“Decarbonization in the maritime industry: Factors to create an efficient transition strategy”

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DECARBONIZATION IN THE MARITIME INDUSTRY: FACTORS TO CREATE AN EFFICIENT TRANSITION STRATEGY

Abstract

The maritime industry faces intense scrutiny to address climate change amid strict environmental regulations and societal expectations. The paper mainly focuses on understanding and evaluating the key factors driving the transition toward decarbonization in shipping. The study utilized qualitative analysis, focusing on reviewing current environmental targets set by major regulatory bodies, notably the International Maritime Organization (IMO) and the European Union (EU).

The study concludes that a clear strategy for reducing emissions is essential, and a holistic approach must be adopted. Thus, the investigation identified several critical factors that can facilitate the creation of an effective strategy to achieve net zero emissions, comply with regulatory goals, and reduce current emissions. They are decarbonization levels (solutions), ecosystem (value chain), and drivers (enablers), collectively referred to as the decarbonization LED model.

The study emphasizes the importance of stakeholder engagement and policy advocacy to support zero-emission transition. For instance, the paper explores the sector's decarbonization potential through a value chain perspective (Scope 3): employing the life-cycle approach to assess the complete environmental footprint of ship – "Cradle-to-Grave" frameworks (from raw material extraction, production, and product use, until the end of its life) and "Well-to-Wake" methodology to evaluate greenhouse gas emissions from fuel production to end-use by a ship. Additionally, the paper assesses the potential impacts of environmental regulations in the maritime sector, predicting significant transformations in the industry's operational, technological, and collaborative practices.

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INTRODUCTION

Many industries face disruption due to the need for transformation, and the maritime sector is under significant pressure to reduce its environmental impact as climate change effects become more evident. The shipping industry is responsible for over 80% of global trade volume and nearly 2-3% of global greenhouse gas emissions, with emissions increasing by 20% in just ten years. Without actions, emissions could rise to 130% of their 2008 levels by 2050.

The aging global fleet adds to the complexity, with the average ship age being 22.2 years as of early 2023 (UN, 2023). In addition, despite the adoption of electricity, sustainable aviation fuels (SAF), hydrogen, and ammonia in road, aviation, and maritime transport, the transport sector will remain the leading oil consumer. By 2050, oil is expected to account for 50% of the global transport sector's energy demand (DNV,

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2023c). Indeed, according to the IMO's report on fuel oil consumption data from 28,834 ships, with a combined gross tonnage of 1,289 million, approximately 213 million tons of fuel were used in 2022, where 94.65% of the total was heavy fuel oil, light fuel oil, or diesel/gas oil, with the remaining 5.35% being other fuel types (IMO, 2022).

Decarbonizing the maritime sector is particularly challenging. There are several reasons for this. Firstly, the current alternatives for reducing carbon emissions in transport are at various stages of development. Energy and carbon intensities are crucial in this context. Secondly, available standards for sustainability in global maritime transport are considered inadequate by key regulatory authorities like the IMO and the European Union (EU). Numerous regulatory measures have been implemented following international UN climate agreements (Kyoto Protocol in 1997, COP21 Paris in 2015, and COP26 Glasgow in 2021) to transform the shipping industry.

Achieving decarbonization goals is complex and requires a clear long-term strategy and a progressive, viable action plan accepted by the IMO, maritime countries, and the global shipping community. Developing such a strategy is challenging due to the global scale of ocean-going vessel operations across various freight market segments and the different levels of interest in transformation among shipowners due to time pressures, costs, potential benefits, and losses (IEA, 2023).

Moreover, according to the EU's and IMO's revised strategies, businesses will need to report their emissions, which requires looking at both upstream and downstream emissions (monitoring Scope 3 emissions). Hence, a collaborative model that engages shipbuilders, operators, fuel suppliers, and regulatory bodies in a concerted effort to reduce emissions, enhance efficiency, and foster sustainable practices is essential (Tuan & Wei, 2019). Lind et al. (2023) foresee that emissions-free value chains will eventually create greater value despite short-term challenges.

Strategically, one must transit from a 'subsidies mindset,' which seeks compensation for climate action, to a 'growth mindset' that emphasizes the comprehensive benefits of decarbonization. Politically, it is crucial to maintain accountability for public goods, as relying solely on the altruistic behavior of companies is insufficient. Operationally, businesses should continue optimizing costs while building resilience against climate change impacts. Hence, achieving decarbonization will require a combination of short-term actions and long-term investments, leading to positive climate impacts and improved financial returns.

The aim of this study is to identify and assess the key factors necessary for creating a potential roadmap to achieve the required reduction of CO2 emissions in global shipping.

1. THEORETICAL BASIS

1.1. Concept framework

Scientists had to work hard to make the international community aware of the dangers posed by global warming. Evidence from the 1960s and '70s showing rising levels of carbon dioxide (CO2) in the atmosphere first prompted climatologists and others to call for action. It took years for the international community to respond. The latest Intergovernmental Panel on Climate Change report underscores the urgent need for humanity to achieve full decarbonization by 2050 to keep the global temperature rise within 2 degrees Celsius, ideally 1.5 degrees Celsius (IPCC, 2021).

Since then, significant progress has been made in combating climate change. Various concepts have been developed, institutions have been established, and numerous conferences and regulations have occurred. It is crucial to highlight these aspects to understand their connections and differences. Primarily, defining terms like "decarbonization," "net zero emissions," and "carbon and climate neutrality" is essential.

1.1.1. *Decarbonization*

As the planet continues to warm, discussions about decarbonization, which involves reducing and eventually eliminating CO2 emissions from daily activities, have become more frequent among governments, businesses, and activists. This concept was first introduced to the public by inventor William E. Ahern in 1915, who created a process to remove carbon residues from internal combustion engines (Ahern, 1915). Since then, technological advancements have rapidly evolved, changing the meaning of decarbonization. Today, decarbonization encompasses reducing emissions from activities or implementing methods to offset these emissions. Essentially, it involves transitioning from a carbon-intensive economy to one that relies on clean energy sources to achieve net zero emissions (Persefoni, 2024). Sun (2005) defines decarbonization as a trend of decreasing CO2 emission intensity. Although the rate of decarbonization in the global energy system is relatively slow (0.3% per year), this trend has persisted over the past two centuries.

Figure 1 visually helps to understand the following elements of decarbonization:

1. Energy Sobriety (Avoid): Aim to reduce energy demand by eliminating certain uses and avoiding energy- and carbon-intensive activities when possible. This involves behavioral changes, strategic decisions, designing out emissions before construction, and focusing only on essential energy needs for individuals and communities.

2. Energy Performance (Reduce): Focus on lowering energy consumption across all supply mixes while maintaining the same level of production or service. This can be achieved by optimizing production processes, upgrading equipment, and continuously monitoring and correcting energy losses to achieve and sustain optimal energy use.

3. Energy Mix (Replace/Switch): Strive to lessen reliance on carbon-based energy sources by transitioning to renewable energies, including nuclear power.

4. Carbon Compensation (Offset/Sequester): Following the Kyoto Protocol, organizations can offset their CO2 emissions by funding projects to develop renewable energy (such as wind farm construction) or carbon sequestration through natural or artificial mechanisms, like reforestation projects, which capture and store atmospheric carbon emissions.

The ongoing trend toward reducing carbon intensity is primarily driven by the gradual substitution of high-carbon fuels with those that have lower carbon content. This link between decarbonization and energy intensity arises because industrial greenhouse gas emissions are closely tied to energy consumption.

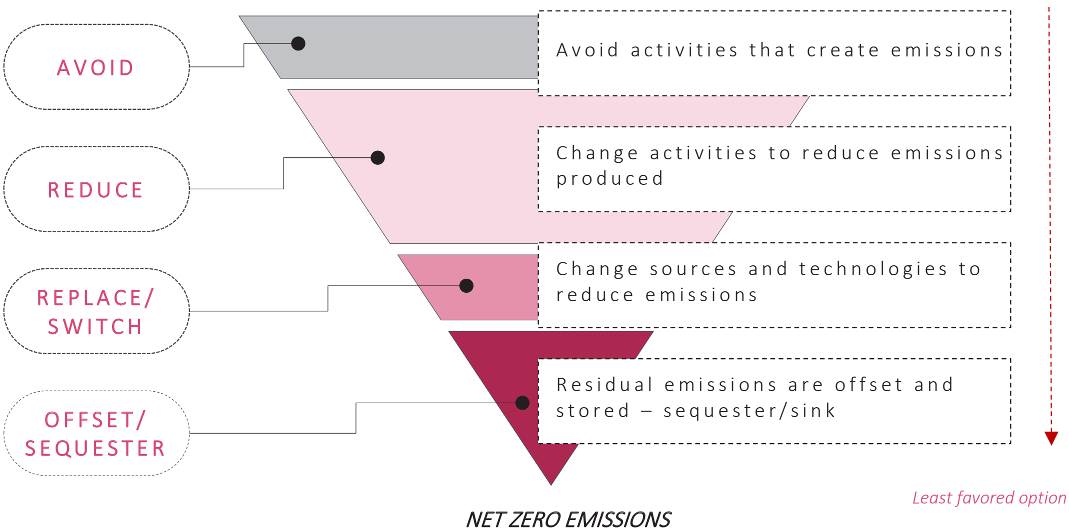

Figure 1. Action levels to reduce carbon footprint and reach net zero emissions

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1.1.2. Energy intensity and carbon intensity

By using energy more efficiently, one can cut down on energy consumption, emissions, and costs. Thus, improving energy efficiency should be the primary step for manufacturers aiming to decarbonize. It forms the bedrock of decarbonization strategies for various organizations and industries. Therefore, decarbonizing the economy, measured as the change in CO2 per unit of GDP, hinges on two key factors: the shift in the energy intensity of the economy (energy use per unit of GDP) and the change in the carbon intensity of the energy supply (CO2 per unit of energy). The compound annual rate of change in CO2/GDP equals the sum of the compound annual rate of change in Energy/GDP and CO2/Energy, allowing an analysis of each nation's reliance on changes in energy intensity or carbon intensity of energy supply to drive overall decarbonization. Adopting low-carbon or zero-carbon energy options decreases overall carbon intensity. Carbon-neutral organizations are committed to evaluating their CO2 emissions.

