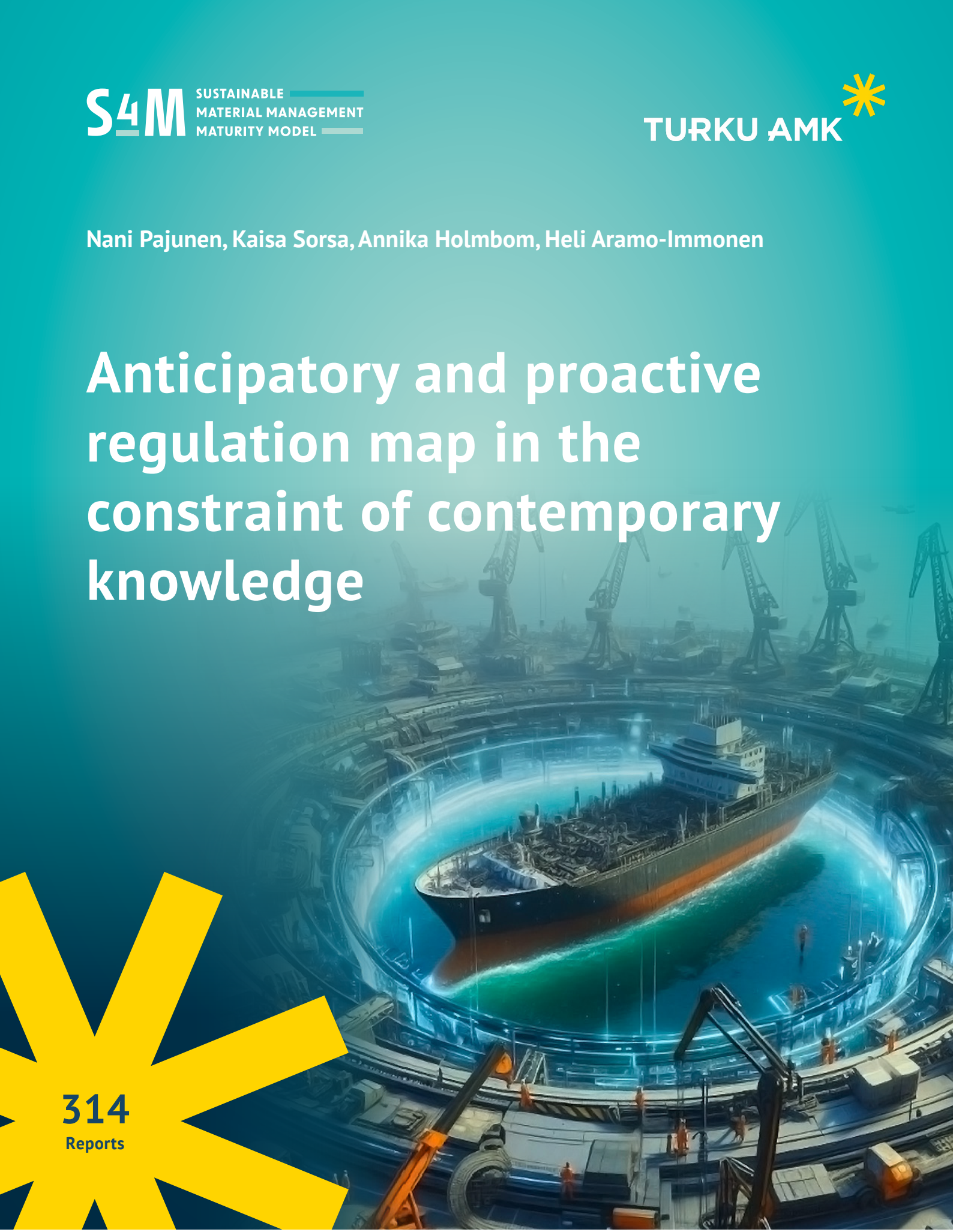
S4M SUSTAINABLE MATERIAL MANAGEMENT MATURITY MODEL

TURKU AMK

Nani Pajunen, Kaisa Sorsa, Annika Holmbom, Heli Aramo-Immonen

Anticipatory and proactive regulation map in the constraint of contemporary knowledge



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This report presents regulatory instruments related to sustainable shipbuilding. It is part of the S4M Sustainable Material Management Maturity Model project. The S4M project focuses on optimising material management processes within ship interior outfitting companies. The project is led by Turku University of Applied Sciences.

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Abstract

The European Parliament and Council have emphasised the need to accelerate the sustainability of transition, implement circular economy practices, enhance material circulation and security of supply and update related legislation. Maritime transport, ship design and shipbuilding are governed by a complex framework of international agreements and legislation.

This report presents regulatory instruments related to sustainable shipbuilding. Shipbuilding is a complex domain, and the legislation governing it is equally multifaceted. The maritime sector is also shaped by various international agreements, standards and voluntary measures. Informational guidance likewise plays a significant role in advancing sustainability objectives.

The S4M project focuses on managing material operations in ship building networks.

The S4M project introduces a novel approach: the development of situational awareness through the sustainable Material Management Maturity Model (S4M). This model serves as a framework for assessing the maturity of sustainable actions across key performance areas (KPA) of business and material management within the supply network. The project aims to answer two key research questions: How can green transition actions in material management be turned into competitive advantage for networks? And how can business be made from network sustainability development?

Policies and regulations promoting the sustainability of transition are continuously evolving within the European Union. The purpose of this report is to provide ship designers, engineers, subcontractors and shipbuilders with an overview of legislation and international agreements related to sustainable shipbuilding. As the regulatory environment is in constant flux, this report provides only a snapshot of the current situation.

Keywords: *Shipbuilding, regulatory instruments, regulation, legislation, sustainability, circular economy, waste management, recycling*

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Introduction

Maritime transport, ship design and shipbuilding are governed by a complex framework of international agreements and legislation. Although shipping is a global industrial sector, regulatory instruments can be highly localised. The role of international maritime organisations, such as the International Maritime Organization IMO, is therefore to seek consensus and establish globally accepted rules.

