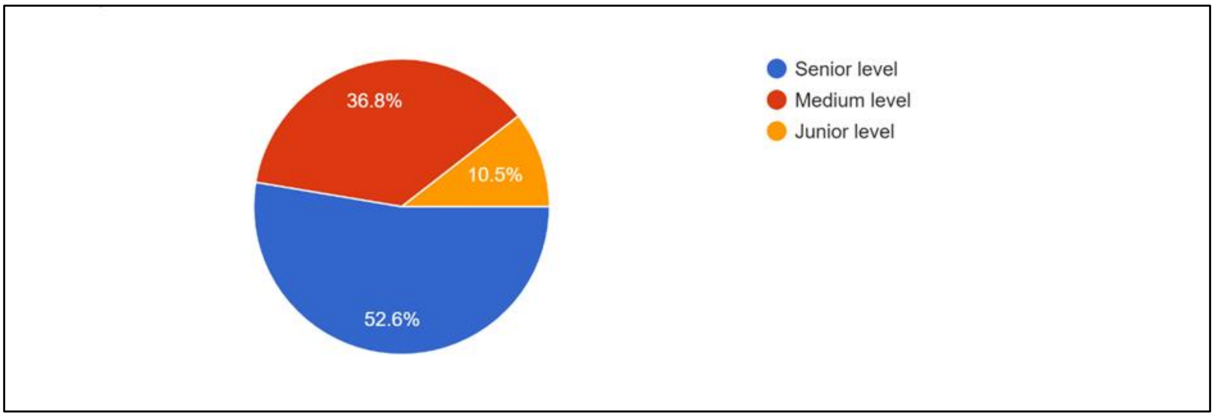


Figure 16. Level of experience of the participants in the survey.

B. Familiarisation with the 2023 IMO GHG Strategy

With regards to their familiarity with the 2023 IMO GHG Strategy and its associated goals, 5 respondents (26.3 %) indicated they have moderate familiarity with the 2023 IMO GHG Strategy and its associated, while 21.1% reported high familiarity, and only 26.3% (1 person) was very familiar with the topic. Additionally, 26.3% had very low or no familiarity with the 2023 IMO GHG Strategy and its associated goals.

Additionally, more than half of respondents (68.4%) indicated moderate, very low or non-familiarity with the GFS, while 10.5% and 21.1% reported high and very high familiarity, respectively. Regarding GHG pricing discussions at the IMO, 5 respondents (26.3%) had moderate familiarity, while 36.9% had very low or no familiarity with the topic, and 5.3% were very low familiar with the topic. Meanwhile, 31.6 % were highly familiar, and very well familiar with the topic.

Analysing the responses, it was determined that more than 52.6% of respondents have moderate or less familiarity with the 2023 IMO GHG Strategy and its associated goals. Furthermore, the responses indicated that familiarity with the basket of midterm measures, such as the GFS and GHG pricing mechanisms, was even lower. Over 68.4% had moderate or less familiarity with the GFS, and more than 68.5% had similar levels of familiarity with the GHG pricing mechanism. Given these results, it is clear that capacity building and training for various stakeholders regarding the 2023 IMO GHG Strategy are essential.

The majority of respondents believed that the targets set by the 2023 IMO GHG Strategy are very ambitious and difficult to meet within the determined timelines. They emphasised the importance of carbon-neutral fuels, the establishment of sustainable infrastructures at ports, and a GHG pricing mechanism in accelerating progress towards these goals. It was suggested that the IMO needs to implement more stringent regulations, develop a GHG mechanism similar to the EU ETS, and provide incentives for early adopters in the transition to zero-emission shipping.

Conversely, a few respondents were more optimistic about meeting the goals of the 2023 IMO GHG Strategy. They acknowledged the ambition of the goals but deemed them achievable with significant effort. These respondents highlighted that achieving a 5% uptake of zero or near-zero GHG emission technologies by 2030 is challenging but feasible with early adoption and infrastructure development. They also believed that a 20-30% reduction in emissions by 2030 is possible through current technologies and efficiency improvements, while a 70-80% reduction by 2040 will require breakthrough innovations and rapid technological shifts. However, reaching net-zero emissions by 2050 will necessitate major advancements in zero-emission technologies and strong regulatory support.

While the majority of respondents emphasised the need for significant technological advancements in zero-emission technologies and extensive infrastructure development for alternative fuels, they also highlighted several main barriers. These include high economic costs, the complexity of implementing and enforcing international regulations, potential resistance from the shipping industry due to operational and financial disruptions, uncertainties regarding future technologies and alternative fuels, and a lack of appropriate regulations.

To overcome these barriers, respondents suggested several strategies: investing in R&D for zero-emission technologies, developing global infrastructure for alternative fuels, providing economic incentives and subsidies to offset high costs, enforcing strong international regulations, and fostering industry collaboration and commitment to sustainability. They also emphasised the importance of considering the green economy at the governmental level and the effective implementation of IMO instruments through their incorporation into national legislation and support from IMO technical cooperation.

In response to promising measures to meet the goals of the 2023 IMO GHG Strategy for 2030, approximately 48% of respondents emphasised improving energy efficiency, while around 42% believed in the use of carbon neutral fuels. Only 5% (1 person) saw potential in using GHG abatement technologies and improving logistical aspects to achieve the 2030 goals (See Figure 17).

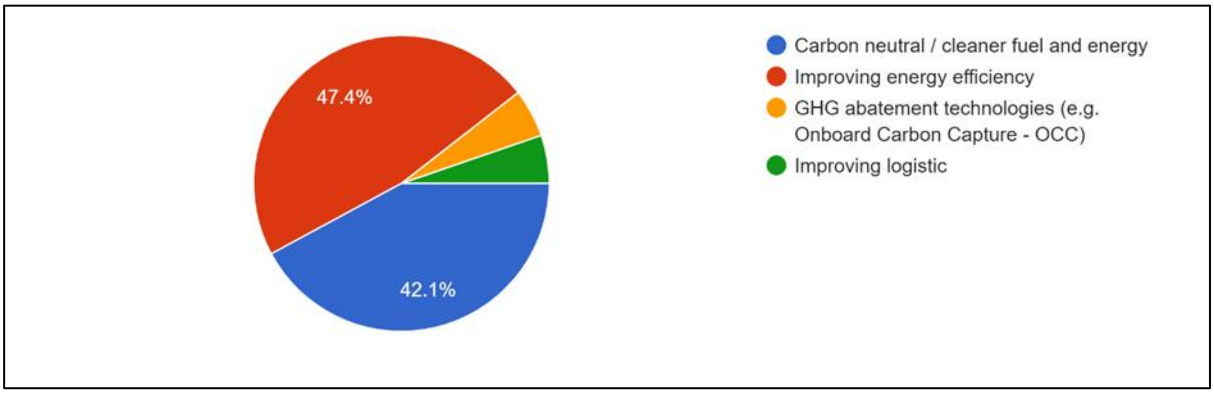


Figure 17. Measures to meet the 2023 IMO GHG Strategy by 2030.

Among the proposed measures and alternative fuels, 36.8% of the respondents believed in hybrid propulsion systems and using sustainable biofuel for meeting the IMO's goal by 2030. About 32% supported speed reduction and JIT arrivals as effective strategies to meet the IMO's goals. Methanol, hydrogen, and OPS emerged as the most popular alternative fuel and technology by 2030 (approximately 26%), similar to OCC technology. E-fuels and fuel cells were the third most favoured options (16%). Meanwhile, only two respondents (approximately 11%) considered wind-assisted propulsion systems among the top three measures to meet the 2023 IMO GHG Strategy. LNG, ammonia, and batteries were chosen by just 5% of respondents. Interestingly, air lubrication did not receive any support from the respondents (See Figure 18).

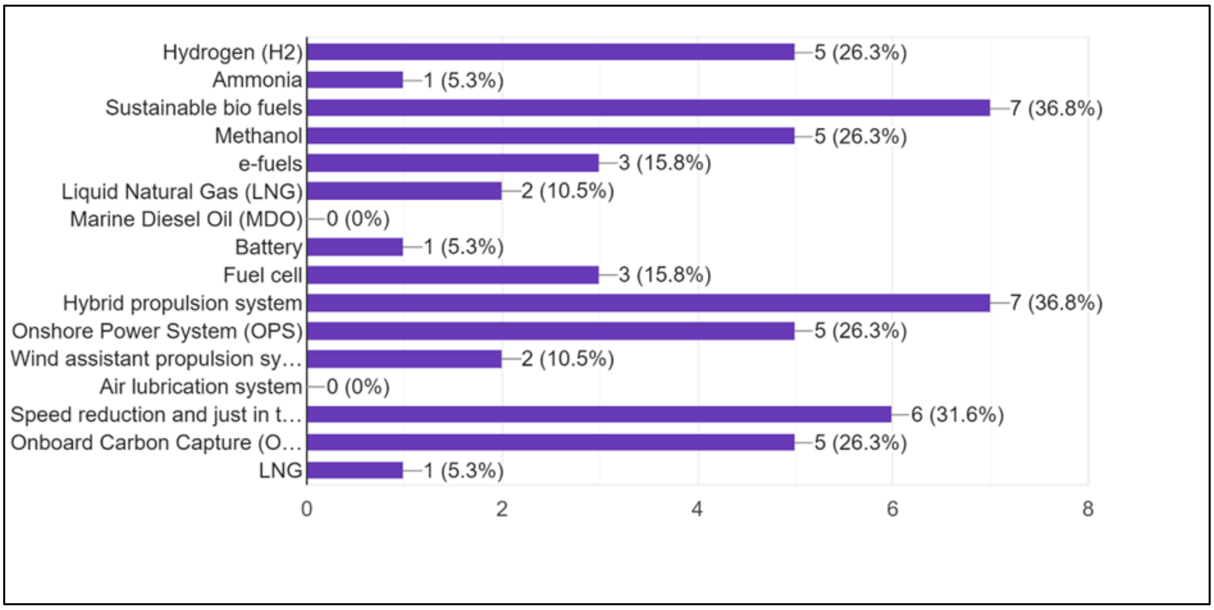


Figure 18. Contribution of the measures to meet the 2023 IMO GHG Strategy by 2030.

To meet the goals of the 2023 IMO GHG Strategy by 2050, the majority of respondents (around 74%) supported the use of carbon-neutral fuels and energy sources, marking a significant 32% increase in support compared to the 2030 goals. Conversely, there was a notable 31% reduction in the emphasis on improving energy efficiency for achieving zero-emission shipping by 2050, with only 16% of respondents believing in the role of energy efficiency, and 10% in logistics, to reduce GHG emissions by 2050. These results align closely with other research and studies, which predict similar trends (Figure 19).

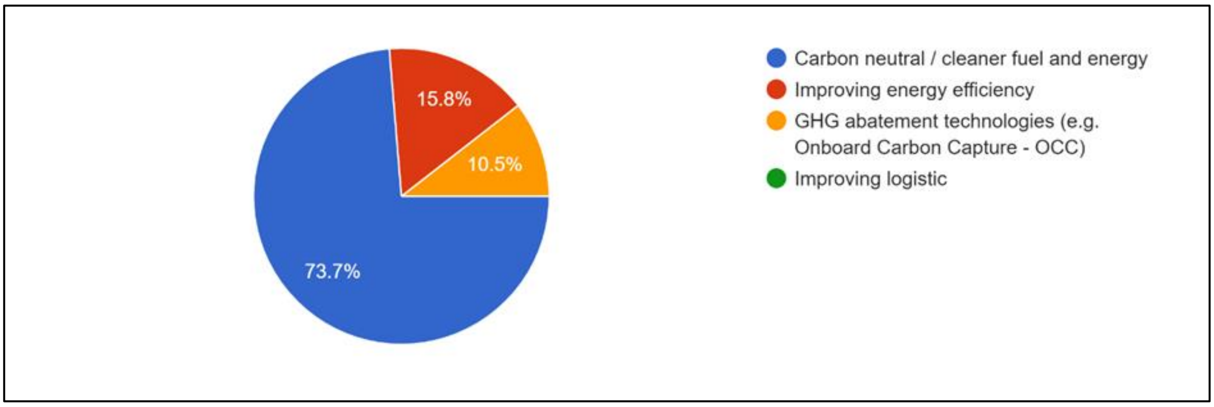


Figure 19. Measures to meet the 2023 IMO GHG Strategy by 2050.

Among the proposed alternative fuels, interest in hydrogen doubled, reaching 53%. Methanol was the second most popular fuel at 42%, while ammonia and fuel cells were the third most popular at 37%. Respondents believed that ammonia and fuel cells would play a larger role in decarbonising the shipping industry, with interest in ammonia increasing sevenfold and fuel cells by a factor of 2.3. Methanol contributed to the decarbonisation of the shipping industry but experienced less growth (1.6 times) compared to hydrogen, ammonia, and fuel cells. Additionally, the contribution of WAPS doubled, reaching 21%. Other technologies and alternative fuels, including sustainable biofuel, LNG, and OCC, garnered 16% interest. E-fuels and batteries received only 5.3% of the attention. Similar to 2030, air lubrication had the least interest, and as expected, speed reduction was not considered a significant contributor to meeting the 2050 goals. Hybrid systems were not chosen by any interviewees (Figure 20).