1.1.3. Net zero emissions and carbon and climate neutrality

While the terms "carbon neutrality," "net zero," and "climate neutrality" are often used interchangeably, they have distinct definitions. Carbon neutrality technically pertains only to carbon but is often used to refer to all greenhouse gases (GHGs) when converting non-carbon GHGs into carbon equivalents. The World Resource Institute (WRI) defines "net zero emissions" as the state where all human-caused emissions are offset by removing carbon from the atmosphere (Levin et al., 2023). The UN describes net zero as reducing carbon emissions to a level where remaining emissions can be absorbed and stored by natural processes and other carbon removal methods, resulting in no net emissions (UN, n.d.).

The European Parliament defines carbon neutrality as maintaining a balance between emitting carbon and absorbing it through carbon sinks, a process known as carbon sequestration (European Parliament, 2019). The Intergovernmental Panel on Climate Change (IPCC) notes that for multiple GHGs, achieving net zero emissions depends on the climate metrics used to compare emissions of different gases and the chosen time horizon (IPCC, n.d.). According to the Science Based Targets initiative (SBTi), the global authority promoting climate action within the private sector, when companies assert carbon neutrality, they are offsetting CO2 emissions with carbon credits. This does not necessarily mean that they have reduced emissions to a level aligned with achieving net zero at either a global or sector-specific scale. This may conceal the need for deeper emissions reductions that are in line with what the science requires the world to keep global warming to 1.5° long-term deep emissions cuts of at least 90% before 2050 are crucial for net zero targets to align with science (SBTi, 2023). That is not to say that carbon offsets cannot play a role in a company's carbon management strategies, but these should be used in con-

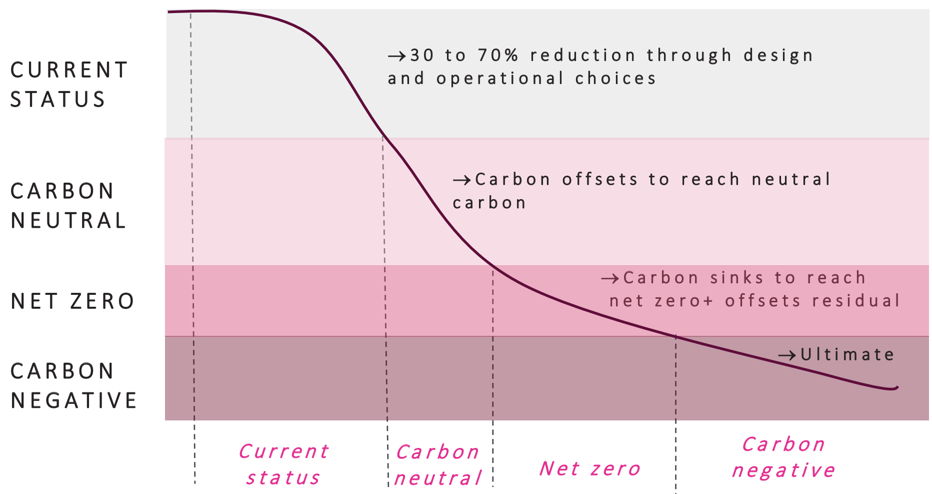

Figure 2. Decarbonization pathway

junction with the development of longer-term reduction – and ultimately, net zero – plans (Elder & Klimczak, 2024).

Figure 2 represents a short summary of the connection between the above-mentioned terms. Figure 2 offers the following understanding (APLANET, 2022; SBTi, 2021):

- Current status is about avoiding emissions;
- Carbon neutral (Climate Neutral) is about balancing carbon emissions thought offset (100% offset);
- Net zero is about minimizing the carbon footprint of activities+offsetting residual emissions (reduce 90% of emissions, reminder offset);
- Carbon negative (Climate positive) – removing or sequestering more CO2 from the atmosphere than is emitted (the ultimate goal).

1.2. Decarbonization maritime policy initiatives: Institutional development

Given that the shipping industry has historically been and continues to be one of the most energy-intensive sectors (with fossil fuels accounting for 80% of its energy use), significant attention has been paid to this industry since the mid-20th century. Industrialization, economic growth, and trade growth, coupled with the energy-intensive nature of shipping, created a substantial demand for the establishment of regulatory bodies like the International Maritime Organization (IMO). The International Maritime Organization (IMO) plays a crucial role in setting targets for reducing GHG emissions in the global shipping industry. Additionally, besides adhering to the International Maritime Organization's (IMO) regulations, the European Commission (EC), as the executive branch of the European Union (EU), is heavily involved in establishing and enforcing GHG emission reduction targets within the European shipping sector.

Moreover, in support of the regulatory requirements set by the IMO, non-governmental organizations within the industry are also taking steps to expedite the successful implementation of the GHG Strategy (Qiao, 2021). Table A1 (Appendix A) outlines the timeline of the development of key maritime decarbonization initiatives.

2. RESULTS

Shipping companies must consider various factors to develop an effective transition strategy toward achieving net zero emissions. The industry needs to comprehend the risks and opportunities associated with customer demand, regulatory changes, financing, operational and technological efficiency, future fuels, and collaborations within the ecosystem. There is a growing trend of customers being willing to pay more for carbon-neutral shipping, which can help finance the transition. Nevertheless, further support, such as subsidies, will also be essential. Moreover, companies are understandably questioning whether to embark on the net zero path now or wait until the regulatory and technological frameworks are more established (Jameson et al., 2021). To begin decarbonizing, shipping companies must make difficult decisions regarding investments, technology adoption, and forming collaborative partnerships. In a climate of uncertainty, businesses need a strategy that not only strengthens their current operations but also prepares them for future developments, such as new alternative fuels and stricter regulations. To create an effective transition strategy, a company should consider three main decarbonization factors (Figure 3):

- Decarbonization levels: future fuels, technological efficiency, operational efficiency.
- Decarbonization ecosystem: stakeholders value chain for LCA of GHG emissions.
- Decarbonization drives: demand, financing, regulation.

Thus, proactive shipping companies should develop a comprehensive strategy for transitioning to a low-carbon future. This involves creating a low-carbon business model, securing climate-proof operations, and engaging transparently with stakeholders.

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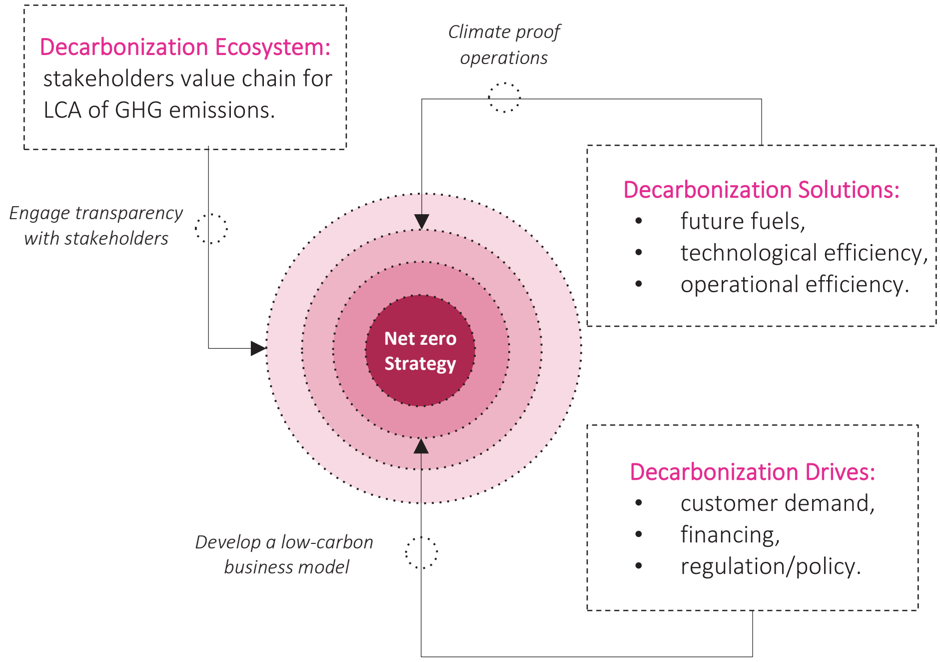

Figure 3. Key factors for developing companies' efficient net zero transformation strategy

2.1. Decarbonization drivers

Three main forces are driving the shift toward decarbonization in shipping.