Finland has a long-standing tradition in shipbuilding. The country possesses advanced expertise in ship construction, and its specialised arctic maritime know-how is of interest internationally.

The sustainability transition in the maritime sector encompasses multiple dimensions. Ships must be designed for repairability and maintainability, and they should remain in use as long as possible. Material choices must be considered based on the origin of raw materials and their production chains. The same principle touches the ship's parts and components. In the context of climate change, the first and most fundamental challenge affecting all modes of transport has been the development of environmentally friendly and low-emission power generation and fuels.

Lifecycle management of ships also includes maintenance during operation and, ultimately, recycling vessels back into materials for reuse—both integral components of the maritime sector's sustainability transition.

Due to the long operational lifespan of ships, ownership may change several times during their lifecycle. This also means that the legislation applicable to a vessel may change over time. Consequently, the regulatory framework governing the design and construction phase may differ from that which is applicable at the end-of-life stage. From the perspective of the sustainability transition, the overarching goal must be to achieve the best possible outcome in terms of environmental, economic and social responsibility.

From the sustainable life-cycle perspective, some questions arise: Are ships currently being designed and constructed in alignment with circular economy principles? Have lifecycle impacts been systematically considered in all design decisions? Where will these vessels be dismantled after the use phase? Has the use of recycled materials become standard practice when a ship reaches the end of its life? As the vessels launched today eventually reach their end-of-life phase, will we already be operating within a global, one-planet economic model?

Background

The European Parliament and Council have emphasised the need to accelerate the sustainability of transition, implement circular economy practices, enhance material circulation and security of supply, and update related legislation. The European Union (EU) has set country-specific recycling targets and is increasingly directing goals toward specific industrial sectors. In the future, stricter circular economy and sustainability targets are expected to apply to all the industrial sectors, and the shipbuilding industry as well.

The European Green Deal (2019) and the EU's growth strategy aim to ensure that Europe becomes climate-neutral and a clean circular economy by 2050, with optimised resource management and minimised pollution. Supporting this goal is the Circular Economy Action Plan (COM/2020/98 final, 2020) and the EU Industrial Strategy (2021), which outline steps to achieve these objectives.

The focus is on promoting circular business models throughout product lifecycles, linking early-stage design and implementation with end-of-life processing, and revising regulations to enhance recycling efficiency. Throughout a ship's long operational life, maintenance and repair involve part replacements, and those parts could also be reused based on circular economy principles.

The target of the S4M project

The S4M project focuses on optimising material management processes within ship interior outfitting companies. A central perspective is the integration of sustainability and lifecycle thinking into material development and product design, encompassing the entire lifecycle from initial design to dismantling. Decisions made during these early stages are critical for enabling material circulation throughout a vessel's operational life.

The S4M project introduces a novel approach: the development of situational awareness through the sustainable Material Management Maturity Model (S4M). This model serves as a framework for assessing the maturity of sustainable actions across key performance areas (KPA) of business and material management within the supply network. The project aims to answer two key research questions: How can green transition actions in material management be turned into competitive advantage for networks? And how can business be made from network sustainability development?

The S4M project is carried out within a ship building network in close collaboration with the companies. The project is funded by Business Finland NEcOLEAP (2022–2025).

The purpose and targets of this report

This report presents regulatory instruments related to sustainable shipbuilding. Shipbuilding is a complex domain, and the legislation governing it is equally multifaceted. The maritime sector is also shaped by various international agreements, standards and voluntary measures. Informational guidance, likewise, plays a significant role in advancing sustainability objectives. Due to the scope and complexity of the topic, the report provides an overview of the current situation but does not present in detail all the legislative guidance related to the theme.

Overview of Finland's Maritime Cluster and the Sustainability Transition in the Marine Industry

The maritime industry is a significant sector in Finland, both now and in the future. Finland possesses strong expertise in maritime operations, from academic research to ship design and construction.

This chapter provides an overview of Finland's maritime cluster and examines the sustainability transition within the marine sector. Particular attention is given to sustainable shipbuilding and its associated perspectives.

The Finnish Maritime Cluster

The maritime cluster—comprising the marine industry, ports and shipping companies—plays a significant role in employment and economic well-being across Finland. Shipbuilding is a global industry, and in Finland alone, approximately 3,000 companies operate within the sector, employing more than 50,000 people directly and many more indirectly. The combined turnover of these companies is estimated at around €17 billion (2024), and this figure is expected to grow further due to new orders. Approximately 90% of the industry's output is exported.

In 2025, Rauma Shipyard delivered a passenger-car ferry to Tasmania. The Finnish Defence Forces' corvette program is currently underway at the same yard, with the fourth and final vessel scheduled for completion in 2029. During the summer of 2025, Meyer Turku delivered the second Icon-class cruise ship, Star of the Seas, to its U.S. client. The third vessel is expected in 2026, followed by the fourth in 2027. Furthermore, the order for the fifth Icon-class ship was confirmed in autumn 2025, including options for sixth and seventh vessels.

The Finnish Border Guard's new vessels, ordered from the Turku Shipyard, are being constructed partly in Poland and partly in Uusikaupunki. The first ship will be completed by the end of 2025 and the second by the end of 2026. The industry outlook is further strengthened by an icebreaker currently under construction at the Helsinki Shipyard for Canada, with hull blocks manufactured in Pori, as well as potential future icebreaker projects for the United States (Etla, 2025).

Recent announcements of new ship orders—such as cruise ships from Turku, naval vessels from Rauma and icebreakers from Helsinki—have significantly increased activity within the sector.

Sustainable shipbuilding

In ship design, customer requirements are central: the ship's intended purpose, operating conditions and port environments. After customer specifications, safety considerations strongly guide the design. Increasingly, environmental aspects must be considered from the outset, including energy production, fuel types, emissions and the ship's impact on marine ecosystems. All of this is influenced by cost—how to manufacture a ship that meets customer expectations, regulatory requirements and international agreements within budget.