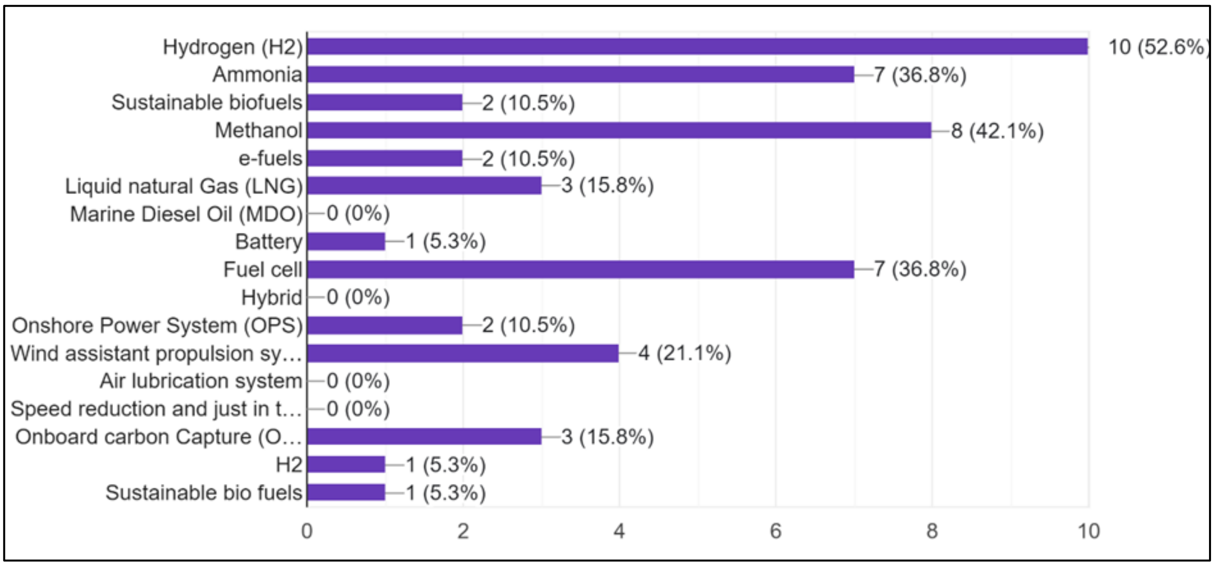


Figure 20. Contribution of the measures to meet the 2023 IMO GHG Strategy by 2050.

Among the top barriers, nearly half of the respondents (47%) identified the lack of appropriate and sufficient regulations, along with the need for significant investments in onboard vessels and port infrastructure, as the two most critical challenges. Around 42% of participants considered the lack of required infrastructure in ports as the third most significant barrier to meeting the 2023 IMO GHG Strategy by 2050. Approximately 37% of survey participants pointed to the high risk of investment, uncertainties regarding future technologies and policies, and the immaturity of technologies as the fourth most significant barriers to achieving the goals of the 2023 IMO GHG Strategy. Other identified barriers included the lack of training and expert staff (21%), split incentives (around 10.5%), and insufficient collaboration among stakeholders (around 5.3%) (See Figure 21).

To overcome these barriers, respondents emphasised the need for a pragmatic approach that involves collaboration among industry stakeholders, such as regulatory bodies, shipowners, port operators, technology providers, bunker suppliers, and financial organisations at national, regional, and global levels. This collaboration is essential to encourage joint investments in sustainable technologies and infrastructure. However, due to uncertainties in promising technologies and alternative fuels, there is a risk associated with investments. Respondents suggested that government actions, such as subsidies, tax breaks, and fostering stakeholder collaboration, are necessary to support investors and reduce the associated risks. Furthermore, the importance of clear regulations in mitigating GHG emissions and meeting the IMO's ambitious goals was highlighted by the respondents (See Figure 21).

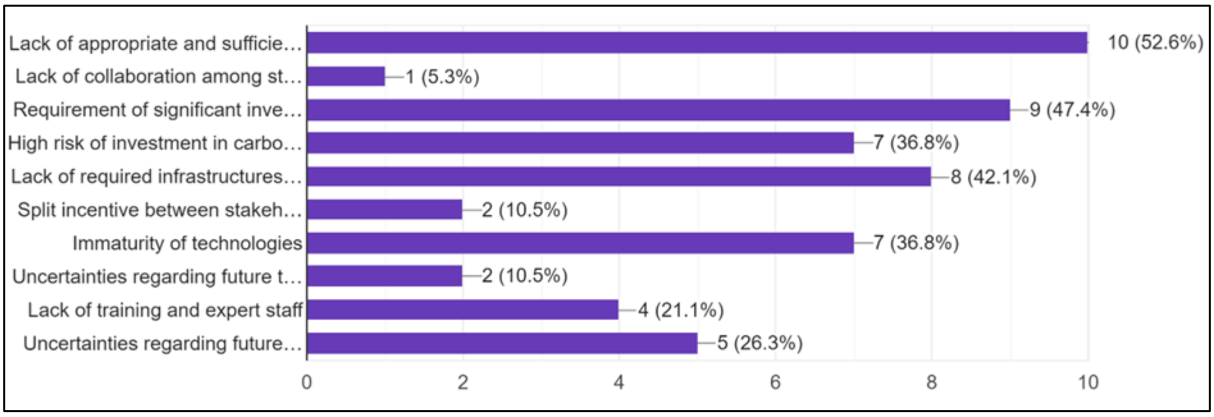


Figure 21. Barriers to meet the 2023 IMO GHG Strategy.

C. The role of ports in meeting the goals of the 2023 IMO GHG Strategy by 2030 and 2050

Almost all respondents emphasised the crucial role of ports in the decarbonisation of the shipping industry, with the majority (around 95%) identifying the provision of sustainable bunkering infrastructures as the most crucial measure for ports to implement for ships (See Figure 22). Additionally, around 5% of participants highlighted OPS as another important technology.

Survey participants suggested that, in the short term, ports can focus on low-hanging fruits like implementing JIT arrivals, reducing speed within port limits, and considering incentive measures. However, to meet the 2023 IMO GHG Strategy in the long term, the focus should shift to establishing carbon-neutral fuel bunkering stations and OPS to achieve ambitious goals. A few respondents also noted that the ship-port interface is highly commercialised and lacks appropriate regulation, indicating a need for further adoption of relevant regulations (See Figure 23).

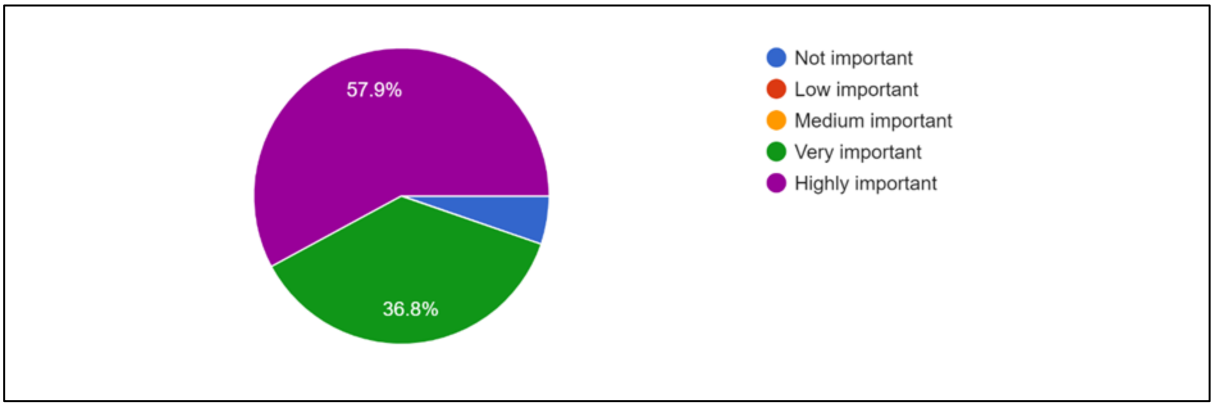


Figure 22. Role of ports to meet the 2023 IMO GHG Strategy.

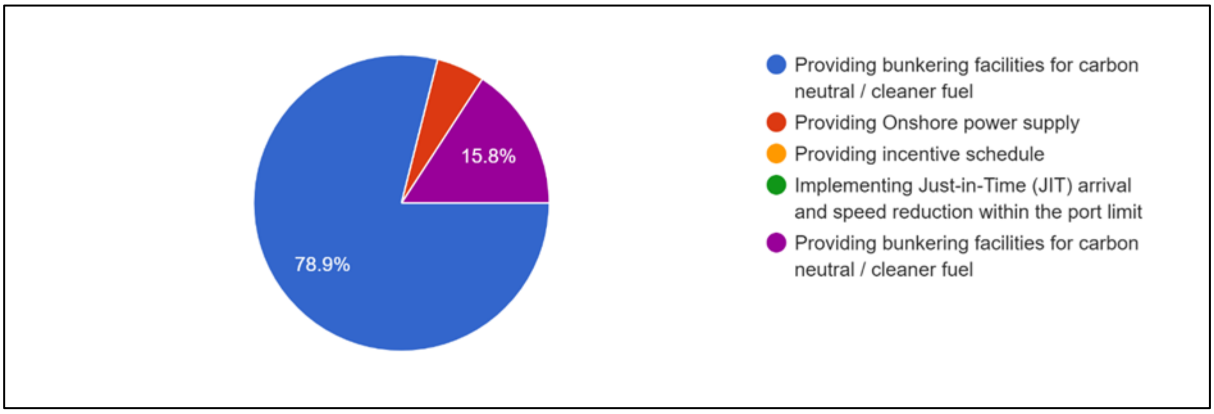


Figure 23. Measures in ports to accelerate in meeting the 2023 IMO GHG Strategy.

Around 53% of respondents highlighted uncertainties regarding future technology and policies and lack of appropriate and sufficient rules and regulation as the main barriers in ports. These uncertainties hinder the implementation of carbon-neutral or cleaner fuel bunkering facilities, posing challenges to long-term planning and investment. Respondents emphasised that without clear regulations and indications about future prominent alternative fuels and technologies, ports are reluctant to invest in new technologies. They noted the absence of harmonised regulations for the decarbonisation of the shipping industry. “Clear and harmonised regulations are essential for accelerating the transition to zero-emission technologies at the ship-port interface” one of the interviewees highlighted. Respondents stressed that governments and international organisations should provide clear and stable regulatory frameworks to mitigate these uncertainties, foster industry confidence, and attract financing for investment.

This need for significant investment in onboard vessels and ports, which was identified as the second most important barrier (47%). It was discussed that governments need to support pioneering companies through appropriate financial mechanisms such as incentives, tax reductions, and subsidies. Required investments can be facilitated through GHG pricing mechanisms. However, it was emphasised that anti-corruption measures should be implemented to ensure that dedicated funds are invested in relevant and appropriate projects with expected emissions reductions.

One comment mentioned that "investments such as Onshore Power Supply cannot be realised without regulatory requirements. To address this, regulatory bodies should develop and enforce clear frameworks, guidelines, and incentives to encourage investment in sustainable infrastructure. This can mitigate uncertainties, build industry confidence, and accelerate the transition to zero-emission technologies at the ship-port interface”. Collaboration among stakeholders, including port authorities, shipping companies, and governments, is essential, addressing the lack of collaboration noted by around 42% of respondents.

Furthermore, the immaturity of technologies and lack of training and expert staff (around 21%), and split incentives (10 %) were other identified barriers. Capacity building, training of personnel, and continued research, development, and investment are proposed solutions to overcome these barriers, advance these technologies, and reduce associated costs (See Figure 24).

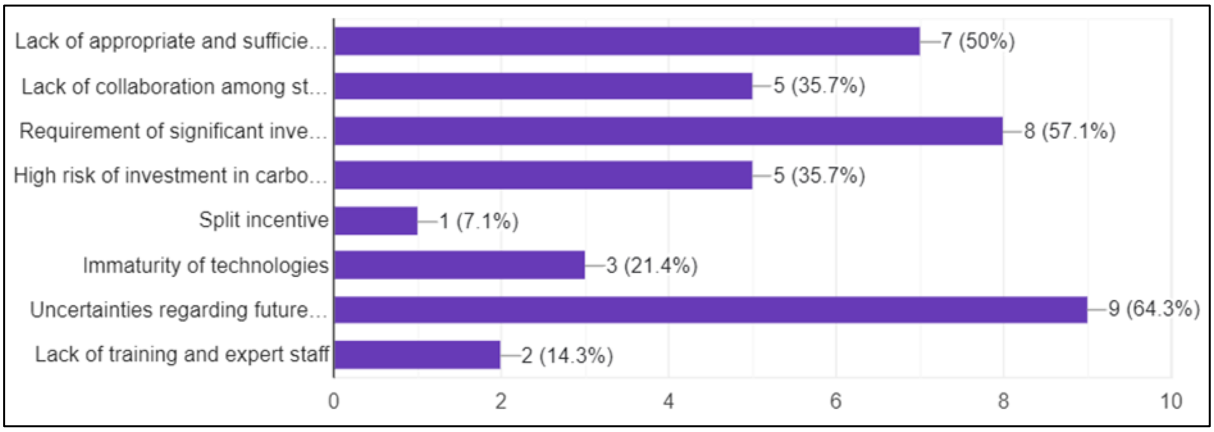


Figure 24. Barriers at Ship-Port interface to reduce GHG emissions from ships at ports.