2.1.1. Customer demand

Shipping customers are increasingly under pressure to reduce Scope 3 emissions, which are those emissions resulting from assets not owned directly by the companies, such as those in their supply chains. This includes maritime transport. Many customers are willing to pay more to achieve this goal. According to a BCG survey involving 125 companies reliant on shipping, 71% indicated they would pay a premium for carbon-neutral shipping services. Additionally, 63% expected their willingness to pay a premium to increase over the next five years. Moreover, 67% would be more loyal to a carbon-neutral shipping company, showing less inclination to switch providers. Currently, customers are willing to pay an average premium of 2% for carbon-neutral shipping. However, it is estimated that a premium of 10% to 15% would be required to fund the industry's transition to net zero emissions by 2050. This indicates that while there is customer willingness to pay more, other financial measures, such as subsidies and additional funding sources, would be necessary to cover the transition costs (Jameson et al., 2021).

2.1.2. Financing

An estimated USD 2.4 trillion in funding will be required for the shipping industry to reach net zero emissions by 2050. Approximately USD 1.7 trillion will be allocated toward alternative fuels. Shipping players themselves will need to invest around USD 0.2 trillion in new engines and onboard storage solutions. In addition to these costs, an investment of approximately USD 0.7 trillion will be needed for operational and technological efficiencies. Traditionally, commercial bank loans have been the main financing source for the shipping industry. However, to achieve net zero emissions, increased involvement from the public sector will be necessary. This could come through direct subsidies or blended finance instruments designed to encourage private sector participation. A diverse group of investors, including institutions, venture capitalists, and high-net-worth individuals, will also play a role in funding the industry. In addition, the rise of ESG finance is adding further pressure on shipping companies to decarbonize (Xue & Lai, 2023). For instance, the Poseidon Principles, an industry framework created to promote the integration of climate considerations into lending decisions, currently has 27 signatories representing nearly half of global shipping loans. As a result, companies will need clear and effective plans for decarbonization. Additionally, major cargo owners have launched efforts like the Sea Cargo Charter in October 2020, and companies are setting ambitious Scope 3 emission targets that affect their entire supply chains. Additionally, the Climate Bonds Initiative (CBI) introduced the Shipping Criteria of its International Climate Bond Standard in November 2020 to promote low-carbon and climate-resilient investments in the shipping sector. According to CBI, these criteria include the following key points: 1) ships must not be primarily dedicated to transporting fossil fuels; 2) ships must either be specified as zero-carbon from the issuance year of the bond or demonstrate that their carbon equivalent intensity aligns with the decarbonization trajectory; alternatively, ships that are not zero-emissions must provide a managed plan showing how they will stay under the emissions intensity threshold throughout their operational life (WfW, 2021).

2.1.3. *Regulation*

Policy interventions are needed to help the shipping industry transition toward low and zero-emission fuel and energy resources (Latapí et al., 2024). However, the regulatory environment for shipping companies remains highly uncertain (Grzelakowski et al., 2022). IMO has established measures to reduce total industry emissions by 2050. Additionally, the European Commission has introduced a package of policy proposals known as "Fit for 55," which aims to cut emissions by at least 55% by 2030 compared to 1990 levels. These regulations will have significant implications for the shipping industry.

In response to growing concerns about climate change, the International Maritime Organization (IMO), a specialized agency of the United Nations (UN), has set environmental targets to decarbonize the maritime industry and reduce its impact on the planet. The IMO aims to halve greenhouse gas (GHG) emissions from shipping by 2050 compared to 2008 levels and to achieve full decarbonization as soon as possible within this century. This ambition translates into specific measures to reach net zero emissions by around 2050.

Decarbonizing shipping following the Initial IMO Strategy involves implementing a combination of short-, mid-, and long-term measures (IMO, 2023b), depicted in Figure 4.

Long-term measures (Beyond 2030) could include actions developed and agreed upon by the Committee as part of the 2028 review of the IMO strategy to be finalized and implemented beyond 2030.

Mid-term measures (2023–2030) fall into three interconnected categories (technological, operational, and market-based measures (MBMs)).

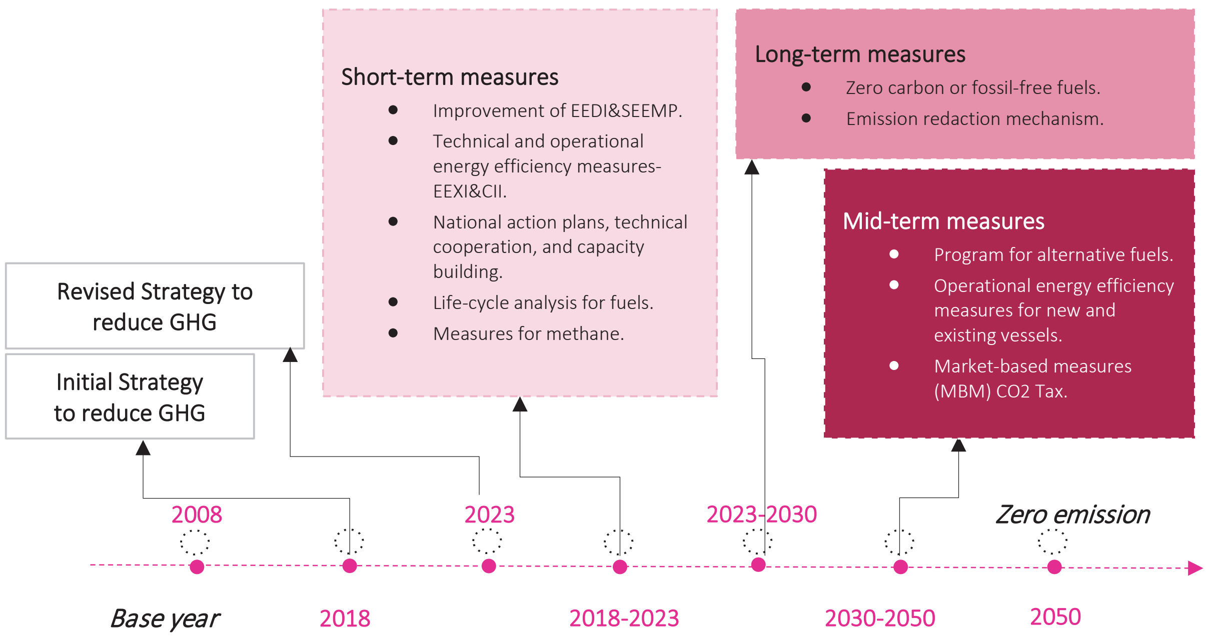

Figure 4. IMO Roadmap and Strategy for the reduction of GHG emission from ships

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Technological measures involve developing and installing green technologies on ships. Operational measures focus on improving ship operations through route and speed optimizations. MBMs primarily deal with carbon/emission pricing, including options like a levy (tax/fee) on GHG emissions or an emission trading system (ETS) that rewards emission reductions and penalizes polluters.

Short-term measures (2018–2023), finalized and agreed upon by the committee between 2018 and 2023, focus on reducing the carbon intensity of international shipping through mandatory goal-based technical and operational strategies. They are to be fully implemented by January 2026. The first significant step in this effort was in 2011 when the IMO adopted mandatory measures to enhance the energy efficiency of international shipping, paving the way for regulations on:

1. Energy Efficiency Design Index (EEDI) for new ships.

2. Ship Energy Efficiency and Management Plan (SEEMP) – a ship-specific document that provides a mechanism to help improve the energy efficiency of a ship cost-effectively. The European Union (EU) has also implemented similar regulations on monitoring, reporting, and verifying fuel consumption (EU-MRV) for ships of 5,000 GT and above calling at European ports. While IMO-DCS is an anonymous public database, the EU-MRV is a distinctive public database.

3. Energy Efficiency Existing Ship Index (EEXI) – calculation and verification of EEXI – retroactive EEDI requirements applied to existing ships from January 1, 2023.

4. Carbon Intensity Indicator (CII) – introduction of a rating mechanism (A to E) linked to the operational CII, taking effect from 1 January 1, 2023.

5. Ship Energy Efficiency Management Plan (SEEMP) enhanced to include targets for operational emissions, where an approved SEEMP needs to be kept onboard from January 1, 2023.