The lifecycle of a ship—from order to dismantling—spans approximately 30–50 years. Maintenance and repair during its operational life affect the dismantling phase, especially how well modifications and part replacements are documented, which influences dismantling efficiency. Ensuring information and data flow throughout the ship's lifecycle is a critical component of the maritime industry's sustainability transition.

Sustainable shipbuilding encompasses the design, construction and operation of vessels in a manner that minimises environmental impacts throughout the entire life cycle of the ship. This objective is achieved through the responsible use of materials with minimal ecological harm, the integration of efficient energy and power generation systems, and operational practices that reduce emissions and waste.

Drawn by Inka Mäkiö, TUAS

Figure 1. The lifecycle of a ship – from design to dismantling.

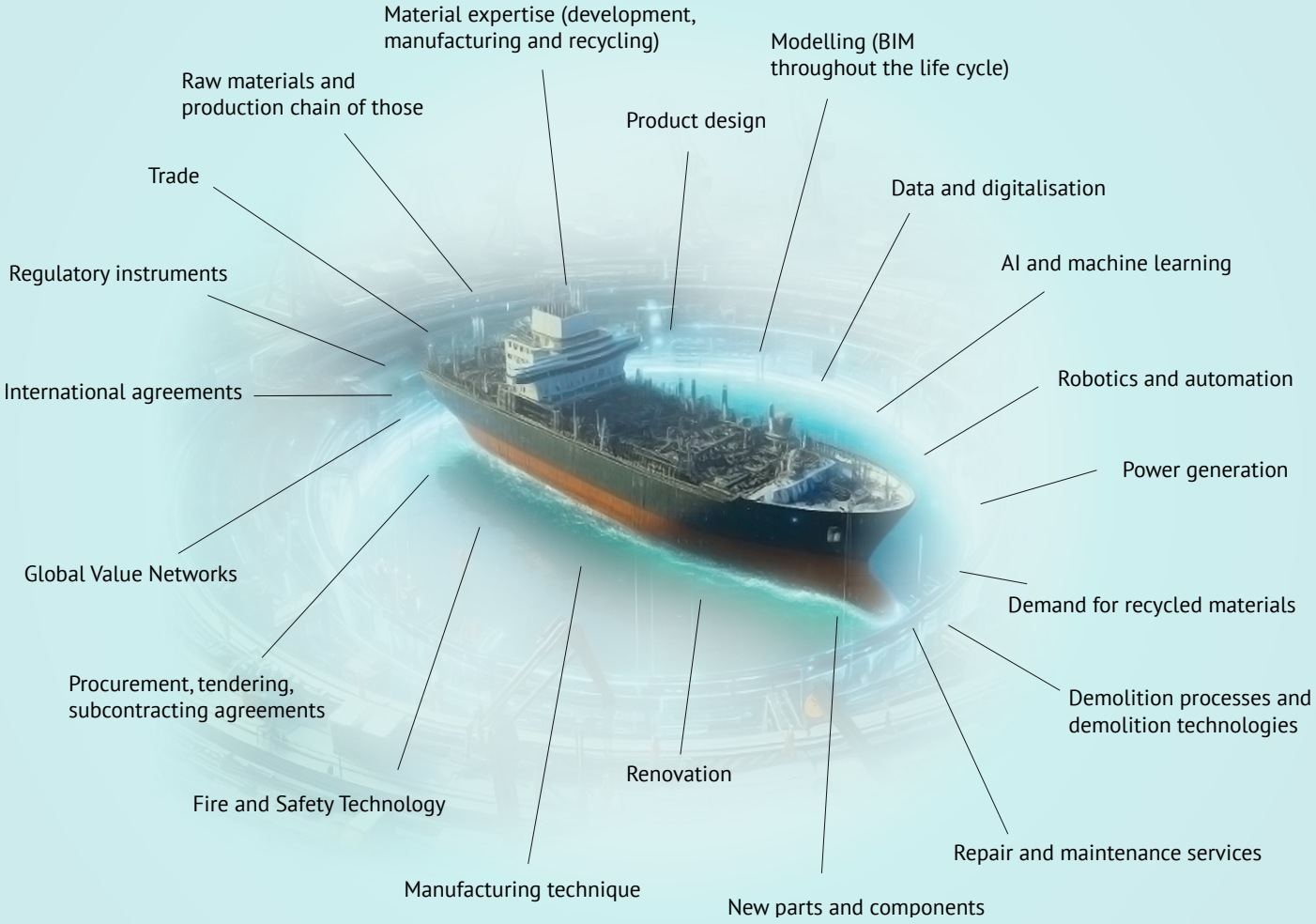

Figure 2. Different perspectives of the ship's life cycle.

The following perspectives highlight essential dimensions of sustainable shipbuilding and marine transport:

- *Sustainability in Material and Product Life Cycles.* Critical decisions regarding recyclability, durability and overall sustainability are made during the early stages of a ship's life cycle—specifically in material development and design phases. Shipbuilders increasingly adopt non-toxic materials, and lightweight composite materials are utilised to improve fuel efficiency. However, these mixed-material solutions may present challenges for recycling at the end-of-life stage.
- *Carbon Emission Reduction.* The shipping industry is among the largest contributors to global greenhouse gas (GHG) emissions. Consequently, significant efforts are directed toward developing vessels powered by low- or zero-emission technologies, including LNG-fueled ships, battery-electric vessels and ships utilising hydrogen or ammonia.
- *Energy Efficiency.* Energy efficiency improvements are achieved through optimised hull designs, advanced propulsion systems and the integration of renewable energy sources, such as wind and solar power.
- *Reduction of Noise and Vibration.* Minimising underwater noise pollution has become a growing priority, as excessive noise can adversely affect marine ecosystems.
- *Waste and Wastewater Management.* Modern ship designs incorporate sustainable waste and wastewater management systems. The goal is to reduce waste generation and mitigate harmful impacts throughout the vessel's operational life.
- *Ship Recycling.* At the end of their operational life, ships must be dismantled and recycled in a manner that minimises environmental harm and ensures socially responsible practices. Safe and sustainable recycling processes are essential for reducing ecological and human health risks.
- *Collaboration with Ports.* Ports serve as critical nodes in global shipping logistics and play a pivotal role in promoting sustainability within the maritime sector. The European Union hosts over a thousand ports, which collectively handled more than 4 billion tons of goods and 437 million passengers in 2018. Major ports, such as Rotterdam, Antwerp and Hamburg, dominate in terms of cargo volume and port call activity. Ports contribute to sustainability by managing ship-generated waste, facilitating the use of alternative fuels and energy supplies, and implementing port call optimisation strategies to reduce emissions during berthing. (EMSA, Sustainable Ports)

However, the design, development and construction phase of the ship has many other perspectives which affect wholeness.