D. EU legislation and policy

Regarding EU actions in the decarbonisation of the shipping industry, two important pieces of EU legislation — the EU ETS Directive and the FuelEU Maritime Regulation—were discussed with the survey participants. It appears that participants were more familiar with the EU legislation than with the IMO’s basket of mid-term measures, such as GFS and GHG pricing mechanisms, likely because the EU ETS is already in force and the FuelEU Maritime Regulation will be applied from January 2025.

The survey revealed that, as the EU ETS has already been implemented, respondents showed greater familiarity with it compared to the FuelEU Maritime Regulation. Approximately 53% were very or highly familiar with the EU ETS, 21% had moderate familiarity, and around 26% were not very familiar or not familiar at all. In contrast, for the FuelEU Maritime Regulation, around 43% were very or highly familiar, 26% had moderate familiarity, and 31% were not familiar or had low familiarity with the directive (See Figures 12 and 13).

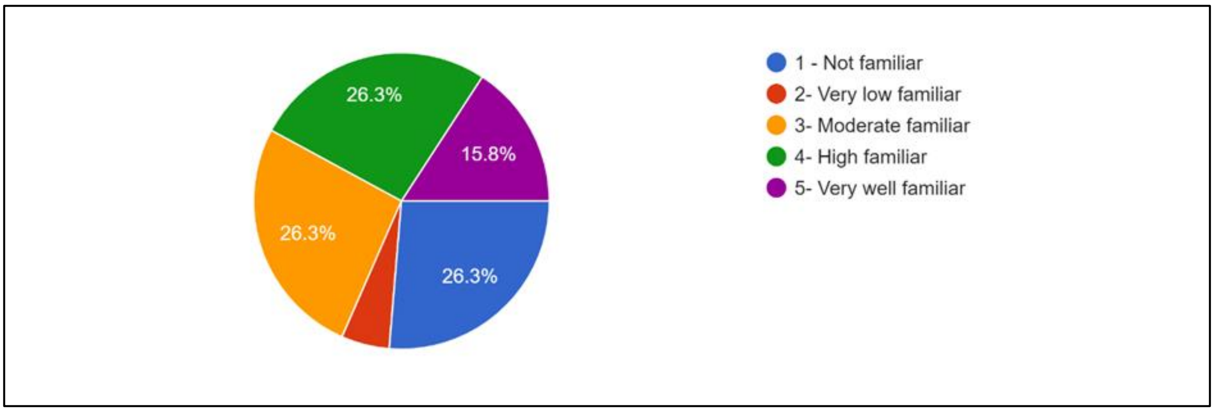


Figure 25. Familiarisation of the participants with Fuel EU

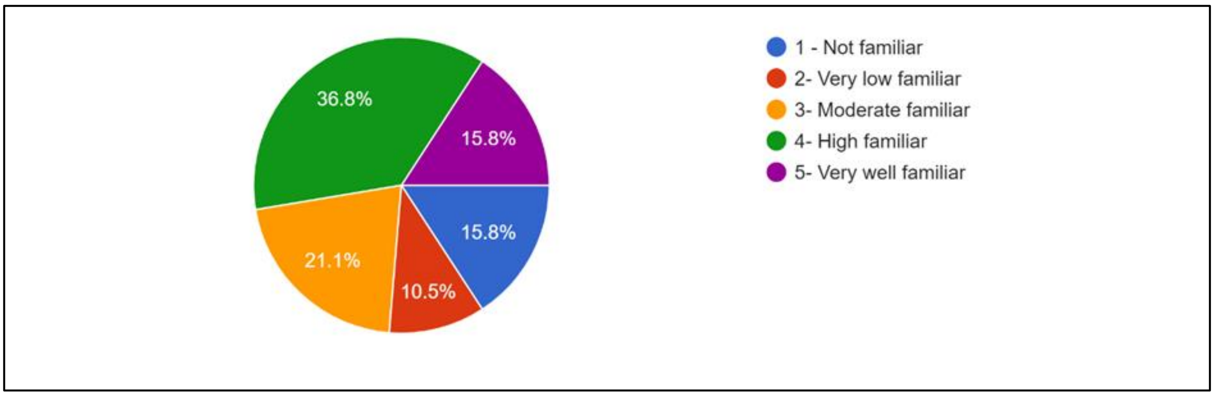


Figure 26. Familiarisation of the participants with EU ETS

Additionally, the analysis determined that 42% of the respondents believed that the EU legislation would positively affect the achievement of the goals of the 2023 IMO GHG Strategy. The majority of this group belonged to EU countries and highlighted that the IMO is slow in tackling climate change. They noted that the EU legislation push the boundaries and incentivise the IMO and other states to take real and sufficient action to decarbonise the industry. One respondent mentioned, “IMO should follow the EU for the decarbonisation of the shipping industry as it is far behind the Paris Agreement.” This group emphasised that discrepancies between EU legislation and IMO regulations could have a low impact on achieving the goals of the 2023 IMO GHG Strategy. While there may be some initial challenges due to differing standards and requirements, both entities share the common goal of reducing GHG emissions from maritime activities. It was also emphasised that as both the EU legislation and IMO regulations aim to address climate change, their convergence could facilitate greater global cooperation and progress towards the goals of the 2023 IMO GHG Strategy.

Meanwhile, 21% of respondents were neutral about the impact of EU legislation on the IMO’s efforts to achieve zero-emission shipping. They believed that experience and lessons gained from the effective implementation of both EU legislation and IMO regulations show that they are on parallel paths.

On the other hand, around 37% believed that the EU legislation would have a negative impact on meeting the IMO goals. The majority of this group belonged to non-EU countries and highlighted that this discrepancy would undermine the role of the IMO in regulating international shipping, lead to confusion due to the existence of multiple regulations, and cause carbon leakage in the region. One respondent noted, “Double standards in a global industry are not facilitating the target of industry decarbonisation.” They believed that the IMO and EU need to have a similar approach to the decarbonisation of the shipping industry and consider harmonised regulations for achieving zero-emission shipping by 2050. They suggested that collaboration and alignment between the EU and IMO could lead to the harmonisation of regulations, ensuring a more consistent and effective approach to achieving GHG reduction targets (See Figure 27).

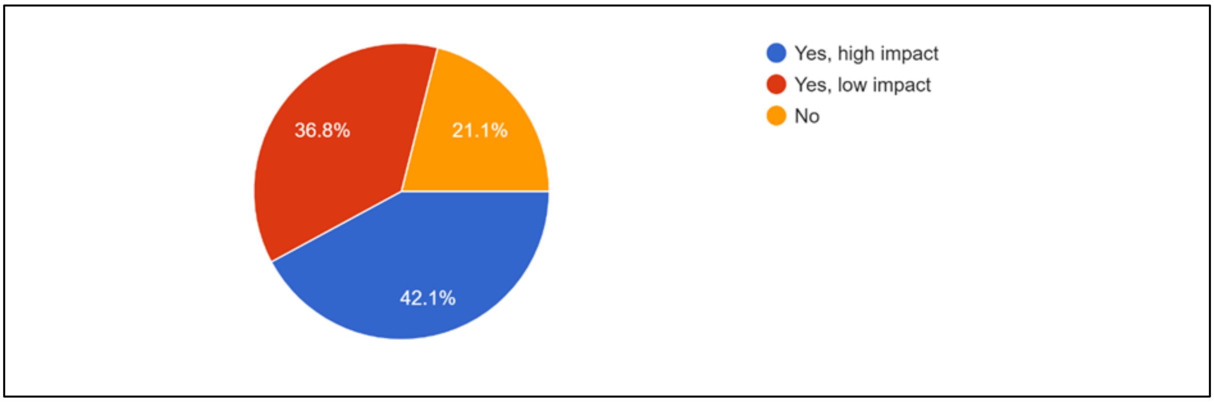


Figure 27. Discrepancies between IMO regulations and EU regulations.

E. Mediterranean context

The need for significant investment and the lack of appropriate and sufficient regulations (58%) were identified as the most important barriers in the Mediterranean region to meeting the 2023 IMO GHG Strategy. The lack of collaboration among stakeholders was identified as the second most significant barrier (around 48%). Additionally, the lack of trained and expert staff—more frequently cited by respondents from non-EU countries—and uncertainties regarding future regulations and technologies (37%) emerged as the third most significant barriers to meeting the goals of the 2023 IMO GHG Strategy. The high risk of investment, cited by around 32% of respondents, was the fourth major barrier. The immaturity of technologies (21%) and split incentives (5.3%) were considered less critical barriers in the region (See Figure 28).Figure 28. Main barriers in the Mediterranean region to meet the 2023 IMO GHG Strategy.

Survey participants highlighted that the complexity of the Mediterranean region, with its diverse economic, social, and political backgrounds, exacerbates these barriers. To overcome them, concerted efforts are needed. Firstly, regulatory bodies should develop comprehensive and harmonised rules and regulations that account for the region's unique challenges and characteristics. This involves aligning with both international (IMO) regulations and regional (EU) legislation to ensure consistency and effectiveness. Secondly, addressing uncertainties regarding future policies requires proactive engagement from governments, industry stakeholders, and international organisations to provide clear and stable regulatory frameworks, fostering confidence and facilitating long-term planning and investment. Finally, fostering collaboration among stakeholders is essential. This involves creating platforms for dialogue, sharing best practices, and promoting partnerships between governments, shipping companies, port authorities, and environmental organisations to collectively work towards achieving the goals of the 2023 IMO GHG Strategy in the Mediterranean region.

7 SWOT Analysis

On the basis of the literature analysis, the answers received by the interviewees and the respondents to our survey, a SWOT analysis was conducted to highlight the Strengths, Weaknesses, Opportunities and Threats of the implementation of the 2023 IMO GHG Strategy in the Mediterranean region.

Table 7. SWOT analysis

Strengths	Weaknesses
• The 2023 IMO GHG Strategy is a significant step towards achieving zero-emission shipping by mid-century. 2050 goals are achievable due to the availability of carbon neutral fuel by that time. • The 2030 goals are achievable in the short term through energy efficiency improvements and existing technologies. • The potential of improving energy efficiency in ports, automation, digitalisation, and the use of artificial intelligence to reduce ship-port stays, thereby decreasing shipping emissions within ports. • The role of OPS as an effective measure for reducing emissions from ships while at port. • The importance of government policies in guiding ports to act as energy hubs in the maritime domain.	• Appropriate regulations are still lacking to determine how to achieve this goal. • Meeting the 2040 goal of a 70% reduction, striving for an 80% reduction in total annual GHG emissions by 2040, requires around 90% reduction in GHG intensity. This necessitates the widespread availability of carbon-neutral fuel. Given the barriers and the required investment in infrastructure, one may be sceptical about the availability of such fuel for the maritime domain. • Several barriers hinder the achievement of zero-emission shipping, including high capital costs, inadequate regulations, associated uncertainties, immature technologies, insufficient sustainable infrastructure such as ports and shipyards, and high investment risks. • Human factors have been underestimated compared to other disciplines in the transition to zero-emission shipping. • Lack of clear guidance on the implementation of regulations and uncertainties surrounding future technologies aimed at meeting the goals of the 2023 IMO GHG Strategy. • Associated barriers for the adoption of the OPS such as high capital costs, technological demands, limited space at ports, electricity costs, energy sources, and the potential strain on the national grid. • While European ports are transitioning to energy hubs due to EU legislation, similar governmental policies also need to be initiated in non-EU ports in the region to accelerate the implementation of the 2023 IMO GHG Strategy.
Opportunities	**Threats**

• There is a limitation on access to carbon neutral fuel by 2030. It becomes more available by 2035 and will uptake after 2040. • The importance of energy efficiency and technologies such as WAPS, air lubrication, and fuel cells. • Capacity building, training, competency improvement, and leadership development should be prioritised to facilitate this transition effectively. • The region's renewable energy resources hold significant potential to transform it into a green energy hub and drive economic growth through job creation. • The strategic importance of the Mediterranean region as a global trade and energy corridor enhances its potential to become a leading energy hub and a pivotal player in the energy transition. • In relation to port long-term sustainability by establishing sustainable bunkering infrastructure and transitioning to energy hubs, government policies are critical in guiding ports to act as energy hubs in the maritime domain.	• The amount of success in overcoming the challenges associated with carbon neutral fuels can affect meeting the goals. • Current ships need to be equipped with carbon-neutral fuel technologies to meet these goals by 2040, which is not the case. The existence of an ageing fleet further complicates achieving the 2040 target. • The uncertainties in selecting the best type of fuel as well as the lack of sufficient and clear regulations for transitioning to zero-emission shipping. • Economic and policy disparities between the Mediterranean coastal States that are EU Member States and those that are not EU Member States create challenges for adopting a unified strategy for zero-emission shipping in the Mediterranean region. • Geopolitical instability in the Mediterranean region or adjacent regions, such as in the Black Sea, obstructs efforts to establish a coordinated approach to the transition. • Shipping companies are opting to pay penalties until they have more certainty, and only then invest in the necessary technology. Their rationale is that, while penalties represent short-term costs, investing in technology requires long-term planning and careful decision-making to avoid further losses.