Energy Efficiency Design Index (EEDI)

The IMO mandated the EEDI in 2011 to promote the use of more energy-efficient engines and equipment on new ships (MARPOL ANNEX VI, 2013). This index measures CO2 emissions in grams per ton-mile and is required for compliance based on ship size and type (DNV, 2023b). There are several phases of EEDI implementation:

- Phase 0 (2013–2014): Encouraged initial energy efficiency measures.
- Phase 1 (2015–2019): Required a 10% CO2 reduction for most cargo carriers and 5% for passenger ships.
- Phase 2 (2020–2024): Mandates a 20% CO2 reduction for large freight vessels.
- Phase 3 (2025 onward): Requires a 30% reduction for all vessel types (IRCLASS, 2013a).

Ship Energy Efficiency Management Plan (SEEMP)

Implemented alongside EEDI in 2013, SEEMP is a ship-specific document that outlines a systematic plan to improve energy efficiency (IRCLASS, 2013b). All ships above 400 GT must have a SEEMP onboard, and it operates through a cycle of planning, implementation, monitoring, and evaluation. It tracks and enhances ship performance and includes:

- Part I: Ship management plan for energy efficiency.
- Part II: Ship fuel oil consumption data collection.
- Part III: Ship operational carbon intensity plan.

Energy Efficiency Existing Ship Index (EEXI)

Proposed by Japan and incorporated into MARPOL Annex VI, EEXI extends EEDI requirements to existing ships from January 2023 (IMO, 2020). It sets specific energy efficiency values for ships based on a percentage reduction relative to the EEDI baseline, focusing on technical measures to reduce energy consumption. The formula for EEDI/EEXI calculations (DNV, 2021b) is:

$$EEDI/EEXI = \frac{Power \cdot SFC \cdot C_F}{DWT \cdot Speed}, \quad (1)$$

where *EEDI* – Energy Efficiency Design Index (gCO2/ton x mile); *Power* – Engine Load (kW): Limit engine power; Technical measure to improve efficiency; *SFC* – Speed fuel consumption (g/kWxh): Derating engine to optimize SFOC; C_F – CO_2 factor: Alternative fuel will reduce CO_2 factor; *Speed* – Design speed (knots): Optimization compared to engine load; *DWT* – Capacity (ton): Jumboizing vessel to increase GRT.

Carbon Intensity Indicator (CII)

Starting in 2023, CII measures the operational efficiency of cargo and Ro-Pax vessels, including cruise ships above 5,000 GT. The CII rating ranges from A to E and becomes more stringent over time. It calculates CO2 emissions per deadweight-mile and requires annual reporting, with targets set to decrease by 1% per year until 2022 and by 2% per year from 2023 to 2026. Like other EE mandates, the CII and its goals for 2027–2030 will be revised and further decided in 2023 (IMO, 2021). There are two main definitions of carbon intensity (i.e., carbon emissions "per transport work") competing to be used when calculating the CII metric – the IMO's own proposed Energy Efficiency Operational Indicator (EEOI) and the Annual Efficiency Ratio (AER). AER (emission per dwt-mile) and capacity gross ton distance (cgDist (emissions per gross ton-miles)) are metrics supported by data elements reported through the IMO DCS system. Since the IMO DCS system does not gather the necessary cargo data to calculate the EEOI (emission per ton-mile), the EEOI cannot be used for the CII at present. However, it is possible to voluntarily report cargo data and calculate the EEOI for those who choose to do so (DNV, 2021a). Thus, the common formula for CII calculations is:

$$CII = \frac{AFC \cdot C_F}{DWT \cdot Distance} \cdot Correction\ factor, \quad (2)$$

where *CII* – Carbon Intensity Indicator (gCO_2/DWT mile); *AFC* – Annual fuel consumption (g/kWxh): Reduced speed; Voyage optimization; Technical measure; C_F – CO_2 factor: Alternative fuel will reduce CO_2 factor; Distance (km): Annual distance traveled (Reduced idle time improves CII; *DWT* – Capacity (ton): Jumboizing vessel to increase DWT_{CAP} will improve CII; *Correction factor*.

Data Collection System (DCS)

Starting in 2024, the CII must be calculated and submitted to the Data Collection System (DCS) verifier, along with the aggregated DCS data for the previous year. This submission should include correction factors and voyage adjustments (Figure 5).

The deadline for DCS and CII submission remains unchanged – no later than March 31 each year. The attained annual operational CII and the environ-

Source: DNV (2023a).

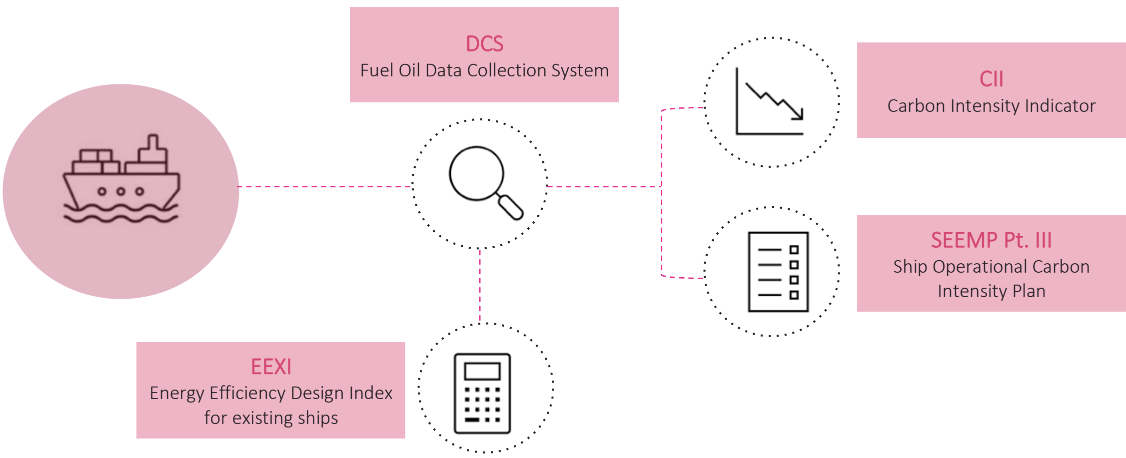

Figure 5. The context of regulations

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mental rating (A to E) will be noted on the DCS Statement of Compliance (SoC), which must be kept on board for five years. In case of a D rating for three consecutive years or one E rating, the SEEMP Part III must be updated with a corrective action plan and verified before the SoC can be issued. The corrective action plan should consist of an analysis of why the required CII was not achieved and include a revised implementation plan.

In addition to the IMO regime, the EU has set itself a target of achieving climate neutrality by 2050 – commonly known as European Green Deal under the European Climate Law. To get there, the current GHG emission levels need to drop substantially over the next decades. Consequently, the EU has raised its 2030 climate ambition, committing to reduce GHG emissions by at least 55% by 2030, compared to 1990 levels (Figure 6).

As part of the European Commission's legislative proposals to deliver the European Green Deal – the 'Fit for 55' package – published on July 14, 2021, several proposals addressed maritime transport's climate impact, in addition to the extension of the EU ETS. This includes European Commission (2021).

FuelEU Maritime initiative aims to promote the use of sustainable fuels by addressing market barriers and uncertainty about available technical options. It targets all ships of 5,000 GT and above calling at EU ports, regardless of their flag. The initiative sets a limit on the GHG intensity of fuels used onboard from 2025 and imposes an obligation on containerships and passenger ships to use onshore power supply from 2030 unless alternative zero emission technology is used while at berth. The reduction targets for GHG intensity compared to the 2020 fleet average are 2% by 2025, 6% by 2030, 13% by 2035, 26% by 2040, 59% by 2045, and 75% by 2050.

Energy Taxation Directive (ETD) proposal, starting in 2023, introduces a new structure of tax rates and removes tax exemptions on marine fuels sold within and for use within the EEA. The new rules establish a minimum excise duty rate on fuels used for intra-EU ferry, fishing, and commercial ships to encourage a switch to more sustainable fuels.

Alternative Fuels Infrastructure (AFI), to support the FuelEU Maritime proposal, sets requirements for the Trans-European Transport Network (TEN-T) maritime ports to ensure adequate LNG bunkering infrastructure by 2025 and to install shoreside power supply to meet the demand of at least 90% of container and passenger ships calling at those ports.