In recent years, global competition for natural resources — particularly mineral-based resources — has intensified. Dependence on imports and unpredictable market fluctuations have heightened industrial interest in securing access to secondary raw materials through various circular economy solutions. This trend has also influenced interest in ship recycling within the European Union, affecting, for example, the availability of recycled steel in Europe. These developments have implications for the ship design phase as well.

Insights learned from another industrial sector

Within the European Union, environmental policies and legislation strongly promote the transition towards a circular economy. However, meaningful impact can only be achieved through effective implementation. While no global legislative framework exists, industrial value networks operate on a worldwide scale. Consequently, the private sector and international trade represent critical pathways for advancing global sustainability objectives.

The central question is as follows: how can we incentivise and support the private sector in developing sustainable circular economy solutions and market-driven business models? Global value networks offer a significant opportunity to accelerate progress towards a sustainable future.

The shipbuilding industry and the built environment sector share numerous similarities. What lessons can the maritime sector draw from the built environment? This chapter is based on the article by Pajunen and Karhu (2022).

How can ships be designed and constructed in a sustainable manner? The following guidelines provide a foundation for addressing this question:

- Before you start, rethink everything – every phase of the project. What can you do differently in a more environmentally friendly way?
- Planning. How is your plan supporting the sustainable use phase and well-being?
- Consider demolition. Is it necessary? If you demolish, make a good plan for the demolition phase. Use as many demolished elements and parts as a product as possible and recycle the rest of the materials.
- Material development is based on recycled materials. Develop new materials using as many recycled materials as possible.
- Use secondary raw materials. Use as many recycled materials and products in the new ship as possible.
- Design for a circular economy. Design and develop ships, products and materials in accordance with circular economy principles.
- Design "everlasting" ships. Make it your goal that the ship designed by you will last forever.
- Demand is the strongest tool to promote the circular economy and sustainability. Use this tool!
- Minimise environmental impacts in the use phase. Take care of the ships, maintain them and efficiently use energy.
- Measure the change made. Monitor and measure the change made. Make changes to the plans if necessary.
- Learn by doing it. There is no time to lose – the sustainability crisis is already here. We need to act now, not only develop, design and conduct surveys. This step might not be perfect, but we can learn by doing it.
- The role of data. Collect important data during the life cycle of a ship to help evaluate change. Use the data model as a data bank for materials and products.
- Responsibility via the life cycle. Challenge the supply chain of organisations to promote circular economy solutions.
- Smart solutions. Use digitalisation and smart solutions where it gives added value. Remember, digitalisation has an environmental footprint as well.
- New circular economy business models. Adopt circular economy business models, such as product-as-a-service and sharing models.
- Collaborate. There is a need for cross-sectoral collaboration. Share your know-how and do better business.
- The role of investors and owners. The circular economy is a new business model – as an owner, a financier or a founder, it is your decision to demand more sustainable solutions.
- Be a proud professional. The best act of sustainability is to build a high-quality ship that will last for future generations.

The next critical step is securing the industry's commitment to implement the necessary changes. Although numerous challenges remain on the path towards sustainability, the circular economy offers substantial business potential. The most important task for the entire sector is to maintain momentum in developmental efforts. It is irrelevant whether a company is a pioneer in circular economy practices or a fast follower—the essential point is that all stakeholders must participate in this transformation. (Pajunen, N. & Karhu, J., 2022)

Instruments and mechanisms driving sustainable shipbuilding

In addition to regulation, other governance instruments are also employed. Accelerating the sustainability of transition requires the combined use of all these instruments — regulation, economic, informative and voluntary. Each plays a critical role in driving systemic change within society and the economy.

Informative instruments refer to measures that increase knowledge, such as communication and education. Economic instruments include mechanisms with financial implications, such as subsidies, incentives or conversely, environmental taxes and penalty fees. Voluntary instruments encompass practices like environmental management systems that companies may choose to adopt independently.

Figure 3 illustrates instruments and measures that either accelerate or hinder the sustainability of transition, as well as actions that can promote progress. Advancing this transition requires the application of all the instruments. Furthermore, challenges and barriers must be identified and addressed. Without concrete actions and active changes in operational practices, the sustainability transition will not progress — making these measures critical from a change management perspective.

Shipping regulations are shaped by various international agreements, guidelines, treaties and government organisations. This publication aims to give an overall picture of the regulation landscape to help understand the different layers of the regulatory environment in which the cruise ships will collide with. When the cruise ship is travelling in international waters, its jurisdiction is primarily governed by the flag state. When cruise ships are travelling in territorial waters, the coastal nation has jurisdiction over its territorial waters. In addition to this, ships must comply with the laws of the countries they visit, which can include additional requirements for safety and security.

Policy and regulation – perspectives at a glance

In the regulation of the maritime industry and shipping, safety is always the foremost priority. All development efforts—including those related to autonomous vessels, alternative fuels and emerging technologies—are driven by the imperative to ensure safety. A second major regulatory theme concerns energy efficiency and emission reduction, which encompasses advancements in both fuel technologies and power generation systems. Instruments aimed at mitigating environmental impacts primarily address the effects of maritime traffic on the environment, such as air and water emissions, waste management, underwater noise and wave formation. From a materials perspective, regulatory measures focus heavily on prohibiting hazardous chemicals and how to ensure the safe dismantling of a vessel and circular economy practices.