8 Discussion

Shipping contributes to 2.89% of global GHG emissions (IMO, 2020). As the regulatory body for international shipping, the IMO is committed to reducing air emissions from the industry. The 2023 IMO GHG Strategy marks a significant milestone in the industry's transition towards zero-emission shipping by approximately 2050. Achieving this target requires a holistic, systematic, and transdisciplinary approach, incorporating a mix of strategies and active collaboration among stakeholders (Vakili et al., 2022).

Carbon-neutral fuels are expected to play a crucial role in achieving this goal. However, uncertainties exist regarding the availability and scalability of the necessary carbon-neutral fuel production by 2050. Additional barriers, such as significant investment requirements, inadequate infrastructure, logistical constraints, limited production scalability, technological maturity of onboard systems, supply infrastructure, ship and engine design considerations, crew training, and safety concerns, raise doubts about meeting the emission targets of the 2023 IMO GHG Strategy by 2050 if reliance is placed solely on carbon-neutral fuels (Vakili et al., 2024).

Given the multifaceted barriers associated with using carbon-neutral fuels, the age of the fleet and its relation to CII regulations, and the challenges in retrofitting and rejuvenating the fleet due to limited shipyard capacities, enhancing energy efficiency is critical to achieving the goals of the 2023 IMO GHG Strategy (Vakili et al., 2024). It is projected that 32% of emissions reductions by 2050 will come from energy efficiency enhancements, with speed reduction alone accounting for approximately 23% of the total reduction needed to meet the targets of the 2023 IMO GHG Strategy (DNV, 2022).

Additionally, several low hanging fruit measures can improve energy efficiency within the fleet. Utilising appropriate hull coatings, conducting regular hull and propeller cleaning, implementing PIDs and ESDs, and adopting practices such as passage planning, power demand management, and weather routing can enhance fleet efficiency and reduce emissions. Given their potential to improve energy efficiency and reduce fuel consumption, along with their associated capital costs, these measures represent investments with short payback times that can help fulfil the 2023 IMO GHG Strategy.

Furthermore, additional measures such as WHR (potentially improving efficiency by up to 12%), air lubrication systems (with a potential efficiency improvement of up to 15%), and WAPS (with a potential efficiency improvement of up to 25%) are poised to play a pivotal role in the industry's decarbonisation endeavours. With the advancement and cost reduction of technologies like air lubrication and WAPS, coupled with the tightening of environmental regulations and the growing disparity between conventional fuels and carbon-neutral fuels, their adoption is anticipated to surge in the forthcoming years, facilitating ship owners in adhering to IMO regulations (Vakili et al., 2024).

Integrating technical and operational measures can further enhance their effectiveness in improving energy efficiency and reducing air emissions. As an example, combining speed reduction with JIT arrivals, voyage optimisation, and the utilisation of WAPS could significantly decrease air emissions by 2030, thereby accelerating the shift towards zero-emission shipping. A reduction in speed by 20-30% from 2018 levels, widespread adoption of wind-assisted propulsion and other technological advancements, and sourcing 5-10% of energy from zero or near-zero-GHG fuels could potentially decrease shipping emissions by 28-47% by 2030 compared to 2008 levels (Faber et al., 2023) (See Figure 13).

Electrification and hybrid propulsion systems are feasible for various sizes and types of vessels. With the anticipated advancements in battery technologies and the reduction in associated costs, it is expected that more vessels, especially in short sea shipping, will be equipped with these technologies. However, it is crucial for these vessels to be supported by sustainable port infrastructures, such as OPS. It is also essential to ensure that the energy source for OPS is cleaner than conventional fuels, as this will impact the operational efficacy and environmental benefits of these systems (Vakili and Ölçer, 2023; 2023a). In addition to energy efficiency measures, other abatement technologies such as OCC are also important. Given the barriers associated with using carbon-neutral fuels in the industry, such technologies can play a significant role in the decarbonisation of the shipping industry in the short- to medium-term, particularly in deep-sea shipping. However, these technologies are not yet mature and are still being piloted. Significant progress is being made, with the IMO tasking, and their adoption is expected to increase in the next decade.

Ports, as crucial nodes in the maritime industry, play a significant role in expediting the transition to zero-emission shipping and meeting the goals of the 2023 IMO GHG Strategy. Effective air emission management at ports should consider three zones: the ship-port interface, port operations, and the port-city interface (Vakili and Ölçer, 2023). The IMO highlighted the importance of the ship-port interface in decarbonising the industry at its MEPC.323(74) Resolution, encouraging voluntary cooperation between the port and shipping sectors to reduce GHG emissions from ships (IMO, 2019).

This cooperation can be facilitated by providing shore-based electricity supply (preferably from renewable energy sources), ensuring safe and efficient bunkering of alternative and carbon-free fuels, developing incentive schemes for sustainable and carbon-free shipping, and optimising port visits by JIT arrival. Given the barriers to establishing sustainable infrastructures for bunkering carbon-neutral fuel and OPS at ports, which position them as long-term targets, low-hanging fruit such as establishing incentive schemes, promoting JIT arrival, and reducing speed within port limits can be considered. This approach not only reduces air emissions from ships in the port area but also mitigates other environmental impacts such as underwater noise from commercial vessels and the risk of ship-whale collisions (Vakili et al., 2020).

While the ship-port interface is essential for the decarbonisation of ships, port operations and the port-city interface also contribute to reducing air emissions from shipping at ports. Digitalisation, automation, electrification, and the use of Artificial Intelligence in logistics and cargo handling can shorten ship port stays, thereby reducing emissions. In alignment with practices such as speed reduction, JIT arrival, and providing incentive measures, the most important action for ports is to transition from being merely hubs for cargo handling to energy hubs. This can be achieved by investing in sustainable infrastructures such as bunkering for alternative fuels and OPS.

Considering the above, adopting and enforcing appropriate regulations are crucial for the decarbonisation of the maritime industry. The IMO is working on adopting regulations for implementing the 2023 IMO GHG Strategy to phase out GHG intensity from the industry, including GHG pricing to incentivise the transition to carbon-neutral energy and zero-emission technologies. Meanwhile, the EU has already implemented the EU ETS and plans to apply the FuelEU Maritime Regulation by 2025.

The unique characteristics of the Mediterranean region influence the shift to net-zero emission shipping. Economic and policy disparities between the Mediterranean coastal States that are EU Member States and those that are not EU Member States create challenges for adopting a unified strategy for zero-emission shipping in the Mediterranean region. Furthermore, geopolitical instability in the Mediterranean region or adjacent regions, such as in the Black Sea, obstructs efforts to establish a coordinated approach to the transition. While the region's renewable energy resources hold significant potential to transform it into a green energy hub, working towards resolving geopolitical issues is essential to attract investors and drive economic growth through job creation. The Mediterranean's strategic importance as a global trade and energy corridor enhances its potential to become a leading energy hub and a pivotal player in the energy transition. However, trying to overcome geopolitical instability and adopting a cohesive approach to maritime industry decarbonisation are crucial for realising this potential.

The ship-port interface is another area where the economic and policy disparities among Mediterranean costal States become evident. Acknowledging the essential role of ports in achieving the goals of the 2023 IMO GHG Strategy, the need for the ports to prioritise the improvement of their energy efficiency in the short term and support decarbonisation efforts within the shipping industry through automation, digitalisation, and the use of artificial intelligence to reduce ship-port stays, thereby decreasing shipping emissions within ports is clear. For example, although the role of OPS as an effective measure for reducing emissions from ships while at port is underlined in existing literature and included in the 2023 IMO GHG Strategy, associated barriers such as high capital costs, technological demands, limited space at ports, electricity costs, energy sources, and the potential strain on the national grid hinder its wide implementation in the Mediterranean region.

Additionally, and in relation to port long-term sustainability by establishing sustainable bunkering infrastructure and transitioning to energy hubs, government policies are critical in guiding ports to act as energy hubs in the maritime domain. Appropriate governmental policies need to be developed as ports adhere to national regulations and policies and will contribute to the decarbonisation initiatives in place. While European ports are transitioning to energy hubs due to EU legislation, similar governmental policies also need to be initiated in non-EU ports in the region to accelerate the implementation of the 2023 IMO GHG Strategy.

To overcome the obstacles to decarbonising the regional shipping industry, collaboration and collective efforts are crucial. Although the region's ports compete with other industries and ports globally, including European ports, for appropriate investment, this competitive status should not result in an unstable legal framework, particularly concerning foreign investments. Therefore, it is vital for the region to adopt a consistent approach to all critical infrastructures and foster reciprocal relationships with other regional ports to establish partnerships that discourage protectionist measures and ensure genuine market access.

Regulatory bodies should develop comprehensive and harmonised rules that address the unique challenges and characteristics of the region. This involves ensuring alignment with both international (IMO) and regional (EU) regulations for consistency and effectiveness. Furthermore, to address uncertainties regarding future policies, proactive engagement from governments, industry stakeholders, and international organisations is crucial. This engagement will help establish clear and stable regulatory frameworks, fostering confidence and enabling long-term planning and investment. Lastly, fostering collaboration among stakeholders is vital. This includes creating platforms for dialogue, sharing best practices, and promoting partnerships between governments, shipping companies, port authorities, and environmental organisations to collectively achieve the goals of the 2023 IMO GHG Strategy in the Mediterranean region.

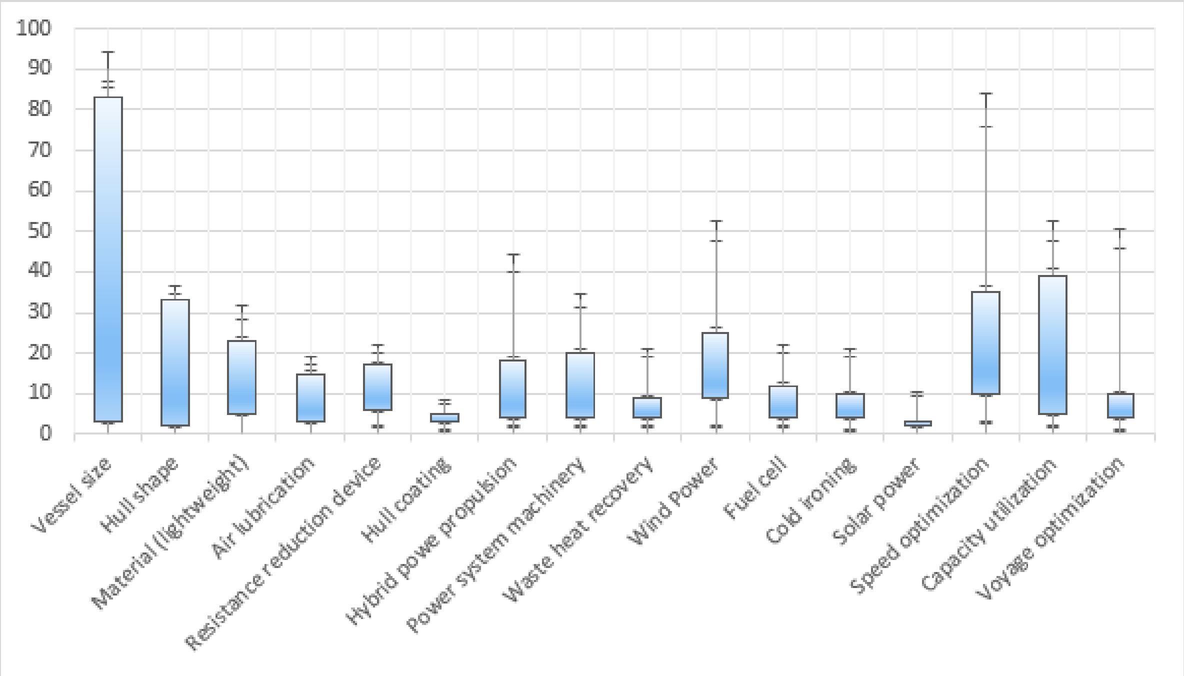


Figure 29. CO_2 emission reduction potential from individual measures.
Source: Vakili, S. and Christodoulou, A.

9 Roadmap and Action Plan

In line with the scope of the study to assess the effective implementation of the 2023 IMO GHG Strategy in the Mediterranean region, a roadmap and action plan are provided in this section (See Figure 30).

This plan aligns with the 2023 IMO GHG Strategy and is designed to guide stakeholders in addressing the issue and establishing mechanisms to achieve the reduction targets of the 2023 IMO GHG Strategy. The action items outlined are intended to be implemented concurrently with the 2023 IMO GHG Strategy. The suggested timeframes for each measure are flexible and should be adjusted by the respective CPs based on their evaluations and needs.

The recommendations listed below are based on the expert analysis tailored to each specific action item. It is important to note that, depending on the policies, economic conditions, and social factors of each CP, the timelines and priorities of these recommendations may vary.