EU's Emissions Trading System (EU-ETS): On July 14, 2021, the EU Commission proposed including emissions from shipping in the EU ETS. This scheme, based on the 'cap and trade' principle,

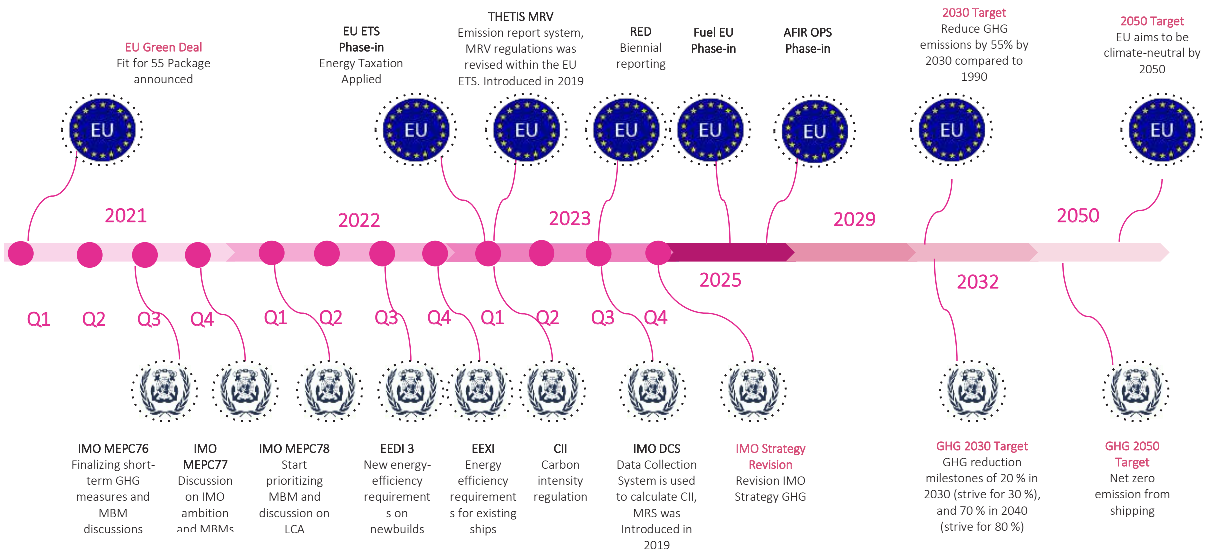

Figure 6. Decarbonization regulatory timeline for EU and IMO overlap

sets a cap on total GHG emissions that decreases over time. Shipping companies will need to purchase and surrender emission allowances for each ton of carbon emitted during voyages or face penalties. The implementation could start as early as 2023 and will be phased in over three years, applying to ships of 5,000 GT and above. Emissions are covered as follows: 100% for voyages within the EU, 50% for voyages starting or ending outside the EU, and emissions while ships are at berth in EU ports. Shipping companies must calculate and report emissions annually, with increasing reporting requirements from 2023 to 2026. Non-compliance may result in detention or denial of port entry, and the names of violating companies could be publicized.

Monitoring, Reporting, and Verifying GHG Emissions (MRV) Regulation, revised in 2023, mandates that companies monitor and report GHG emissions, fuel consumption, and other relevant parameters for each voyage. Verified annual emissions reports must be submitted to the Commission and flag States by April 30 (March 31 starting 2025). By June 30 each year, companies must ensure their ships carry a document of compliance, subject to inspections by Member States' authorities.

2.2. Decarbonization levels

Once shipping companies have assessed the impact of decarbonization drivers on their operations, they should concentrate on reducing emissions through targeted strategies. According to the BCG report, improvements in operational efficiency and technological efficiency have already reduced carbon emissions per transported unit by 20% to 30% since 2008, with the potential to further decrease them by an additional 20% to 25% by 2050 (Jameson et al., 2021). While these improvements are significant, achieving net zero emissions will also require the adoption of zero-emission fuels.

2.2.1. *Operational efficiency*

Enhancing operational efficiency involves utilizing onshore computer systems and digital technologies, such as machine learning and internet-connected sensors. These technologies can extend asset life and improve routing, fuel efficiency, and cargo distribution (IRENA, 2021). Factors like cargo volume, vessel age, and routing can be classified under operational risk (Ozbilitekin-Pala et al., 2024). A key goal of operational efficiency measures is to reduce bunker fuel consumption. Since fuel savings lead to both cost reductions and lower emissions, these investments can potentially be self-financing. Moreover, several approaches can be taken within the broad strategy of fuel optionality. These include constructing vessels with the possibility of a shorter lifespan or considering future retrofits, building dual-fuel or potentially multi-fuel vessels, using drop-in fuels, and preparing vessels during the construction phase for future retrofits (Bourboulis et al., 2022). A Transition Strategy study conducted by the University of Maritime Advisory Services (UMAS) and the Getting to Zero Coalition (GtZ) indicates that by 2046, the number of retrofitted vessels will reach approximately 35,000. It is anticipated that larger vessels will need to transition to zero-emission fuels sooner due to their operating profiles. The initial retrofits are expected to occur among vessels with the highest demand pressures and higher margins, such as large cargo vessels and cruise ships (UMAS & GtZ, 2021).

2.2.2. *Technological efficiency*

Technological efficiency improvements focus on onboard technologies designed to reduce emissions by enhancing a vessel's energy efficiency or decreasing bunker fuel consumption. Alternatives include new propulsion systems, drag reduction technologies, and improvements to existing power and propulsion systems. The potential for CO2 emission reduction in the operational fleet varies depending on the type of ship, the condition of its engine, and sometimes its operational profile and weather conditions. The report from the Organization for Economic Co-operation and Development (OECD) outlines potential fuel savings achievable through various technological measures (OECD, 2018): light materials (0-10%), slender design (10-15%), propulsion improvement devices (1-25%), bulbous bow (2-7%), air lubrication and hull surface (2-9%), and deep heat recovery (0-4%). However, the maturity of these technologies varies widely. Emerging technologies like air lubrication and waste heat recovery have yet to

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demonstrate their full potential. Shipping companies must consider these maturity differences when planning their strategies.

2.2.3. Future fuels

The industry must adopt alternative fuels to achieve net zero emissions by 2050, which will require significant structural changes. New vessels designed to run on zero-emission fuels must be built, and existing ships will need retrofitting. Commercially viable zero-emission vessels need to start joining the global fleet by 2030 to meet the net zero target. This will necessitate the development of alternative fuel production facilities and bunkering infrastructure. Identifying future-fuel leaders will be crucial, with leaders likely emerging based on factors such as vessel type and geographic area. While biofuel can be blended with conventional fuels today, its scalability issues and relatively high emissions make it more of a short-term solution. Retrofitting dual-fuel engines is generally more cost-effective than traditional ones. For instance, retrofitting a traditional engine to run on ammonia could cost up to USD 10 million, compared to USD 1 million to USD 2 million for dual-fuel alternatives. When selecting the right engine for a new vessel, companies should take a comprehensive approach, considering capital expenditure (CAPEX), operating expenses (OPEX), and revenue impacts. This includes evaluating the acquisition cost of the engine, retrofitting costs, the likelihood of retrofit options being available, potential changes in fuel prices, the opportunity cost of lost cargo space, and the impact on customer demand.

2.3. Decarbonization ecosystem

A value chain is a sequential business process transforming a product or service from concept to final delivery. Each step in this chain is intended to add value. However, these value-creating activities typically involve energy consumption, leading to GHG emissions. Therefore, it is crucial to conduct detailed analyses of value chains to drive profitable decarbonization across the maritime sector and the broader economy. Three interdependent maritime value chains play a pivotal role in decarbonizing shipping (Koilo & Grytten, 2022): marine fuel, shipbuilding, and maritime operational value chains (Figure 7).

Figure 7 shows that it is necessary to understand the distribution of GHG emissions across the three critical maritime value chains for different types of shipping services. Lind et al. (2022) offer a breakdown of the typical lifecycle of carbon di-

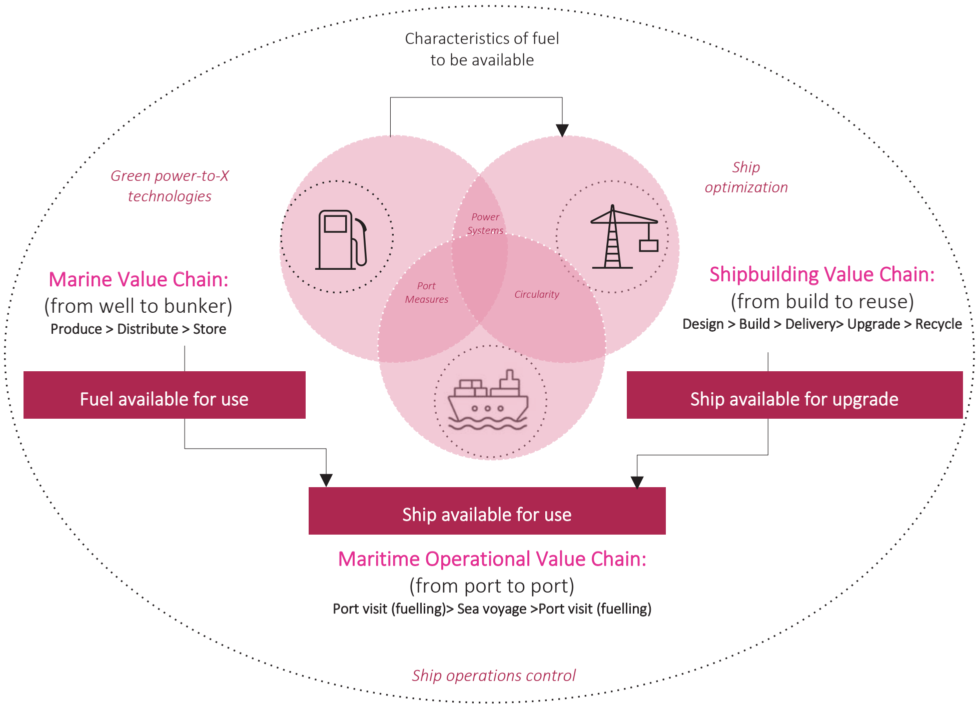

Figure 7. Interdependent value chains in the maritime ecosystem

oxide equivalent (CO_2e) emissions for cruise ships based on data from the Meyer Turku shipyard. It was found that most emissions lie within the operational value chain (67%). A fifth of the emissions are emitted during fuel production (20%), and only 5% stem from shipbuilding. Despite the differences in impact among value chains, every actor must exert maximum effort to drive decarbonization to ensure the industry meets the IMO 2023 ambitions. This necessitates commercial incentives, effective regulation, and collaboration (Lind et al., 2022).