Sustainability in the ship building – Drivers, barriers and the actions

Drivers	Barriers	Transition towards sustainability how and what?
Regulation / Legislation	Regulation / Legislation	R&D willingness and ability
Policy	Price and costs	Trust
Circular Economy Action Plan	Lack of know-how	Know-how
International Agreements	Lack of solutions	Activity
Sustainability crisis • Climate Change • Biodiversity loss • Natural Resources (scarcity and overuse)	Lack of experts	Common will
	Security of supply	Cooperative organisations
	Business as usual “Easy way to proceed”	Cluster work
Availability of the raw materials	Business risks	New business models
Security of supply	Lack of new business models	Novel collaborative business
Competition / Market pressure	Lack of (digital) data	Sustainable economic growth
Customers / Demand (B to B and B to C)	Data incompatibility	New organisations
Reputation	Market change is slow	Creation of new jobs
Business potential	General state of economy – economic cycles	Operator / development company
Business risks (from the market, from nature)	Time-consuming RDI	From planning to the implementation phase
	Difficulties of systemic change	Pilots
		Progress in security of supply

Figure 3. Drivers, barriers and actions.

The main regulatory themes in marine traffic and shipbuilding centres are two overarching priorities: environmental protection and operational safety. Safety and security regulations, primarily governed by the SOLAS Convention (1974), establish standards for ship design, construction and operation to protect life at sea. These cover structural integrity, fire safety, navigation systems and emergency preparedness, with recent amendments addressing advanced fire protection and lifesaving appliances.

Environmental regulations, led by instruments such as the MARPOL Convention (1973), aim to minimise pollution and emissions throughout a ship's life cycle, including measures for energy efficiency, waste and wastewater management, and the adoption of low- or zero-emission fuels. The IMO's greenhouse gas reduction strategy and the EU's Fit for 55 package further reinforce decarbonisation goals through mechanisms such as the FuelEU Maritime Regulation (2009/16/EC) and Emissions Trading System (EU ETS,2025).

Sustainability principles also extend to ship design and recycling, with frameworks like the EU Ship Recycling Regulation and the Hong Kong Convention (2009), ensuring safe dismantling and circular economy practices.

Increasingly, regulatory themes also encompass emerging challenges, such as cybersecurity, autonomous vessel operations and port-state control to enforce compliance. Together, these regulatory domains form a comprehensive governance structure that seeks to balance technological innovation, environmental responsibility and global maritime safety.

Introduction to anticipatory and proactive regulation

As the regulatory environment is so complicated, we argue that anticipatory and proactive regulation is needed to guide the transition to sustainable shipbuilding. Reasons behind this argument are several.

According to Impperiale (2025), a deeply rooted reactive mindset in legal and business communities prohibits smooth transitions from using law for reactive problem-solving purposes to the anticipatory problems prevention and using law and contracts to bring value for money (same Kuronen & Tapaninen 2010). In addition, proactivity is not only combined with the mindset. It can be applied to the development of contents of law, (Sorsa 2011; Schartum 2006; Saliternik & Shlomo Agon 2024), meaning that the law (OEESC 2009) and contracts (Sorsa 2009; Kaave & Storsjö 2025) can be designed to encompass incentives for continuous improvement of processes and compliance of law instead of focusing on setting only sanctions for behaviour against the law.

According to Sorsa (2011), proactive regulation means enabling and empowering a dynamic and user-friendly regulation. Enabling regulation means, for example, that the organisation subject to regulation has the opportunity to innovate or choose the most appropriate technology while complying with legal requirements. According to Sorsa (Sorsa 2011), empowering as an attribute of the regulation refers to the fact that the actors subject to regulation have the opportunity to influence the content of the regulation in the beginning of the law-making process, to develop procedures for compliance with the law in the implementation phase, or to develop new means of enforcing compliance with the law.

Saliternik & Shlomo Agon argue (2024) that international law is notably reactive in nature: "For the most part, international law has developed in response to specific crises and incidents, be they wars, pandemics, environmental disasters, economic breakdowns, or technological advances." They illustrate how the reactive approach is used in numerous regulatory fields, e.g. in anti-terrorism regulation and public health regulation.

Because a reactive approach is largely based on yesterday's crises, and it does not take into account tomorrow's threats and opportunities, it does not prioritise between short- and long-term risks and opportunities (Saliternik & Sholomo 2024); therefore, it cannot be sufficient in preventing today's global threats. Prioritising is necessary to positively influence the direction of the international community's development. Saliternik and Sholomo (2024) point out that a narrow approach to legislation leads to international legislators failing to see the big picture of phenomena that require regulation. Regulation of the maritime industry's transition towards sustainable development requires a holistic view. For example, Rayfuse (2017) has studied technological development and how regulation considers the risks associated with it and has concluded that the industry is unable to "anticipate, assess, minimize, and mitigate the risks posed by new technologies."

The International Maritime Organization has made proactive efforts to set future targets and develop frameworks like the Net-Zero Framework (NZF) to drive decarbonisation in the shipping sector ahead of major technological breakthroughs. Instead of waiting for technology to mature, the IMO establishes long-term goals, like reaching net-zero emissions by 2050, and then developing the regulatory structure, including fuel standards and economic mechanisms, to incentivise and mandate the necessary innovation from the industry. The tasks of the Maritime Environmental Protection Committee (MEPC) within the IMO are to address shipping-related environmental issues: e.g., greenhouse gas emissions, garbage, air and water pollution, and underwater noise.