The plan is broken down into the following actions:

Short-term actions

- **Capacity Building**: Enhanced Action Plan for Stakeholder Capacity Building on Decarbonisation and Regulatory Compliance.
- **Raising Awareness and Fostering Commitment**: Launch comprehensive awareness programs and secure commitments from maritime companies to reduce carbon emissions while highlighting the advantages of complying with the 2023 IMO GHG Strategy.
- **Disseminating and Improving Existing Recommendations, Principles, and Guidelines**: Spread and enhance current guidelines and develop new ones to facilitate the implementation of the 2023 IMO GHG Strategy.
- **Conducting a Comprehensive Impact Assessment Study**: Analyse the impact of the implementation of the 2023 IMO GHG Strategy and EU maritime legislation.

Short- to mid-term actions

- **Supporting Decision-Makers**: Design and develop tools to assist decision-makers in reducing GHG emissions from the maritime industry.
- **Encouraging Participation in Research and Development (R&D)**: Motivate scientific, technical, and industrial organisations to engage in R&D efforts aimed at enhancing energy efficiency and reducing GHG emissions, including at the ship-port interface.

Short- to long-term actions

- **Developing and Implementing Sustainable Port Infrastructure Plans**: Ensure the provision of adequate facilities to support ships using alternative energy sources and promote emissions-free shipping.
- **Establishing Green Corridors**: Create Green Corridors linking ports within the region and extending beyond it.

Figure 30. Roadmap and the action plan.

<u>***Short-term actions***</u>	a. Capacity Building: Enhanced Action Plan for Stakeholder Capacity Building on Decarbonisation and Regulatory Compliance.	• *In-Depth Training on MARPOL Annex VI* a. Develop a comprehensive training module that covers all aspects of MARPOL Annex VI, including updates and amendments. b. Offer regular workshops and webinars led by industry experts to explain the practical implications of compliance. • *Structured Training Courses and Seminars* a. Organise a series of training courses and seminars aimed at different levels of stakeholders, ensuring relevance and depth. b. Use case studies and real-world scenarios to demonstrate the application of knowledge in operational settings. • *Understanding the 2023 IMO GHG Strategy* a. Provide detailed sessions on the specific goals and requirements of the 2023 IMO GHG Strategy. b. Discuss the implications for the shipping industry and outline strategies for alignment with these goals. • *Short-Term and Mid-Term GHG Reduction Measures* a. Break down the IMO's short-term and mid-term measures for GHG emissions reductions, explaining the expected impact and implementation processes of each measure. b. Facilitate interactive discussions on how these measures can be integrated into current practices. • *EU Legislation and Shipping GHG Emissions Reductions* a. Conduct specialised training on EU legislation regarding GHG emissions in the maritime industry. b. Compare and contrast EU legislation with global (IMO) standards to provide a holistic view of the regulatory landscape. • *Deepening Knowledge in GHG Emission Reduction Techniques* a. Provide advanced training on innovative technologies and operational strategies that contribute to GHG emission reduction. b. Encourage the adoption of best practices through demonstration projects and pilot studies. • *Tools and Resources for Decision-Makers* a. Develop and distribute decision-making tools that incorporate data analytics and forecasting to help stakeholders evaluate the effectiveness of various GHG reduction strategies. b. Organise workshops to train decision-makers on using these tools to make informed choices about investments and operations. • *Regular Updates and Continuous Learning* a. Establish a digital platform for continuous learning, offering updated resources, new research findings, and regulatory changes.

		b. Encourage a community of practice among stakeholders to share insights, challenges, and successes in reducing GHG emissions. • *Feedback Mechanisms and Impact Assessment* a. Implement a feedback system to assess the effectiveness of training and seminars and make necessary adjustments. b. Conduct annual reviews to measure progress against the set objectives and refine strategies as needed. • *Engagement and Partnerships* a. Foster collaborations with educational institutions, industry experts, and international organisations to enhance the quality and reach of training programs. b. Create a network of stakeholders that promotes collective action and shared responsibilities in achieving decarbonisation goals.
	b. Raising Awareness and Fostering Commitment: Launch comprehensive awareness programs and secure commitments from maritime companies to reduce carbon emissions while highlighting the advantages of complying with the 2023 IMO GHG Strategy.	• *Educational Campaigns and Workshops*: Create and conduct educational campaigns to educate stakeholders on the significance and advantages of the initiative. Arrange interactive workshops to facilitate hands-on learning and stimulate discussion on pertinent issues. • *Communication Strategy*: Develop a robust communication strategy that delivers frequent updates, showcases success stories, and shares crucial data points to keep stakeholders engaged and informed. Employ various channels like e-mails, newsletters, social media, and webinars to reach a broad audience. • *Leadership Involvement*: Ensure that organisational leaders are visibly committed to the initiative. Leaders should actively engage in these efforts, communicate the importance of awareness and commitment transparently, and set an example for others. • *Stakeholder Engagement*: Engage a diverse group of stakeholders during both the planning and implementation stages to consider their views and needs. • *Incentives and Recognition Programs*: Implement incentive programs to reward active participation and accomplishments towards achieving the set goals. Moreover, establish recognition programs that celebrate the contributions and successes of individuals or teams, thereby reinforcing their commitment. • *Feedback Mechanisms*: Install mechanisms for stakeholders to provide feedback on the initiatives. Regularly review this feedback to refine approaches, demonstrating that their input is both valued and integral to the process. • *Sustainability Reporting*: Regularly report on the progress and results of awareness and commitment activities. This not only ensures transparency but also aids in evaluating the effectiveness of various strategies and actions. • *Continuous Improvement*: Continuously assess and enhance strategies and activities based on the results and fresh insights. This process of continual improvement is crucial for adapting to changes and maintaining the relevance and effectiveness of the initiatives.

	c. Disseminating and Improving Existing Recommendations, Principles, and Guidelines: Spread and enhance current guidelines and develop new ones to facilitate the implementation of the 2023 IMO GHG Strategy.	To implement existing and newly developed guidelines and regulations, specifically focusing on the Energy Efficiency Design Index (EEDI), Energy Efficiency for Existing Ships (EEXI), Ship Energy Efficiency Management Plan (SEEMP), Carbon Intensity Indicator (CII), Data Collection System, GHG Fuel Standard (GFS), and GHG pricing mechanisms. Design and develop guidelines to comply with the 2023 IMO GHG Strategy based on the country's priorities with consideration of their characteristics. This process may entail: • *Understanding the 2023 IMO GHG Strategy*: The first step is to thoroughly understand the objectives and requirements outlined in the 2023 IMO GHG Strategy that sets global targets to reduce maritime emissions and aims to phase them out as soon as possible within this century. Knowing the specifics will guide the development of effective guidelines. • *Assessment of Current Practices*: Evaluate the current operational and environmental practices within the maritime industry to identify where changes are needed to meet the new GHG reduction targets. This might involve reviewing fuel usage, ship design, operational efficiency, and existing pollution control methods. • *Development of Guidelines*: Based on the objectives and the initial assessment of the 2023 IMO GHG Strategy, develop comprehensive guidelines that address key areas for emission reduction. These guidelines could include: a. Fuel Efficiency: Recommendations for using more efficient propulsion systems or alternative, less polluting fuels like LNG or hydrogen. b. Operational Adjustments: Guidelines for optimising routes and speeds to reduce fuel consumption. c. Technology Adoption: Encouraging the use of new technologies such as exhaust gas cleaning systems, energy-saving devices, and digital tools for better fuel management. d. Reporting and Monitoring: Establishing protocols for monitoring emissions and reporting in compliance with IMO regulations. • *Stakeholder Engagement*: Engage with various stakeholders including ship owners, operators, shipbuilders, and technology providers to ensure the guidelines are practical and achievable. Stakeholder input is crucial for gaining buy-in and ensuring that the guidelines are aligned with industry capabilities. • *Implementation Strategy*: Develop a clear plan for how these guidelines will be implemented across the industry. This might include timelines, resource allocation, and identifying key parties responsible for various aspects of the implementation.
	d. Conducting a Comprehensive Impact Assessment Study: Analyse the	Conduct a comprehensive Impact Assessment Study on the implementation of the 2023 IMO GHG Strategy and EU maritime legislation. This study should evaluate the effects on maritime stakeholders in the Mediterranean region, identify potential challenges, and ensure alignment with broader environmental and regulatory goals. The

	impact of the implementation of the 2023 IMO GHG Strategy and EU maritime legislation.	assessment will help in understanding the practical implications, devising strategies to bridge gaps, mitigate risks, and optimise the benefits of these initiatives.
<u>Short- to mid-term actions</u>	a. Supporting Decision-Makers: Design and develop tools to assist decision-makers in reducing GHG emissions from the maritime industry.	Achieving the goal of designing and developing decision-making tools to reduce air emissions from the maritime industry involves a series of strategic and technical steps as follow: • *Identify Key Emission Sources*: Begin with a detailed analysis of the maritime industry to pinpoint the primary sources of air emissions, including emissions from ships, port operations, and associated activities. • *Gather and Analyse Data*: Collect and analyse data on emission levels, operational patterns, fuel consumption, and existing emission control measures. Leveraging big data analytics and Internet of Things (IoT) sensors can enhance real-time data collection and monitoring. • *Develop Emission Models*: Construct models that simulate the impact of various activities and changes in operations on emissions. These models are crucial for pinpointing the most effective emission reduction strategies. • *Create Simulation Tools*: Design simulation tools that enable decision-makers to visualise the potential outcomes of different emission reduction strategies. These tools can simulate scenarios based on technological changes, fuel types, operational adjustments, and regulatory compliance. • *Integrate Best Practices and Technologies*: Integrate proven best practices and emerging technologies into the decision-making tools, such as alternative fuels, energy efficiency measures, speed optimisation, and advanced WHR systems. • *Develop User-Friendly Interfaces*: Design the tools with user-friendly interfaces to ensure ease of use for decision-makers, which can facilitate wider adoption and more effective application. • *Training and Support*: Offer training for users to maximise the effectiveness of these tools, along with ongoing support and updates as new data and technologies emerge. • *Policy Integration*: Collaborate closely with policymakers to ensure that the tools are aligned with current regulations and can help shape future legislation aimed at emission reduction. • *Feedback and Continuous Improvement*: Establish a feedback system to collect insights from users and assess the effectiveness of the tools, using this feedback for continual refinement and enhancement. • *Collaboration and Partnerships*: Encourage collaboration and partnerships between technology developers, maritime companies, regulatory bodies, and environmental experts to drive innovation and ensure the tools are comprehensive and effective.

	b. Encouraging Participation in Research and Development (R&D): Motivate scientific, technical, and industrial organisations to engage in R&D efforts aimed at enhancing energy efficiency and reducing GHG emissions, including at the ship-port interface.	To provide a comprehensive approach to engaging key stakeholders in the scientific and industrial sectors, promoting advanced research, facilitating the implementation of new technologies, and sharing knowledge across a wide network to drive improvements in energy efficiency and emissions reduction in international shipping. ● *Define Objectives and Goals*: ● Main Objective: To improve energy efficiency and reduce GHG emissions associated with international shipping and ship-port interfaces. ● Specific Goals: ● Increase participation of scientific and industrial organisations in R&D projects. ● Foster innovations in energy efficiency and emissions reduction. ● Disseminate findings and technologies across the Mediterranean coastal States. ● *Stakeholder Engagement*: ● Identify Key Stakeholders: Include but not limit to scientific communities, shipping industries, port authorities, environmental agencies, technology providers, and relevant governmental bodies. ● Engagement Strategies: ○ Host stakeholder meetings to align goals and interests. ○ Form collaborative partnerships and consortia. ○ Provide platforms for regular communication and updates. ● *Research and Development (R&D) Promotion* ● Initiatives and Programs: ○ Develop specific R&D programs targeting innovations in ship and port technologies for improving energy efficiency and reduction of GHG emissions. ○ Offer grants, subsidies, and incentives to encourage participation. ○ Sponsor PhD and postdoctoral research positions focused on specific challenges in the industry. ● *Policy Support and Regulation* ● Develop Policies: Formulate policies that support energy efficiency and GHG reduction, including GHG pricing, tax incentives for green technology adoption.