Hence, an effective corporate climate change strategy is required to understand a company's GHG impact. The most widely used tool is IMO's LCA emission guidance and the GHG Protocol Corporate Standard (Scope 1, 2, and 3).

2.3.1. IMO's GHG emissions accounting

To monitor the progress of emission reduction with a lifecycle (LCA) approach, in 2023, IMO revoked the Initial GHG Strategy. According to recent updates, the levels of ambitions and indicative checkpoints should take into account the Well-to-Wake GHG emissions of marine fuels as outlined in the guidelines on the lifecycle GHG intensity of marine fuels (IMO, 2023a). These regulations will be mandatory for all ships, with no exceptions based on the flag under which they are registered. The LCA guidelines facilitate a Well-to-Wake calculation, which includes both Well-to-Tank and Tank-to-Wake emission factors, to assess the total GHG emissions related to the production and use of marine fuels.

The life cycle assessment (LCA) methodology evaluates greenhouse gas emissions from fuel production to end-use by a ship (Well-to-Wake). This includes the Well-to-Tank component (from primary production to the carriage of the fuel in a ship's tank, also known as upstream emissions) and the Tank-to-Wake (or Tank-to-Propeller) component (from the ship's fuel tank to the exhaust, also known as downstream emissions).

Well-to-Wake refers to the comprehensive analysis of the greenhouse gas emissions associated with marine fuels, from their production (well) to their end-use (wake), described in Figure 8.

Hence, according to IMO requirements, reporting of emissions involves two value chains: marine fuels value chain and maritime operational value chain.

2.3.2. EU's GHG emissions accounting

According to the EC's proposal from 2023, the EU must become the first climate-neutral continent by 2050 (European Commission, 2023a). The EU Taxonomy has emerged as a "green compass" to enhance transparency by requiring companies to disclose the extent of their compliance. The Corporate Sustainability Reporting Directive (CSRD) and European Sustainability Reporting Standards (ESRS) are important components of the European Green Deal, designed to improve the transparency and comparability of sustainability information throughout the EU (European Commission, 2023b). Under the CSRD mandates, since 2024 businesses must report their Scope 3 emissions, i.e., it requires looking at both upstream and downstream emissions; thus, LCA methodology is required here as well. The directive also integrates sustainability reporting with financial processes, fostering a holistic approach to corporate sustainability.

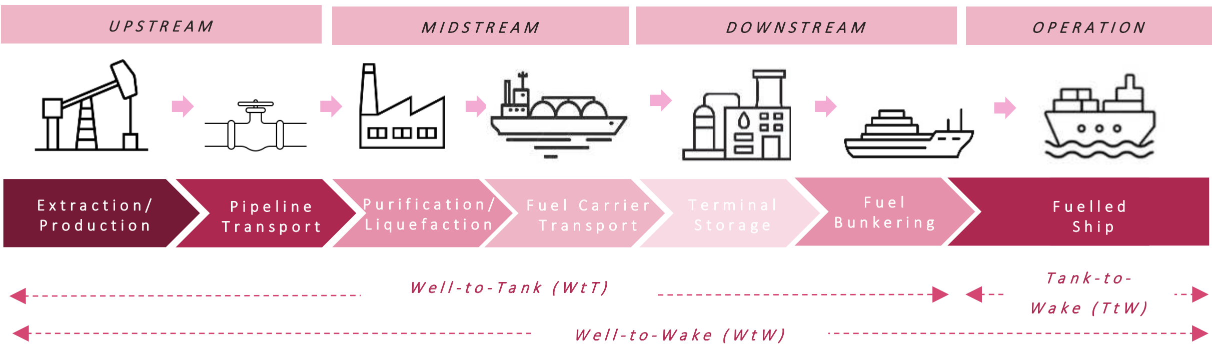

Figure 8. Well-to-Wake accounting of GHG Emissions (LCA methodology)

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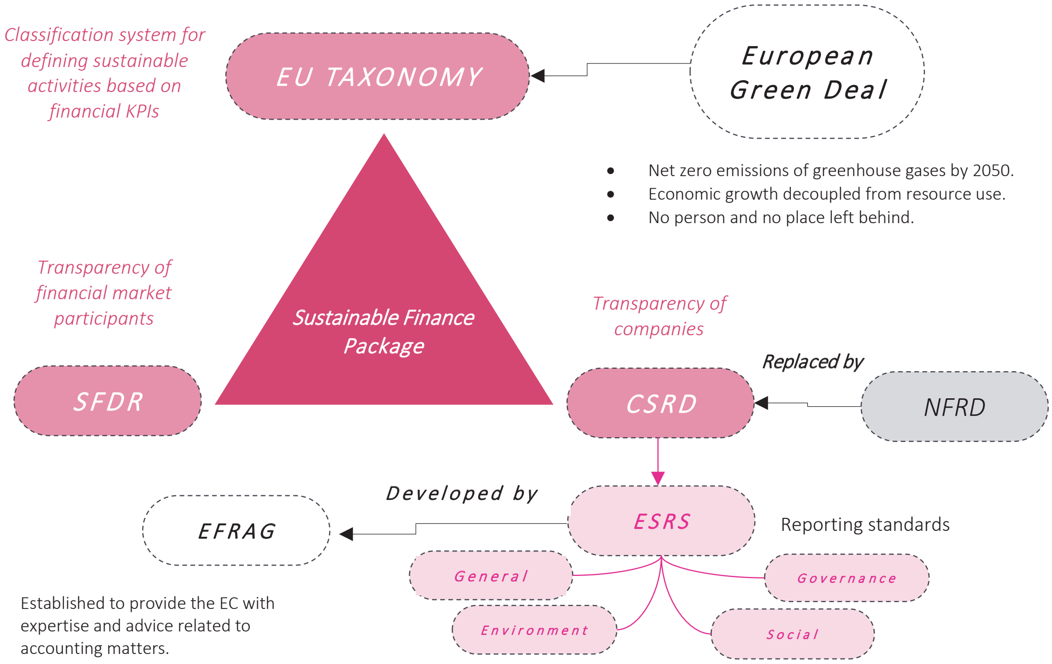
Source: Compiled by the author based on Adaman (2022) and EC (2023b).



Note: EFRAG – European Financial Reporting Advisory Group; *SFDR* – Sustainable Finance and Disclosure Regulation; *CSRD* – Corporate Sustainable Reporting Directive; *ESRS* – European Sustainability Reporting Standards, adopted in 2021; *NFRD* – Non-Financial Reporting Directive.

Figure 9. The EU "Green compass" towards transparency in sustainable reporting

The details of Scope 1, 2, and 3 are outlined in with the Greenhouse Gas Protocol, developed by the World Resources Institute and World Business Council for Sustainable Development (WRI/ WBCSD, 2024). Division of the organization's emissions is depicted in Figure 10.