Even though the IMO, as an international organisation, has the power to set rules for the maritime industry, it does not have any enforcement authority over its own rules. Instead, the member states are responsible for implementing the IMO's regulations (see, e.g., Traficom 2024) in their national regulation system. Member states also have an adequate administrative organisation to discharge their obligations as flat, port and/or coastal states emanating from applicable international law. If, e.g., cruise lines ignore Safety of Life at Sea recommendations, the IMO cannot impose any sanctions, such as fines or criminal sanctions, against cruise lines. Enforcement authority of the sanctions belongs to the flag states, like the Bahamas and Panama. Because the effective implementation of the IMO's guidance documents is crucial, an IMO Member State Audit Scheme (IMSAS) was developed and launched as a voluntary scheme in 2006 and became mandatory on 1 January 2016.

Some of the IMOs regulations are used in this report to concretise what proactive and anticipatory regulations in practice mean.

Maritime Policy Instruments and Governance

Policy instruments in maritime governance are categorised into three categories: regulatory instruments, e.g. laws in national legal systems or European Union regulations and directives; economic instruments, e.g. subsidies and taxes and information-based instruments like education or certifications. The aim of these different governance instruments is to protect either private goods (e.g., company competitiveness) or public goods (e.g., protection of environment from pollution), using preventive measures or with sanctions and penalties for non-compliance.

Due to global environmental challenges, like climate change, the importance of policy guidance has grown. Governance in the maritime industry is complex and fragmented, involving both public (e.g., states, European Union, United Nations) and private actors (e.g., standard-setting organisations) in setting and monitoring standards. It is important for actors in the maritime sector to understand how these different regulations are interwoven together.

The International Maritime Organization is the UN's specialised agency open only to states. The IMO's area of specialisation is to set safety, security and environmental performance standards for international shipping. Its goal is to establish a universally accepted regulatory framework for the maritime sector. (IMO 2024a)

Private regulation also plays an important role in setting standards for the maritime sector. Private standards (e.g., technical standards, process standards, service standards) are very important for governance tools, although compliance is mostly on a voluntary basis.

The regulatory systems of the European Union and the IMO are constantly interacting with each other. The role of the IMO's regulatory system is to create a global framework for maritime business which the EU incorporates into its own legal system. The European Union, more specifically, the legislative bodies of the European Union (European Commission as the initiator of legislative proposals, the European Parliament and the Council of the European Union as the approving bodies) often exceeds international minimums with stricter rules. An example is the EU Emission trading system and FuelEU Maritime, which go beyond the IMO standards to achieve higher environmental goals. The EU transforms IMO rules into its system using Regulations and Directives.

Collaboration with the European Commission and the IMO is based on IMO Resolution A.1168(32), which defines the procedures and terms for the cooperation between the IMO and intergovernmental organisations. Based on this IMO Resolution, and further arrangements since 1974, the European Commission has been participating as an observer in all IMO Committee and Sub-Committee meetings.

Proactive measures of IMO instruments governing protection of the marine environment

The United Nations Convention on the Law of the Sea (UNCLOS) is the main legal instrument to protect the marine environment. Its purpose sets out the framework for safe, sustainable and responsible governance of the world's oceans and seas.

UNCLOS is complemented by global environmental treaties, regional agreements and soft law. So-called soft law instruments are non-legally binding, quasi-legal documents that lack legal force, but they still influence behaviour and generate practical effect, because organisations comply with them voluntarily. Soft law instruments may be resolutions of international organisations, declarations, guidelines and codes of conduct.

The proactive nature of UNCLOS is reflected in its requirement (UNCLOS Part XII, Art. 192) that states must prevent environmental damage, must assess potential impacts, as well as to apply the precautionary principle in cases of scientific uncertainty. Additionally, Articles 194, 211 and 212 provide further guidance on how to prevent and reduce marine pollution, among others (Duron & Palocz-Andresen, 2025). All of these obligations imply preventive action to resolve environmental issues. Through provisions on environmental impact assessment (EIA) and marine protected areas (MPAs), UNCLOS enables proactive measures to protect the marine environment and marine resources. This is in line with the broader concept of proactive law, which focuses on preventing future harm and managing new challenges rather than merely responding to existing problems.

Three means of proactive law measures under the UNCLOS Convention are as follows:

1. Use of Precautionary Principle: Even though there is scientific uncertainty, states are encouraged to take preventive actions against marine pollution and environmental degradation.

2. Environmental impact assessment (EIA) as a preventive measure: The Convention (UNCLOS Art. 204) and related agreements oblige states to carry out environmental impact assessments if their activities, which they permit or undertake, may harm the marine environment. States or authorising competent international organisations shall analyse the risks or effects of pollution of the marine environment using recognised scientific methods for observation, measurement, assessment and analysing.

   The area under national jurisdiction is no exception. In fact, according to the UNCLOS Convention, "States shall take all necessary measures to ensure that activities under their jurisdiction or control are conducted in such a manner that they do not cause pollution damage to other States and their environment, and that pollution resulting from events or activities under their jurisdiction or control does not spread beyond the areas where they exercise their sovereign rights" (UNCLOS, Article 194(2)).

   However, there was no framework or details for implementing this obligation (UNCLOS Art. 194(2)) before the adoption of the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement) on 4 March 2023.

   The agreement was opened for signature on 20 September 2023 and remained open for signature for two years. The BBNJ Agreement will enter into force early 2026, after 120 days, where 60 states had ratified it by 20 September 2025. Until then, signatories are obliged to refrain from actions that would be contrary to the objectives and purpose of the agreement. The BBNJ Agreement effectively implements the requirements of the UNCLOS Agreement by ensuring the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction, both now and in the long term (Currie & Müller 2023).

Parties to the BBNJ Agreement shall conduct environmental impact assessments (EIAs) in accordance with the BBNJ Agreement or national procedures for activities under national jurisdiction that may affect areas beyond national jurisdiction. In the context of the BBNJ Agreement, environmental impact assessments and regional management tools are aimed at conserving marine ecosystems, which prevent adverse impacts and promote the sustainable use of marine resources. These are both examples of forward-looking mechanisms typical of proactive legislation.