		● Regulatory Frameworks: Collaborate with the IMO and EU to ensure alignment with global standards and regulations. ● *Implementation of Research Findings* ● Prototype Development: Support the development of prototypes and pilot projects to test new technologies. ● Commercialisation: Assist in bringing successful technologies to market. ● Integration with Existing Systems: Facilitate the integration of new technologies with existing ship and port infrastructure. ● *Monitoring and Evaluation* ● Performance Metrics: Define clear metrics to evaluate the impact of R&D efforts on energy efficiency and GHG emissions. ● Reporting Mechanisms: Establish a system for regular reporting and evaluation of ongoing projects. ● Adjustments and Scaling: Use the findings from evaluations to refine approaches and scale successful practices. ● *Dissemination and Communication* ● Information Sharing: Create an online portal for sharing R&D findings, best practices, and technological advancements. ● Workshops and Conferences: Regularly organise workshops, seminars, and conferences to disseminate knowledge and foster networking among stakeholders. ● Public Awareness Campaigns: Engage the public and industry through targeted campaigns to increase awareness and adoption of new technologies.
Short- to long-term actions	a. Developing and Implementing Sustainable Port Infrastructure Plans: Ensure the provision of adequate facilities to support ships using alternative energy sources and	For developing sustainable port infrastructure to support ships using alternative energy sources and promoting emissions-free shipping, the following actions need to be taken: ● *Assessment of Current Infrastructure*: Conduct a comprehensive assessment of existing port infrastructure to identify strengths, weaknesses, and areas for improvement in supporting alternative energy use and emissions reduction. ● *Stakeholder Engagement*: Engage with stakeholders including port authorities, shipping companies, energy providers, environmental organisations, and local communities to gather input and perspectives on the development of sustainable port infrastructure.

	promote emissions-free shipping.	• *Identification of Alternative Energy Solutions*: Research and identify viable alternative energy sources for maritime use, such as LNG, hydrogen fuel cells, ammonia, shore power, and renewable energy sources like solar and wind power. • *Infrastructure Design and Planning*: Develop detailed plans for the design and implementation of sustainable port infrastructure, taking into account the specific requirements of alternative energy systems and emissions reduction technologies. • *Investment and Funding*: Secure funding and investment for the development of sustainable port infrastructure, leveraging public-private partnerships, government grants, and other financial mechanisms to support the implementation of infrastructure projects. • *Regulatory Compliance*: Ensure that all infrastructure development plans comply with relevant regulations and environmental standards, including those set forth by international bodies such as the IMO and local regulatory authorities. • *Construction and Implementation*: Begin construction and implementation of sustainable port infrastructure projects, including the installation of alternative energy systems, shore power facilities, and other emissions reduction technologies. • *Monitoring and Evaluation*: Establish monitoring and evaluation mechanisms to track the performance and effectiveness of sustainable port infrastructure in supporting alternative energy use and emissions reduction. Make adjustments and improvements as needed based on monitoring data and feedback from stakeholders. • *Promotion and Awareness*: Promote the benefits of sustainable port infrastructure and emissions-free shipping to raise awareness among stakeholders and encourage greater adoption of alternative energy solutions in the maritime industry. • *Continued Collaboration*: Foster ongoing collaboration and partnership between port authorities, shipping companies, government agencies, and other stakeholders to ensure the continued development and improvement of sustainable port infrastructure in support of emissions-free shipping.
	b. Establishing Green Corridors: Create Green Corridors linking ports within the region and extending beyond it.	Establishing a green corridor involves several actions to ensure its success. Here are some required steps: • *Feasibility Study*: Conduct a comprehensive study to assess the viability of the green corridor concept, considering factors such as geographical location, available resources, infrastructure, and potential environmental impact. • *Stakeholder Engagement*: Engage with relevant stakeholders including government agencies, local communities, industry partners, environmental organisations, and potential investors to garner support and gather input for the project. • *Policy and Regulatory Framework*: Develop and implement supportive policies and regulations that incentivise the establishment and operation of green corridors, including tax incentives, subsidies, emission regulations, and environmental protection measures.

		● *Infrastructure Development*: Invest in the development of necessary infrastructure such as renewable energy sources (solar, wind, hydro), carbon neutral fuel bunker stations, OPS, and smart grid systems to support the functioning of the green corridor. ● *Technology Integration*: Adopt and deploy innovative technologies such as IoT, blockchain, and data analytics to optimise energy usage, monitor emissions, and improve overall efficiency within the green corridor. ● *Capacity Building and Training*: Provide training programs and capacity-building initiatives for workforce development, focusing on green technologies, sustainability practices, and environmental stewardship. ● *Monitoring and Evaluation*: Establish a robust monitoring and evaluation framework to track progress, measure performance indicators, and ensure compliance with environmental standards and goals. ● *Public Awareness and Education*: Conduct awareness campaigns and educational initiatives to inform the public about the benefits of green corridors, promote sustainable practices, and encourage active participation and support from the community. ● *Partnerships and Collaboration*: Foster partnerships and collaboration with other regions, organisations, and institutions working towards similar goals to leverage resources, share best practices, and enhance collective impact.

9.1 Formulate, construct, and execute a roadmap to adhere to the 2023 IMO GHG Strategy and its related objectives for the region.

To craft, create, and execute a roadmap for aligning with the 2023 IMO GHG Strategy and its associated objectives, the following actions may need to consider:

- **Convene Stakeholder Meetings**: Organise meetings involving key stakeholders from the maritime industry, including representatives from shipping companies, maritime organisations, environmental groups, governmental bodies, and research institutions.

- **Review Current Progress**: Evaluate the current status of efforts to meet the 2023 IMO GHG Strategy. Assess the achievements made thus far, identify any barriers or challenges encountered, and determine areas requiring urgent attention.

- **Develop Roadmap Objectives**: Establish clear and measurable objectives for the roadmap, aligned with the targets outlined in the 2023 IMO GHG Strategy. Define specific goals related to emission reduction, technological innovation, regulatory frameworks, and industry collaboration.

- **Identify Priority Actions**: Identify priority actions necessary to accelerate progress towards the goals of the 2023 IMO GHG Strategy. This may include measures such as promoting the uptake of low-carbon technologies, enhancing energy efficiency measures, implementing alternative fuels, and fostering international cooperation.

- **Engage in Technical Workshops and Studies**: Organise technical workshops and commission studies to explore innovative solutions and best practices for reducing GHG emissions from ships. Share knowledge and expertise to facilitate informed decision-making.

- **Develop Implementation Plans**: Collaborate with relevant stakeholders to develop detailed implementation plans for each priority action identified in the roadmap. Define responsibilities, timelines, and resource requirements for executing the proposed initiatives.

- **Allocate Funding and Resources**: Secure funding and allocate resources necessary to support the implementation of the roadmap initiatives. Explore opportunities for public-private partnerships and international funding mechanisms to ensure adequate financial support.

- **Establish Monitoring and Reporting Mechanisms**: Establish robust monitoring and reporting mechanisms to track progress towards achieving the objectives of the roadmap. Regularly assess performance against set targets and adjust strategies as needed to stay on course.

- **Promote Knowledge Sharing and Capacity Building**: Facilitate knowledge sharing and capacity building initiatives to empower stakeholders with the necessary skills and expertise to drive forward the implementation of the roadmap. Foster collaboration and peer learning among industry players.

- **Periodic Review and Revision**: Conduct periodic reviews of the effectiveness and relevance of the roadmap in light of evolving circumstances, technological advancements, and regulatory developments. Revise the roadmap as needed to ensure its continued alignment with the goals of the 2023 IMO GHG Strategy.

10 Conclusions and Recommendations

10.1 Conclusions

The Study was conducted to assess the effective implementation of the 2023 IMO GHG Strategy in the Mediterranean region and make recommendations on any regional policies that may be considered for a more effective implementation of the Strategy within the Mediterranean region, including the adoption of the most appropriate GHG reduction measures. To achieve this, the awareness of the maritime stakeholders in the Mediterranean region regarding the 2023 IMO GHG Strategy and its associated goals was evaluated. In line with a literature review to identify measures for decarbonising the shipping industry and pathways to meet these goals, a questionnaire and interviews were conducted to pinpoint gaps among stakeholders in the region. Due to time constraints, interviews were conducted with top experts in the field to enhance the credibility of the findings.

The results of the questionnaire revealed a lack of awareness about the 2023 IMO GHG Strategy among stakeholders in the Mediterranean region. However, awareness of the EU legislation was slightly higher, especially among the stakeholders in Mediterranean coastal States that are EU Member States. Many stakeholders believe that complying with the EU legislation will suffice to meet the 2023 IMO GHG Strategy. In light of these findings, capacity building and staff training on these issues are essential.

Mediterranean coastal States that are EU Member States, with their green economy policies and legislation such as the EU ETS, FuelEU Maritime and the AFID, are in a better position regarding the decarbonisation of the maritime industry compared to Mediterranean coastal States that are not EU Member States. However, the level of compliance with the EU legislation varies based on national policies.

Many Mediterranean coastal States have already developed comprehensive plans for producing carbon-neutral fuels, positioning themselves as significant energy hubs. While a few major ports in Mediterranean coastal States that are not EU Member States have begun providing alternative fuels such as LNG and methanol, some of major ports in some Mediterranean coastal States that are EU Member States have established sustainable infrastructure for OPS and bunkering alternative fuels, aiming to become future energy hubs.

There is a noticeable discrepancy among stakeholders between Mediterranean coastal States that are EU Member States and those that are not EU Member States regarding the 2023 IMO GHG Strategy and related EU legislation. Stakeholders in Mediterranean coastal States that are EU Member States believe that the EU legislation encourages the IMO and other IMO Member States to transition to zero-emission shipping. In contrast, stakeholders in Mediterranean coastal States that are not EU Member States argue that the EU should comply with the IMO, the international regulatory body for global shipping. This discrepancy could complicate the process and result in carbon leakage. However, stakeholders in Mediterranean coastal States that are EU Member States believe that, overall, the implementation of regulations like the EU ETS offers greater environmental benefits than the potential risk of carbon leakage.

The Mediterranean region's unique characteristics influence the shift to zero-emission shipping, with economic and policy disparities among the Mediterranean coastal States that are EU Member States and those that are not EU Member States creating challenges for a unified strategy. Geopolitical instability in the Mediterranean region or adjacent regions, such as in the Black Sea, further obstructs coordinated efforts. Despite significant potential in renewable energy resources to transform the region into a green energy hub, working towards resolving geopolitical issues is essential for attracting investors and driving economic growth. The Mediterranean's strategic importance as a global trade and energy corridor enhances its potential in the energy transition but trying to overcome geopolitical instability and adopting a cohesive maritime decarbonisation approach are crucial.

The economic and policy disparities are evident in the ship-port interface. Ports should prioritise energy efficiency and support decarbonisation through automation, digitalisation, and AI to reduce ship-port stays and emissions. Barriers to the wide implementation of OPS in the region include high costs, technological demands, limited space, and electricity-related issues.

For long-term sustainability, government policies are critical in guiding ports to become energy hubs. While European ports transition due to EU legislation, similar policies are needed in non-EU ports to accelerate the 2023 IMO GHG Strategy.

- A lack of awareness about the 2023 IMO GHG Strategy among stakeholders in the Mediterranean region.

- Awareness of the EU legislation was slightly higher, especially among the stakeholders in Mediterranean coastal States that are EU Member States.

- Mediterranean coastal States that are EU Member States, with their green economy policies and legislation such as the EU ETS, FuelEU Maritime and the AFID, are in a better position regarding the decarbonisation of the maritime industry compared to Mediterranean coastal States that are not EU Member States.

- Many Mediterranean coastal States have already developed comprehensive plans for producing carbon-neutral fuels, positioning themselves as significant energy hubs.

- Some of major ports in Mediterranean coastal States that are EU Member States have established sustainable infrastructure for OPS and bunkering alternative fuels, aiming to become future energy hubs.

- Stakeholders in Mediterranean coastal States that are not EU Member States argue that the EU should comply with the IMO, the international regulatory body for global shipping due to the risk of carbon leakage.

- Stakeholders in Mediterranean costal States that are EU Member States believe that the EU legislation encourages the IMO and other IMO Member States to transition to zero-emission shipping and that, overall, the implementation of regulations like the EU ETS offers greater environmental benefits than the potential risk of carbon leakage.

- The Mediterranean region's unique characteristics influence the shift to zero-emission shipping, with economic and policy disparities among the Mediterranean coastal States that are EU Member States and those that are not EU Member States creating challenges for a unified strategy.

- Geopolitical instability in the Mediterranean region or adjacent regions, such as in the Black Sea, further obstructs coordinated efforts.

- The Mediterranean's strategic importance as a global trade and energy corridor enhances its potential in the energy transition, but overcoming geopolitical instability and adopting a cohesive maritime decarbonisation approach are crucial.

- Ports should prioritise energy efficiency and support decarbonisation through automation, digitalisation, and AI to reduce ship-port stays and emissions.

- Barriers to the wide implementation of OPS in the region include high costs, technological demands, limited space, and electricity-related issues.

- For long-term sustainability, government policies are critical in guiding ports to become energy hubs.

- While European ports transition due to EU legislation, similar policies are needed in non-EU ports to accelerate the 2023 IMO GHG Strategy.

Figure 31. Conclusions

10.2 Recommendations

10.2.1 Holistic, Systematic, and Transdisciplinary Approach with Collaboration Among Countries and Stakeholders.

Transitioning to zero-emission shipping is a complex task that involves numerous active stakeholders with varying priorities. To achieve this transition, a holistic, systematic, and transdisciplinary approach is essential (Vakili and Ölçer, 2023). Additionally, robust collaboration among stakeholders is crucial to overcoming barriers and expediting progress towards meeting the 2023 IMO GHG Strategy.

Given the unique features and geopolitical complexities of the Mediterranean region, achieving a harmonised approach to decarbonisation presents significant challenges. While some Mediterranean coastal States, particularly those that are EU Member States, have made significant strides towards zero-emission shipping due to stringent EU legislation, similar initiatives are lacking in other Mediterranean coastal States, notably those that are not EU Member States. This disparity can lead to carbon leakage within the area.