Scope 1 covers direct emissions from an organization's facilities. Scope 2 covers emissions from generating electricity purchased by the organization. Scope 3 covers other indirect emissions (WRI/ WBCSD, 2011). Currently, the quantification of the impact of activities on each scope remains difficult to measure. In the transition to net zero, companies can compensate or neutralize emissions that are still being released into the atmosphere while they transition toward a state of net zero emissions. Once they have reached net zero, companies with residual

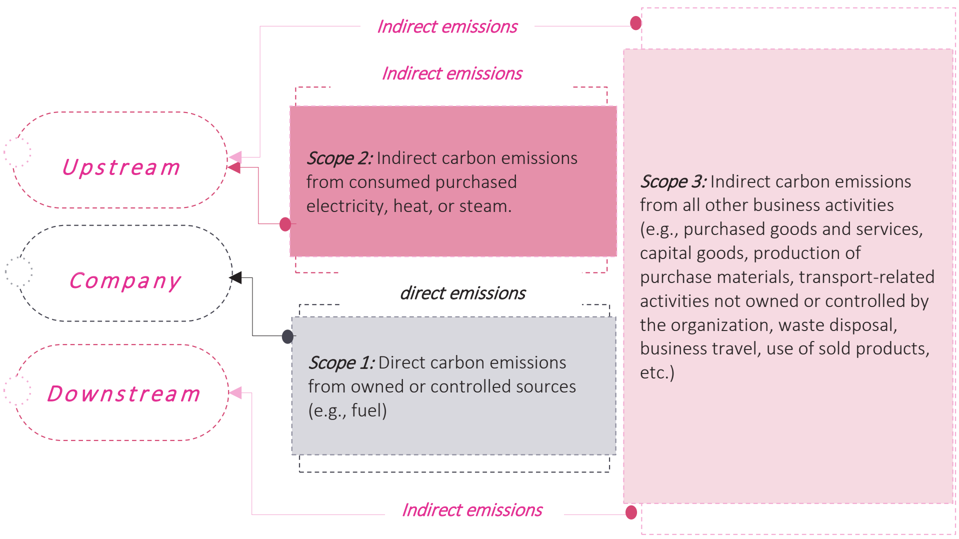


Figure 10. The Scopes to reduce carbon footprint and reach net zero emissions

emissions can neutralize those emissions with an equivalent amount of carbon dioxide removal. Thus, the value chain is essential in achieving emission reduction targets (Koilo, 2021, 2022).

Scope 3 Emissions represent the indirect emissions that occur within the value chain of the reporting company. These include both upstream and downstream emissions that are not directly produced by the company but are associated with its operations. The maritime sector is particularly complex when it comes to Scope 3 emissions. A single vessel can have multiple suppliers, from engine manufacturers to food providers. Each of these suppliers has its own emissions, which need to be accounted for in a comprehensive Lifecycle Assessment. The LCA approach is crucial for understanding the full climate impact of a vessel, from cradle to grave.

Cradle-to-Grave is a model used in the scientific footprint method Life Cycle Assessments (LCA). It assesses the complete environmental footprint of products, from raw material extraction, production, and product use until the end of its life. This is the standard in our current "linear" (as opposed to circular) economy (Figure 11).

In shipping:

- Scope 1 emissions are the direct emissions created during fuel consumption – operation (maritime operations value chain).
- Scope 2 emissions refers to indirect emissions that result from purchasing electricity, heat, or steam from external sources rather than being produced by the organization itself (marine fuels value chain).
- Scope 3 emissions include indirect emissions generated both upstream (supply chain) and downstream (distribution chain). For shipowners, this can cover emissions from suppliers, manufacturers, and even the end-of-life phase of the vessel.

By accounting for all three scopes, a comprehensive emissions profile over a vessel's entire life cycle, including the shipbuilding value chain, can be obtained.

3. DISCUSSION

The pressure to tackle the decarbonization challenge is intensifying and is driven by various factors. Companies with clear decarbonization strategies can effectively overcome both practical and reputational challenges, achieving higher total shareholder returns. This success is attributed to revenue growth, cost reductions, and increased valuation multiples. To decarbonize effectively, companies focus on three main actions. However, each of these actions presents specific challenges that need to be addressed. Therefore, this analysis allows for formulating several conclusions regarding the ongoing process of maritime decarbonization.

3.1. Fuel: Addressing the carbon paradox

The regulatory landscape for shipping fuels is evolving, creating uncertainty about fuel standards and potential carbon taxes, which makes companies hesitant to invest in green technologies. Low-carbon fuels can paradoxically have

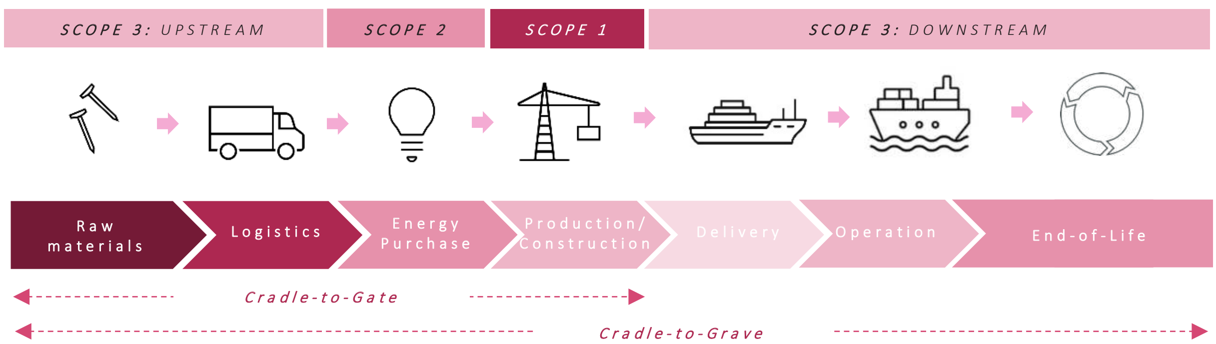


Figure 11. Cradle-to-Grave accounting of GHG Emissions (LCA methodology)

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high carbon footprints during production. For example, hydrogen fuel production through steam methane reforming and electrolysis using fossil fuels is carbon-intensive (Elder & Klimczak, 2024). LNG, although reducing CO2 emissions by about 25%, poses challenges with fugitive methane emissions (Deng & Mi, 2023). Addressing these issues requires advancements in production technologies and infrastructure upgrades, such as alternative fuel stations and energy-efficient port facilities (Oloruntobi et al., 2023).

3.2. Technology: Future of fuel engines

Technological innovation is critical for shipping decarbonization, but it comes with high costs and infrastructure challenges (Grzelakowski et al., 2022). Integrating alternative fuels like hydrogen, LNG, and biofuels presents safety and availability concerns. Implementing these technologies requires substantial R&D and a thorough techno-economic assessment to determine the most feasible options based on ship types, routes, and regulatory requirements (Curran et al., 2024). One challenge of retrofitting is the limited experience across the value chain. This lack of experience, coupled with the limited physical capacity of shipyards, is likely to create bottlenecks in the retrofitting process. Since vessels in operation are business assets, they cannot be docked for extended periods, underscoring the need for efficient retrofitting processes. The initial retrofits are particularly costly, requiring substantial resources and investment. Therefore, there is a need to incentivize first movers to encourage early adoption (UMAS & GtZ, 2021).

3.3. Operation: Geopolitical and supply chain disruptions

Slow steaming has been identified as an effective strategy for reducing fuel consumption and emissions by about 25%, but it necessitates ships designed for safe operation at lower speeds, especially in adverse weather conditions (Pelić et al., 2023; Taskar et al., 2023). Geopolitical events, such as attacks in the Red Sea, disrupt supply chains and force ships to take longer routes, significantly increasing emissions (Reuters, 2023). For instance, avoiding the Suez Canal due to security threats can lead to a 38% increase in CO2 emissions for a journey from Shanghai to Hamburg (Ozbiltekin-Pala et al., 2024; Kumar, 2022). Similar challenges arise at the Panama Canal, the world's second most crucial maritime choke point, where over 14,000 ships carrying 275 million tons of cargo transit annually (Kumar, 2022). As a result of the lower water levels in the lake, the Panama Canal Authority had to restrict ship transits and draft limits. This situation adversely affected the cost and feasibility of shipping (Kivalov, 2024).

3.4. Regulation: ETS and carbon tax over bunkering

Decarbonization targets driven by ESG awareness necessitate significant capital expenditure. The inclusion of shipping in the EU Emissions Trading Scheme (ETS) is a notable step, but it may shift operations to non-EU ports, leading to unfair competition and carbon leakage (Latapí et al., 2024; Lynce de Faria, 2023). Uniform carbon pricing, such as the proposed USD 450 per ton of bunker fuel by Maersk, is essential for bridging the gap between fossil fuels and greener alternatives (Maritime Executive, 2021). A coordinated international approach is needed to avoid competitive imbalances and support the adoption of low-carbon fuels. Moreover, according to Sheng et al. (2017) and Dong et al. (2022), unilateral regulations may actually increase total emissions, whereas unified regulations consistently reduce overall emissions. Nevertheless, the impact of carbon pricing on transport costs, particularly in developing countries, small island developing states, and least developed countries, is a critical area of study (Rojon et al., 2021; Halim et al., 2019). The IMO (2019) Initial Strategy also lists transport costs as one of eight factors impact assessments should pay attention to.

3.5. Demand: Customers' willingness to pay (WtP)

BCG research shows a growing willingness among shipping customers to pay a premium for carbon-neutral services, although current premiums are insufficient for achieving net zero emissions by 2050 (Jameson et al., 2022). Companies like Maersk, CMA, and COSCO are investing in green methanol vessels to lead the market in sustainable shipping. To bridge the gap between current and target behaviors, collaborative action from policymakers, shipping companies, and financial institutions is crucial.