Another proactive legislative measure in the BBNJ Agreement is that it establishes a framework for the development of marine protected areas to conserve marine biodiversity and manage areas beyond national jurisdiction.

3. From the compliance management point of view, the voluntary IMO Member State audit scheme is a proactive programme that encourages member states to improve their implementation of IMO regulations, including those derived from UNCLOS.

Proactive measures of IMO instruments governing the safe ship design

The work on ship design is carried out by the Subcommittee on Ship Design and Construction (SDC) under the Maritime Safety Committee of the IMO's parent organisation. The key regulations concerning the safety of cruise ships at the design stage are the International Convention for the Safety of Life at Sea (SOLAS). SOLAS has minimum safety standards for ship construction, equipment and operation. Other governance instruments are the 1966 Load Line Convention and the related 1988 Protocol, the 1969 Tonnage Convention and the 2008 International Code of Stability and Integrity.

The SOLAS Convention was adopted on 20 January 1914, but its entry into force was delayed due to the European war. The Convention has since been revised four times (1929, 1948, 1960 and 1974). The entry into force of the conventions has varied from three years to as long as 17 years. A set of amendments to SOLAS and the associated Codes entered into force on 1 January 2024 (Resolutions MSC.474(102); MSC.482(103)).

According to Sotiroski (2016), the relationship between EU law and international law is very much influenced by Maritime Safety Law.

The SOLAS convention was established after the Titanic sinking in 1912, representing a reactive regulatory framework for safety. Also, several amendments have been made as a reaction to new risks and technological development. Many of SOLAS's provisions, like those for fire safety, structural integrity and life-saving appliances, are direct responses to known risks and potential dangers identified from past incidents, which indicates SOLAS' focus on mitigating past risks. SOLAS can be called reactive also from its acceptance procedure point of view.

Tacit acceptance procedure is used, meaning that an amendment to the convention is assumed to be accepted if a certain number of contracting governments (based on fleet tonnage or number of states) do not explicitly reject it within a specific period.

The overall aim of the convention is to have well-maintained safety equipment, along with properly trained personnel to handle the situation. Key provisions include the standards for ship construction, fire protection, safety of navigation, life-saving appliances, radio communications, the carriage of cargoes and maritime security.

Specifically, for passenger ships, in 2000, the IMO initiated preparation of a comprehensive improvement of regulations, which were adopted in 2006 by the Maritime Safety Committee (MSC). The basic philosophy since 2000 has been preventing casualty. The idea is that, in the first place, the regulatory framework should place more emphasis on the prevention of casualty from occurring. Second, improved survivability should be designed so that, in the event of casualty, people can stay safely on board as the ship proceeds to port.

We can find some proactive law elements in SOLAS: First, its ongoing amendments and updates, driven by technological advancements and lessons learned from incidents, aim to proactively mitigate future risks by incorporating new safety features and technologies. Second, a continuous improvement approach is integrated into the ongoing process of amending SOLAS. This will ensure SOLAS remains relevant and effective by pre-emptively considering new technologies and potential safety issues before they lead to major casualties. Third, standardisation of advanced equipment, e.g. Automatic Identification Systems (AIS) in Chapter V (Safety of Navigation), shows a proactive approach to enhancing safety by providing tools for long-range tracking and collision avoidance. We can also say that the risk-based amendments, while originating from incidents, often incorporate risk-assessment methodologies to proactively enhance safety across various maritime operations, reflecting a shift towards risk mitigation rather than just reaction.

Although the SOLAS Convention is based on reactive legislation, its dynamic nature and continuous updates reflect a commitment to a more proactive approach that takes into account future-oriented safety measures.

Proactive measures of IMO instruments governing pollution from ships

The International Convention for the Prevention of Pollution from Ships (MARPOL) is a primary global treaty, which aims to protect the marine environment from various forms of pollution from ships. MARPOL addresses pollution from oil, noxious liquid substances, harmful substances in packaged form, sewage, garbage and air pollution. It was established by the IMO in 1973, and it entered into force in October 1983. All European union Member States are parties to MARPOL, but the European Union is not.

The proactive regulatory approach of MARPOL is demonstrated in several ways during the whole lifecycle of the convention: from contents development, to adoption, to the enforcement phase. MARPOL employs a proactive approach through its technical and operational regulations, inspection regimes and the requirement for adequate shore-based reception facilities for ship-generated waste to ensure ongoing compliance and continuous improvement in marine environmental protection.

One proactive law feature is the dynamic nature of the legal instrument. In the case of MARPOL, this is demonstrated in the continuous

amendment processes: The contents of the Convention need to follow the development of the changes in society. Therefore, the Convention is periodically amended by the Marine Environment Protection Committee (MEPC) of the IMO, allowing for the adaptation to new challenges and evolving environmental understanding, as well as considering the technological developments. The most recent amendment process is going on in 2025, focusing on the Net-zero-GHG.

Another proactive law feature of MARPOL is that it is user-friendly. The adoption of the convention is both mandatory and voluntary, depending on the chapter. Compliance with the MARPOL Convention is mainly mandatory. However, the Convention includes several different annexes, some of which are voluntary, depending on whether the contracting state has ratified them on an optional basis. The overall scope of the Convention could, therefore, be both mandatory and voluntary, depending on the annex in question.

> ***For example, annexes concerning oil and harmful substances are mandatory for signatory countries. Also, annex VI includes mandatory technical and operational measures to improve energy efficiency and reduce greenhouse gas emissions from ships. Other annexes, such as Annex IV concerning sewage, may be adopted on a voluntary basis. Some organisations support the voluntary adoption of upcoming environmental regulations even before they become mandatory.***

Mandatory compliance is enforced through national laws that require port states to conduct inspections and may impose significant penalties, such as fines, detentions and other sanctions for violations.