Therefore, a coordinated effort that includes the following is recommended (Figure 32):

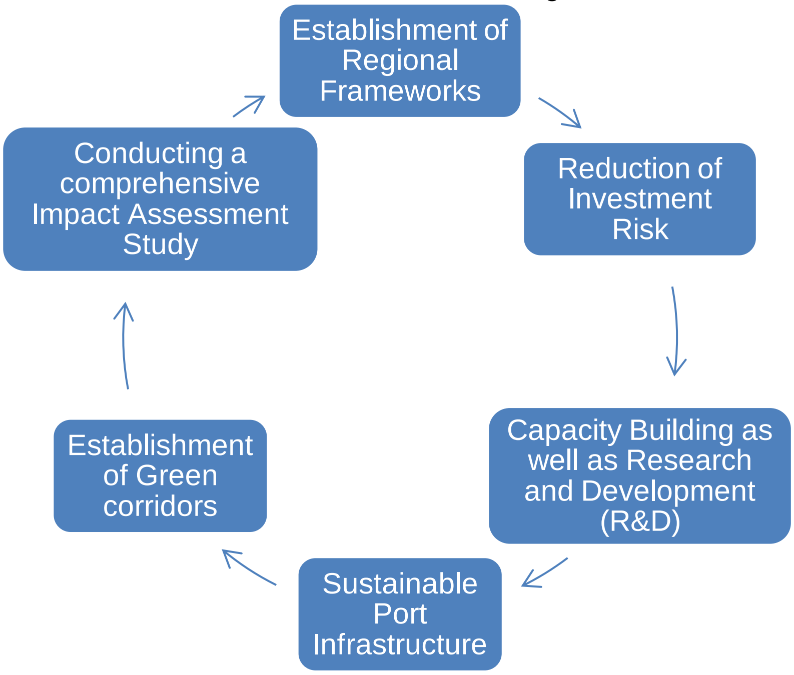


Figure 32. Recommendations
Source: Vakili, S. and Christodoulou, A.

10.2.2 Establishment of Regional Frameworks

The CPs should design, develop, and implement a holistic, systematic, and transdisciplinary framework that aligns the decarbonisation efforts of all Mediterranean coastal States, ensuring consistent policies and regulations for meeting the 2023 IMO GHG Strategy. The framework should integrate technical, innovative, operational, human factors, policy and regulatory and economic disciplines to achieve the goals. It should also foster stronger collaboration among governments, shipping companies, ports, technology providers, and other stakeholders to create unified strategies and share best practices.

10.2.3 Reduction of Investment Risk

CPs should explore the possibility of reducing the risk associated with investing in new and green technologies. To facilitate the transition to zero-emission shipping, it is crucial to mitigate investment risks. The uncertainty surrounding the most effective strategies for achieving zero-emission shipping heightens the financial risk for investors in new zero or near-zero emission technologies. Regulatory bodies and governments can alleviate these risks by offering clear guidelines and financial support to early developers. This support can take the form of low-interest loans, tax exemption schemes, and utilising funds from the EU ETS and future IMO carbon pricing schemes. Such measures will encourage investment in green technologies and sustainable infrastructure, driving the industry towards a zero-emission future.

10.2.4 Capacity Building as well as Research and Development (R&D)

CPs should enhance capacity building, raise awareness, and invest on research and development as these are essential tools for accelerating the transition to zero-emission shipping and achieving the 2023 IMO GHG Strategy. This includes comprehensive training for personnel and staff in accordance with MARPOL Annex VI, as well as IMO and EU goals for zero-emission shipping. Training programs should be holistic, systematic, and transdisciplinary, involving active stakeholders such as government officials, shipyards, port authorities, and shipping companies across various levels of management. Simultaneously, R&D efforts should focus on data collection and analysis, sustainable infrastructure development, technology transfer, and socio-economic development. These initiatives are crucial for supporting the transition to a sustainable and zero-emission maritime industry.

10.2.5 Sustainable Port Infrastructure

Developing and implementing plans for sustainable port infrastructure, ensuring the provision of adequate facilities to support ships using alternative energy sources and advancing emissions-free shipping is crucial. CPs should first conduct a comprehensive assessment of existing port infrastructure to identify strengths, weaknesses, and areas for improvement in supporting alternative energy use and emissions reduction at the national level. Engaging with stakeholders, including port authorities, shipping companies, energy providers, environmental organisations, and local communities, is crucial to gather input and perspectives on the development of sustainable port infrastructure.

CPs should then proceed with the research and identification of viable alternative energy sources for maritime use, such as LNG, hydrogen fuel cells, ammonia, shore power, and renewable energy sources like solar and wind power. Detailed plans should be developed for the design and implementation of sustainable port infrastructure, taking into account the specific requirements of alternative energy systems and emissions reduction technologies. Securing funding and investment for the development of sustainable port infrastructure is also essential, leveraging public-private partnerships, government grants, and other financial mechanisms to support the implementation of infrastructure projects. Finally, fostering ongoing collaboration and partnership between port authorities, shipping companies, government agencies, and other stakeholders is vital to ensure the continued development and improvement of sustainable port infrastructure in support of emissions-free shipping.

10.2.6 Establishment of Green corridors

CPs should explore the possibility of establishing green corridors that can significantly accelerate the transition to zero-emission shipping. By creating these corridors between EU and non-EU ports as well as supporting investments and technology transfer, a harmonious approach to decarbonising the maritime industry and meeting the 2023 IMO GHG Strategy is facilitated. This initiative provides an opportunity for regional ports to adopt innovative measures and green technologies throughout the value chain to achieve zero-emission shipping. However, while the benefits are clear, there are challenges such as establishing sustainable infrastructure, managing high costs and required investments, meeting regulatory framework requirements, integrating the value chain, raising public awareness and acceptance, and managing the transitional period. Addressing these challenges will require further collaboration among all stakeholders.

10.2.7 Conducting a comprehensive Impact Assessment Study

In light of the critical role that the 2023 IMO GHG Strategy plays in the decarbonisation of the shipping industry, alongside the effectiveness of EU legislation in expediting the transition to zero-emission shipping, addressing the regional discrepancies is imperative. Therefore, CPs should undertake a thorough impact assessment on the implementation of the 2023 IMO GHG Strategy and the EU legislation. This assessment should focus on evaluating the effects on maritime stakeholders in the Mediterranean region, identifying potential challenges, and ensuring alignment with broader environmental and regulatory goals. Through this comprehensive evaluation, stakeholders in the Mediterranean region can better understand the practical implications and devise strategies to bridge gaps, mitigate risks, and optimise the benefits of these crucial initiatives.

References

Aroca, J., Giménez Maldonado, J. A., Ferrús Clari, G., Alonso i García, N., Calabria, L., & Lara, J. (2020). Enabling a green just-in-time navigation through stakeholder collaboration. European Transport Research Review, 12(1), 1-11.

Asia-Pacific Economic Cooperation (APEC). (2019). Analysis of the impacts of slow steaming for distant economies, APEC Transportation Group, APEC Project: TPT 03 2018A, produced by Starcrest Consulting Group for the Asia-Pacific Economic Cooperation Secretariat, December. (2019).

ASYAPORT. (2024). Integrated management system. Retrieved from: Integrated Management System | Asyaport.

Bakar, N. N. A., Bazmohammadi, N., Vasquez, J. C., & Guerrero, J. M. (2023). Electrification of onshore power systems in maritime transportation towards decarbonisation of ports: A review of the cold ironing technology. Renewable and Sustainable Energy Reviews, 178, 113243.

Ballini, F., & Bozzo, R. (2015). Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology. Research in Transportation Business & Management, 17, 92-98.

Becqué, R., Fung, F., Zhu, Z., 2017. Incentive Schemes for Promoting Green Shipping. Natural Resources Defense Council (NRDC).

Clarkson. (2023). Green Technology Tracker: July 2023.

Climate action tracker. (2023). Retrieved from: Türkiye - Assessment - 20/03/2023 | Climate Action Tracker.

Chang, C. C., Huang, P. C., & Tu, J. S. (2019a). Life cycle assessment of yard tractors using hydrogen fuel at the Port of Kaohsiung, Taiwan. Energy, 189, 116222.

Christodoulou, A., & Cullinane, K. (2021). Potential for, and drivers of, private voluntary initiatives for the decarbonisation of short sea shipping: evidence from a Swedish ferry line. Maritime Economics & Logistics, 23(4), 632-654.

Christodoulou, A., D. Dalaklis, A.I. Ölcer, and F. Ballini. (2021). Can market-based measures stimulate investments in green technologies? A review of proposed market-based measures. Transactions on Maritime Science 10(1): 208.

Christodoulou, A., Gonzalez-Aregall, M., Linde, T., Vierth, I. and Cullinane, K. (2019). Targeting the reduction of shipping emissions to air: A global review and taxonomy of policies, incentives and measures. *Maritime Business Review* 4(1), pp. 16-30. https://doi.org/10.1108/MABR-08-2018-0030

Christodoulou, A. and Cullinane, K. (2024). The Prospects for, and implications of, Emissions Trading in Shipping. *Maritime Economic & Logistics*.

Christodoulou, A. and Cullinane, K. (2022). Potential alternative fuel pathways for compliance with the 'FuelEU Maritime Initiative'. *Transportation Research Part D: Transport and Environment* 112, 103492. https://doi.org/10.1016/j.trd.2022.103492

CSI. (2021). Clean Shipping Index ranks vessels on environmental performance beyond regulatory compliance. Retrieved from: https://www.cleanshippingindex.com/projektwebbar/clean-shipping-index/methodology.html).

DNV. (2022). Energy Transition Outlook. Maritime forecast to 2050. Retrieved from: https://www.dnv.com/maritime/publications/maritime-forecast-2022/index.html

DNV. (2023). Energy Transition Outlook. Maritime forecast to 2050. Retrieved from: Maritime Forecast to 2050 - DNV.

Dupuy, Maxime & Letournel, Lucas & Paakkari, Ville & Rongère, François & Sarsila, Severi & Vuillermoz, Louis. (2023). Weather Routing Benefit for Different Wind Propulsion Systems. Conference: International conference on innovation in high performance sailing yachts and wind-assisted ships at Lorient.

European Environment Agency. (1999). State and pressures of the marine and coastal Mediterranean environment. Office for Official Publ. of the European Comm.

Egypt oil and Gas. (2024). Egypt’s Energy Overview. Retrieved from: https://egyptoil-gas.com/reports/egypts-energy-overview-2024/

Elkafas, A. G., Rivarolo, M., Gadducci, E., Magistri, L., & Massardo, A. F. (2022). Fuel cell systems for maritime: a review of research development, commercial products, applications, and perspectives. Processes, 11(1), 97.

Enerdata. (2023). Turkey's National Energy Plan for 2035 will boost solar and wind capacities. Retrieved from: Turkey's National Energy Plan for 2035 will boost solar and wind capacities | Enerdata.

ESI. (2021). Environmental Ship Index. Retrived from: https://www.environmentalshipindex.org/
Faber, J., Huigen, T., & Nelissen, D. (2017). Regulating speed: a short-term measure to reduce maritime GHG emissions. CE Delft.

Faber, J., Nelissen, D., Hon, G., Wang, H., & Tsimplis, M. (2012). Regulated Slow Steaming in Maritime Transport. An assessment of options, costs and benefits.

Flodén, J., Zetterberg, L., Christodoulou, A., Parsmo, R., Fridell, E., Hansson, J., Rootzen, J., & Woxenius, J. (2024). Shipping in the EU emissions trading system: implications for mitigation, costs and modal split. *Climate Policy*, 1–19.

Fuelcell work. (2023). Turkey’s Leap into the Future: HYSouthMarmara and the promise of Green Hydrogen. Retrieved from: Turkey’s Leap Into The Future: HYSouthMarmara And The Promise Of Green Hydrogen - FuelCellsWorks.

GM. (2021). Green Marine. Retrieved from: https://green-marine. org/about-us. (accessed in June 2022).

González. G. (2022). Meeting the challenges of Mediterranean maritime traffic: supporting and implementing a collective and sustainable vision/strategy by 203. Retrieved from: CETMO_IEMED_Mar_Sustainable-Strategy-2031_GGonzalez_EN.pdf

Heinke, H.-J., Hellwig-Rieck, K. (June 2011). Investigation of Scale Effects on Ships with a Wake Equalizing Duct or with Vortex Generator Fins, Second International Symposium on Marine Propulsors, smp’11, Hamburg, Germany.

Heinke, H.-J., Lübke, L. O. (2014). Maßnahmen zur Energieeinsparung, Schiff & Hafen, Nr. 10.

Hutchison Ports Sustainability Report. (2023). Building Resilience through Sustainable Development. Sustainability Report 2022. Retrieved from: https://hutchisonports.co.th/wp-content/uploads/2023/06/Hutchison-Ports-Sustainability-Report-2022.pdf
Hydrogen insight. (2023). Green hydrogen targets and incentives | Turkey unveils new national H2 strategy and roadmap. Green hydrogen targets and incentives | Turkey unveils new national H2 strategy and roadmap | Recharge (hydrogeninsight.com).