3.6. Finance: Sustainable and green lending

Despite the suitability of the shipping industry for green loans, adoption remains limited. Although the CBI issued some clarifications, there is a lot of debate around sustainable finance and greenwashing, with a particular focus on the shipping industry. The closure of the consultation period on the EU Sustainable Finance Taxonomy in January 2021 means that investors and shipping companies will have some certainty in determining whether certain economic activities will be classified as climate sustainable. The growing emphasis on ESG finance increases pressure on shipping companies to decarbonize, necessitating comprehensive and transparent sustainability practices. Simply put, ESG is a subset of the SDGs that enable enterprises to measure their performance in the aspects of environmental, social, and governance compliance. Consequently, responsible shipping, which is considered environmental, social, and responsibility management, must encompass the whole process, including design, manufacturing, operations, shipping governance, management, and finance (Xue & Lai, 2023).

3.7. Ecosystem: High-quality data access

According to BCG's 2024 survey of cargo owners, although over 60% of respondents have committed to reducing Scope 3 shipping emissions – emissions for which a carrier is indirectly responsible throughout its value chain – less than half report having sufficient budgets to meet these targets. This reveals a significant gap between their ambitious goals and the necessary financial resources (Jameson et al., 2024). Hence, the high-quality data from rigorous lifecycle assessments (LCAs) on Scope 3 emissions, which encompass indirect emissions from all suppliers and value chain activities, are essential for informed decision-making and regulatory compliance. Nevertheless, due to their intricate nature and the involvement of multiple stakeholders, these emissions are often more challenging to quantify and manage. Platforms like Integrated Digital Twin can help manage emissions more effectively by providing detailed insights and improving transparency (Gaspar et al., 2023; Koilo, 2024).

3.8. Future studies

Based on these findings, future research should quantitatively assess the importance of the identified barriers and drivers. Additionally, it should investigate how policy actions from relevant stakeholders can be effectively orchestrated and incentivized to facilitate industrial decarbonization. In addition, future research aims to explore the multifaceted nature of collaboration and digitalization. A particular emphasis will be placed on uncovering collaborative strategies for sustainability through digitalization within a shared ecosystem platform.

CONCLUSION

The main objective of this article was to identify the essential driving forces that facilitate an effective transition strategy to net zero emissions, meet regulatory targets, and reduce current emissions. The research methodology employed a qualitative case study approach, utilizing process tracing and document analysis as primary methods. The paper revealed the main concepts and background of decarbonization, including the differences between carbon neutrality, net zero, and climate neutrality. Additionally, findings highlight the importance of the institutional development of decarbonization maritime policy initiatives. This study presents critical factors driving the emission reduction of maritime companies and introduces the decarbonization LED model, which consists of three key components: levels, ecosystem, and drivers. The study also examines potential and current pitfalls toward decarbonization in the maritime industry.

Green transition requires a far-reaching integration of all parties interested in maritime decarbonization and emphasizes the importance of a value chain approach and a coherent regulatory framework. By integrating life cycle assessments, adhering to strict greenhouse gas regulations, and fostering innovation and collaboration, the maritime sector can effectively navigate the complexities of decarbonization, aligning its operational goals with achieving a sustainable and resilient future.

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Funding acquisition: Viktoriia Koilo.
Investigation: Viktoriia Koilo.
Methodology: Viktoriia Koilo.
Software: Viktoriia Koilo.
Validation: Viktoriia Koilo.
Visualization: Viktoriia Koilo.
Writing – original draft: Viktoriia Koilo.
Writing – review & editing: Viktoriia Koilo.

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APPENDIX A

Table A1. Development of key maritime decarbonization initiatives

International initiatives	European initiatives	Industrial Initiatives
1948: The Geneva Conference led to the adoption of the Convention establishing the Inter-Governmental Maritime Consultative Organization (IMCO), later renamed the International Maritime Organization (IMO) in 1982 (IMO, 1948) **1973**: The IMO adopted the MARPOL Convention, which included Annex VI to regulate air pollution from ships, setting the first CO2 emissions standards in any sector. Next year, the International Convention for the Safety of Life at Sea (SOLAS) was introduced (IMO, 1973) **1975:** The 9th Assembly formed the Marine Environment Protection Committee (MEPC) and elevated it to the same status as the Maritime Safety Committee (MSC) **1988:** The Intergovernmental Panel on Climate Change (IPCC) was established, issuing its first assessment report in 1990, which confirmed the reality of global warming **1992:** The United Nations Framework Convention on Climate Change (UNFCCC) was created, ready for signature at the Earth Summit in Rio de Janeiro, committing industrialized countries to reduce GHG emissions **1995:** The first UN Climate Change Conference was held and started to serve as a yearly event and the formal meeting of the UNFCCC parties, i.e., the Conference of the Parties (COP), to assess progress in dealing with climate change **1997:** The Kyoto Protocol was adopted, setting legally binding obligations for developed countries to reduce GHG emissions and allowing for international emissions trading **2003:** The IMO adopted a resolution urging MEPC to develop mechanisms for limiting GHG emissions from ships **2013:** The IMO introduced the Energy Efficiency Design Index (EEDI) for new ships and SEEMP Part 1 as an operational measure **2015:** The Paris Agreement was adopted, aiming to limit global warming to 1.5°C, with significant GHG reduction targets (Connect4Climate & World Bank Group, n.d.). 17 sustainable development goals (SDGs) were approved by the UN member states (UNFCCC, n.d.). **2018:** The IMO adopted an Initial Strategy to reduce GHG emissions from ships, targeting a 40% reduction in carbon intensity by 2030 and a 50% reduction in total GHG emissions by 2050 compared to 2008 level **2019:** The IMO introduced the Data Collection System (DCS) for fuel consumption and SEEMP Part II was formed **2022:** The IMO initiated the Energy Efficiency Existing Ship Index (EEXI) for existing ships and SEEMP Part III, including the Carbon Intensity Indicator (CII) methodology **2023:** MEPC 80 approved a revised GHG Strategy to achieve net-zero GHG emissions from international shipping by 2050 and ensure the uptake of alternative zero and near-zero GHG fuels by 2030	**2011:** The European Commission issued a white paper on transportation in March 2011, aiming to reduce transportation carbon emissions by 60% by 2050 compared to 2008 levels. Specifically, maritime transport emissions were targeted for a 40-50% reduction (European Commission, 2011) **2013:** The European Commission proposed a regulation on Monitoring, Reporting, and Verification (MRV) of GHG emissions from shipping (DNV, 2024) **2020:** The European Commission approved the European Green Deal, aiming to reduce carbon emissions by 55% from 1990 levels by 2030 and achieve climate neutrality by 2050 **2021:** As part of the 'Fit for 55' package, the European Commission introduced several proposals to address maritime transport's climate impact (European Commission, 2021) FuelEU Maritime Energy Taxation Directive (ETD) Alternative Fuels Infrastructure (AFI) EU's Emissions Trading System (EU-ETS) **2023:** The EU adopted proposals to align climate, energy, transport, and taxation policies with the goal of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (European Commission, 2023a)	**Global Maritime Forum (GMF)**: The GMF is an international organization that brings together maritime industry leaders to address global challenges, including climate change (GMG, 2021). Initiatives like the **Getting to Zero Coalition (GtZ)**, which aims to have commercially viable zero-emission vessels operating along deep-sea trade routes by 2030, are part of GMF's efforts (GMF, 2020) **Sustainable Shipping Initiative (SSI)**: The SSI is a coalition of shipping companies, cargo owners, and NGOs working toward creating a sustainable shipping industry. Focus is a reduction of GHG emissions through innovation and collaboration across the value chain **International Chamber of Shipping (ICS)**: The ICS represents shipowners and operators globally and works to influence international maritime policy (ICS, 2022). It supports initiatives like the Poseidon Principles and Sea Cargo Charter to promote transparency and accountability in GHG emissions reporting and reduction efforts (ICG, 2020) **International Renewable Energy Agency (IRENA)**: IRENA advocates for the use of renewable energy sources in various sectors, including shipping. It provides research, data, and policy recommendations to promote the adoption of clean energy solutions in maritime transport **Zero-Emission Waterborne Transport (ZEWT):** ZEWT is in a partnership within the Horizon framework, focused on advancing sustainable and zero-emission solutions in maritime transport. This initiative aims to foster innovation and collaboration among stakeholders to achieve reductions in GHG emissions from the shipping industry **Clean Cargo Working Group (CCWG)**: The CCWG is a business-to-business initiative involving major cargo carriers and shippers. They work on developing standardized methods for measuring and reducing GHG emissions from cargo transport **Poseidon Principles**: This global framework for responsible ship finance integrates climate considerations into lending decisions. It encourages financial institutions to assess and disclose the climate alignment of their shipping portfolios, promoting investments in low-carbon technologies. **Sea Cargo Charter**: Like the Poseidon Principles, the Sea Cargo Charter provides a global framework for aligning chartering activities with climate goals. It enables cargo owners and charterers to assess and disclose the climate impact of their shipping activities, fostering more sustainable practices **Maritime classification societies:** The maritime classification societies and technical consultancies provide certification, verification, and advisory services to help the shipping industry meet and exceed GHG emission reduction targets. Examples are Lloyd's Register (LR), Det Norse Veritas (DNV), Bureau Veritas, etc.