IAMU. (2014). Istanbul Technical University, Improving Energy Efficiency of Ships Through Optimisation of Ship Operations. Retrieved from: https://gmn.imo.org/wp-content/uploads/2017/10/20140301-ITUMF_Ship-optimization.compressed.pdf
IEA. (2023). Retrieved from: https://iea.blob.core.windows.net/assets/5dc74a29-c4cb-4cde-97e0-9e218c58c6fd/Greece2023.pdf .

IMO. (2000). First IMO GHG Study. Retrieved from: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/First%20IMO%20GHG%20study.pdf

IMO. (2011). MEPC, I. 63/4/8. Transparent and reliable hull and propeller performance standard.

IMO. (2018). Initial IMO Strategy on Reduction of GHG Emissions from Ships. MEPC, 72, 17.

IMO. (2019). RESOLUTION MEPC.323(74). Invitation to Member States to Encourage Voluntary Cooperation between the Port and Shipping Sectors to Contribute to Reducing GHG Emissions from Ships. Retrieved from: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.323%2874%29.pdf

IMO. (2020). Fourth IMO GHG Study. Retrieved from: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf

IMO. (2020a). IMO. ISWG-GHG 7/2/20. Further consideration of concrete proposals to improve the operational energy efficiency of existing ships, with a view to developing draft amendments to chapter 4 of MARPOL Annex VI and associated guidelines, as appropriate. Retrieved from: https://shipowners.fi/wp-content/uploads/2020/02/ISWG-GHG-7-2-20-Detailed-impact-assessment-of-the-mandatory-operational-goal-based-short-term-measure-Denmark-France-and-Germa....pdf

IMO. (2023). Resolution MEPC.377(80). Reduction of GHG emissions from ships. Revised GHG reduction strategy for global shipping adopted. Retrieved from: https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/Resolution%20MEPC.377(80).pdf

ITF. (2023). Decarbonisation, Coastal Shipping and Multimodal Transport: Summary and Conclusions, ITF Roundtable Reports, No. 192, OECD Publishing, Paris.

GA. (2021). Green Award Certification and Incentive Program for Shipping Retrieved from: https://www.greenaward.org

GreenPort. (2024). Retrieved from: https://www.portstrategy.com/environment-and-sustainability/algeciras-begins-lng-cruise-bunkering-services/1489960.article

Kılıç, A., Yolcu, M., Kılıç, F., & Bilgili, L. (2020). Assessment of ship emissions through cold ironing method for Iskenderun Port of Turkey. Environmental Research and Technology, 3(4), 193-201.

Krantz R, Søgaard K, Smith T (2020). The scale of investment needed to decarbonize international shipping. January. Available at: https://www.globalmaritimeforum.org/content/2020/01/Getting-toZero-Coalition_Insightbrief_ Scale-of-investment.pdf

Kumagai, I., Takahashi, Y., & Murai, Y. (2015). Power-saving device for air bubble generation using a hydrofoil to reduce ship drag: Theory, experiments, and application to ships. Ocean Engineering, 95, 183-194.

Lloyd's Register, U. M. A. S. (2020). Techno-economic assessment of zero-carbon fuels. Lloyds Register.

Lloyd's Register. Retrieved from: https://www.lr.org/en/services/statutory-compliance/fit-for-55/fueleu-regulation/

Loni, R., Najafi, G., Bellos, E., Rajaee, F., Said, Z., & Mazlan, M. (2021). A review of industrial waste heat recovery system for power generation with Organic Rankine Cycle: Recent challenges and future outlook. Journal of cleaner production, 287, 125070.

Lutmar, C., & Rubinovitz, Z. (2023). The Suez Canal: past lessons and future challenges (p. 264). Springer Nature.

Madsen, R. T., Klebanoff, L. E., Caughlan, S. A. M., Pratt, J. W., Leach, T. S., Appelgate Jr, T. B., ... & Ghosh, S. (2020). Feasibility of the Zero-V: A zero-emissions hydrogen fuel-cell coastal research vessel. International Journal of Hydrogen Energy, 45(46), 25328-25343.

Magli. (2023). SCZONE invests $1 billion on East Port Said green bunkering. Retrieved from: SCZONE invests $1 billion on East Port Said green bunkering - Port Technology International.

Marine Battery Forum (MBF). (2023). Retrieved from: https://www.maritimebatteryforum.com/ship-register

Maritime Transport Sector. (2019), Maritime Transport Sector Achievements 2019.

Marlow, P.B. and Paixão Casaca, A.C. (2003), Measuring Lean Ports Performance, International Journal of Transport Management, Vol. 1, No. 4, pp. 189–202.

Merk, O. , Kirstein, L., Halim, R. (2018). Decarbonising Maritime Transport: Pathways to Zero-carbon Shipping by 2035. (2018). Case-specific Policy Analysis, International Transport Forum/ OCED, Paris, 2018. Retrieved from: https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport.pdf

Ministry of Environment, Urbanization, and Climate Change. (2021). The 2053 Net-Zero Target and Türkiye's Long-Term Climate Change Strategy. Retrieved from: The 2053 Net-Zero Target and Türkiye's Long-Term Climate Change Strategy – Net Sıfır Türkiye (netsifirturkiye.org).

Mizzi, K., Demirel, Y. K., Banks, C., Turan, O., Kaklis, P., & Atlar, M. (2017). Design optimisation of Propeller Boss Cap Fins for enhanced propeller performance. Applied Ocean Research, 62, 210-222.

Mohamed Hussein, K. N. (2021). Development of sustainable port supply chain integration in Egypt.

OECD. (2018). Reducing Shipping Greenhouse Gas Emissions: Lessons from Port-Based Incentives. International Transport Forum and Organisation for Economic Cooperation and Development, Paris.

Offshore energy. (2023). Retrieved from: https://www.offshore-energy.biz/185-global-ports-can-bunker-lng/.

Offshore energy. (2024). Retrieved from: https://www.offshore-energy.biz/better-shipyard-capacity-key-to-building-refitting-3500-green-ships-by-2050/

Peksen. (2013). A new appr A new approach for Turkish ports to reduce ship emissions case educe ship emissions case study: application of cold ironing system for Marport container terminal. Retrieved from: https://commons.wmu.se/cgi/viewcontent.cgi?article=1004&context=all_dissertations

Pesyridis, A., Asif, M. S., Mehranfar, S., Mahmoudzadeh Andwari, A., Gharehghani, A., & Megaritis, T. (2023). Design of the Organic Rankine Cycle for High-Efficiency Diesel Engines in Marine Applications. Energies, 16(11), 4374.

Port of Long Beach. (2024). Retrieved from: https://polb.com/business/incentives/#green-flag-program.

Port of Valencia. (2021). Retrieved from: https://www.valenciaport.com/en/valenciaport-leads-spain-in-natural-gas-supply-operations/.

Psaraftis, H., & Lagouvardou, S. (2022). Implications of the EU Emissions Trading System (ETS) on European container routes: A carbon leakage case study. Maritime Transport Research, 3, 100059.

Psaraftis, H.N., T. Zis, & S. Lagouvardou. (2021). A comparative evaluation of market based measures for shipping decarbonization. Maritime Transport Research 2: 100019.

PwC. (2023). Türkiye's promising steps at the verge of crossroads for establishing the green hydrogen economy. Retrieved from: Strategy& Turkey - the global strategy consulting team at PwC.

RINA. (2023). Damen to supply Air Cavity System to Amisco for reduced emissions. Retrieved from: https://www.rina.org/en/media/press/2023/07/19/damen-air-cavity-system

Sari. (2023). EBRD unveils plan for greener maritime sector in Türkiye. Retrieved from: EBRD unveils plan for greener maritime sector in Türkiye.

Sea-LNG. (2019). Retrieved from: https://sea-lng.org/2019/01/if-2018-was-the-tipping-point-for-lng-as-a-marine-fuel-2019-will-be-the-year-of-acceleration/.

Ship Technology. (2023). Hapag-Lloyd announces development of new transshipment terminal in Egypt. Retrieved from: https://www.ship-technology.com/news/hapag-lloyd-transshipment-terminal-egypt/

Silverstream, (2023). What is Air Lubrication? Retrieved from: https://www.silverstream-tech.com/what-is-air-lubrication/

Singh, D. V., & Pedersen, E. (2016). A review of waste heat recovery technologies for maritime applications. Energy conversion and management, 111, 315-328.

Song, J., & Gu, C. W. (2015). Parametric analysis of a dual loop Organic Rankine Cycle (ORC) system for engine waste heat recovery. Energy Conversion and Management, 105, 995-1005.

Spengler, T., & Tovar, B. (2021). Potential of cold-ironing for the reduction of externalities from in-port shipping emissions: The state-owned Spanish port system case. Journal of Environmental Management, 279, 111807.

Speranza, N., Kidd, B., Schultz, M. P., & Viola, I. M. (2019). Modelling of hull roughness. Ocean Engineering, 174, 31-42.

TEN-T. Retrieved from: https://www.tencnggreece.eu/en/ten-cef

The Maritime Executive. (2022). Retrieved from: https://maritime-executive.com/article/egypt-proceeding-with-plans-for-lng-bunkering-operation-at-suez-canal

Tillig, F., Mao, W., & Ringsberg, J. (2015). Systems modelling for energy-efficient shipping. Chalmers University of Technology.

Union of Greek Shipowners (UGS). (2024). Retrieved from: https://www.ugs.gr/en/greek-shipping-and-economy/greek-shipping-and-economy-2022/characteristics-of-the-greek-owned-fleet/.

Union of Greek Shipowners (UGS). (2023). Retrieved from: (https://www.ugs.gr/en/views/maritime-safety-and-protection-of-the-environment/ghg-emissions-reduction-from-ships/.

UMAS. (2024). An overview of the discussions from IMO ISWG-GHG 16.

UNCTAD. (2023). Review of Maritime Transport 2023. Towards a green and just transition. UNCTAD/RMT/2023.

Vakili, S., Ballini, F. (2023). Towards Decarbonisation: Examining the Role of Onshore Power Systems (OPS) in Nordic Ports and Recommendations for Successful Integration. IAME Conference. Greece.

Vakili, S., Ballini, F., Schönborn, A., Christodoulou, A., Dalaklis, D., & Ölçer, A. I. (2023). Assessing the macroeconomic and social impacts of slow steaming in shipping: a literature review on small island developing states and least developed countries. Journal of Shipping and Trade, 8(1), 2.

Vakili., S., White,P., Turnock, S.R. (2024). The impact of shipping's energy efficiency measures on reduction of underwater radiated noise, and opportunities for co-benefit. Retrieved from: https://www.ics-shipping.org/resource/the-impact-of-shippings-energy-efficiency-measures-on-reduction-of-underwater-radiated-noise-and-opportunities-for-co-benefit/

Vakili, S., & Ölçer, A. I. (2023). Are battery-powered vessels the best solution for the domestic ferry segment? Case study for the domestic ferry segment in the Philippines. *Energy*, *282*, 128323.

Vakili, S., & Ölçer, A. I. (2023a). Techno-economic-environmental feasibility of photovoltaic, wind and hybrid electrification systems for stand-alone and grid-connected port electrification in the Philippines. Sustainable Cities and Society, 96, 104618.

Vakili, S., Ölcer, A. I., & Ballini, F. (2020). The development of a policy framework to mitigate underwater noise pollution from commercial vessels. Marine Policy, 118, 104004.

Vakili, S., Ölçer, A. I., & Ballini, F. (2021). The development of a transdisciplinary policy framework for shipping companies to mitigate underwater noise pollution from commercial vessels. Marine Pollution Bulletin, 171, 112687.

Vakili, S., Ölçer, A. I., Schönborn, A., Ballini, F., & Hoang, A. T. (2022). Energy-related clean and green framework for shipbuilding community towards zero-emissions: A strategic analysis from concept to case study. International Journal of Energy Research, 46(14), 20624-20649.

Winkel, R., Weddige, U., Johnsen, D., Hoen, V., & Papaefthimiou, S. (2016). Shore side electricity in Europe: potential and environmental benefits. Energy Policy, 88, 584-593.

World Bank. (2021). The Potential of Zero-Carbon Bunker Fuels in Developing Countries. Retrieved from: https://openknowledge.worldbank.org/entities/publication/b5697ebf-30cd-5491-8e34-2edb199ae5b7

World bank. (2023). The potential of zero carbon bunker fuels in developing countries. Retrieved from: https://openknowledge.worldbank.org/entities/publication/b5697ebf-30cd-5491-8e34-2edb199ae5b7

Wärtsilä. (2022). POWER-SAVING DEVICES. Retrieved from: https://www.wartsila.com/encyclopedia/term/power-saving-devices

Xinhuanet. (2021). Roundup: Egypt implements plan to upgrade sea ports, promote int'l trade: experts. Retrieved from: https://www.xinhuanet.com/english/africa/2021-06/23/c_1310022164.htm

YNAPN. (2021). Retrieved from https://www.ynanp.gr/media/documents/2021/04/02/Strategy_2021_FINAL.pdf.

Zis, Thalis PV. "Prospects of cold ironing as an emissions reduction option." Transportation Research Part A: Policy and Practice 119 (2019): 82-95.