Impact of MARPOL

The impact and significance of the MARPOL convention is remarkable: The MARPOL Convention applies to nearly 99% of the world's merchant tonnage, which means that it affects a wide range of vessels, from oil tankers to small pleasure craft. According to Riadh (2024), MARPOL has contributed to a significant reduction in pollution from international shipping, despite a substantial growth in the global shipping industry. Riadh's research (2024) argues that there is a significant correlation between MARPOL compliance and a reduction in key environmental indicators, such as a 30% decrease in oil spills and a 25% reduction in greenhouse gas emissions over the past decade. Also, Sade (2024) found out that MARPOL has successfully reduced traditional pollutants like SOx and NOx by over 70%. However, Sade's findings reveal that the frameworks are inadequate for addressing greenhouse gas emissions, because regulations are fragmented between developed and developing nations. There are also financial barriers in alternative fuel adoption, as well as limited technological readiness of the global fleet.

The IMO is going towards its goals to further reduce greenhouse emissions by approving the Net-Zero Framework at the MEPC 83 session in April 2025. The IMO's 2023 Strategy for Reduction of GHG Emissions sets lines for further work towards GHG reduction. A new Chapter 5 of the Draft Revised Annex VI of MARPOL convention comprises a set of international regulations including two key elements: a global fuel standard and global GHG emissions pricing mechanism (SopS 51/1981 and EU/923/2025). In addition to the new chapter, the net-zero framework (NZF) also includes punitive changes to other areas of MARPOL, such as definitions, inspections/ verification, certification, port state control, Ship Energy Efficiency Management Plan (SEEMP) and Data Collection System (DCS) (EU/923/2025).

The climate regulation currently undergoing approval consists of a two-tier fuel standard and fees based on exceeding the requirement levels. The development curve for reducing greenhouse gas emissions is upward: Over time, ships must reduce their annual greenhouse gas fuel intensity (GFI), i.e., how much greenhouse gas is generated per amount of energy used. The GFI is calculated based on the well-to-wake emissions of the energy used by the ship. A ship whose greenhouse gas intensity exceeds the permitted annual limit must pay for its excess emissions. There are two limits: the baseline and the direct requirement. The baseline is easier to achieve, as it requires fewer low-emission energy sources than the direct requirement. (EU/923/2025)

Net-Zero-Framework

From the perspective of proactive regulation, which is the core theme of our report, the NZF framework is a concrete example of dynamic and user-friendly regulation that rewards pioneering efforts:

1. If a company meets the requirements and accumulates so-called surplus units, it can transfer them to other ships under certain conditions, store them for use during the next two calendar years or voluntarily cancel them.

2. In addition, annual financial rewards serve as an incentive. Ships can receive financial rewards if they use zero- or near-zero-emission technologies, fuels or energy sources with a greenhouse gas intensity of no more than 19 gCOe/MJ until 2034 and a maximum of 14 gCOe/MJ thereafter. If the gas intensity exceeds the permitted annual limit, a fee must be paid for emissions exceeding the limit. There are two limits: the baseline and the direct requirement. The baseline is easier to achieve, as it requires fewer low-emission energy sources than the direct requirement level. The reward mechanism is to be specified in the rules of procedure. At this stage, it is not possible to estimate the amount of the reward (EU/923/2025).

According to the DNV report, "The NZF is groundbreaking in introducing a global technical requirement in combination with a GHG pricing scheme. It presents a new regulatory era where ships will be required to gradually adopt fuels that are considerably more expensive than conventional fossil fuels or alternatively pay a contribution to the IMO Net-Zero Fund. Given the long lifespan of ships, shipowners should prepare now for the new regulations to ensure cost-effective compliance, both at the ship and the fleet levels." (DNV 2025)

The EU is actively working to ensure that the reward mechanism achieves its objective of genuinely encouraging the adoption of zero- or near-zero-emission technologies.

Example of the complexity of the negotiation process:

> *The negotiation process concerning the new GHG reduction regulations in chapter 5 of MARPOL Annex VI was complex because the provisions of the MARPOL convention under negotiation fall partly within the exclusive competence of the EU and partly within the shared competence of the EU and its Member States. As the European Union does not have recognised status in the IMO, it cannot be a party to IMO agreements. For this, the Member States negotiate amendments to the MARPOL Convention and present the EU's common positions on behalf of the EU. They also commit to the amendments in their own name, insofar as the provisions fall within the exclusive competence of the Union. The agreement*

is, therefore, comparable to a mixed agreement. On 31 July 2025, the European Commission issued its proposal for a Council decision on the position to be taken on behalf of the EU on amendments to the MARPOL Convention (COM (2025) 431 final). The Commission proposed that the comprehensive reform of Annex VI to the MARPOL Convention be accepted as a Union's position. The positions were negotiated in the Maritime Transport Working Party in September 2025, after which the Permanent Representatives Committee submitted them to the Council for approval under the silence procedure. (EU/923/2025)

EU Member States have participated very actively in the negotiations at the IMO. At the 83rd session of the Marine Environment Protection Committee, all EU Member States expressed their support for the preliminary agreement on the net zero framework.

The negotiating situation at the IMO is very challenging. If no unanimous agreement on the amendments is reached at the session, a vote will be held. For the amendments to be adopted, two-thirds (2/3) of the parties to Annex VI to the MARPOL Convention to participate in the vote must support them. The outcome of the vote will depend on how the parties to Annex VI of the MARPOL Convention attend the session of vote.

If the amendments to Annex VI of the MARPOL Convention are adopted, they are intended to enter into force in accordance with the so-called silent acceptance procedure under the MARPOL Convention. According to the proposal, the amendments would enter into force on 1 March 2027, unless they are opposed by at least one-third of the parties or parties whose combined merchant fleets account for at least 50 per cent of the gross tonnage of the world's merchant fleet by 1 September 2026. The IMO's NZF regulation is intended to apply from the beginning of 2028. The dates may still be subject to change during negotiations. (IMO 2025c IMO 2025d)

The NZF for reducing greenhouse gas emissions from shipping is an important step towards achieving the medium-term climate goals set out in the IMO's 2023 greenhouse gas strategy. The IMO's goal is for maritime transport to be carbon neutral (i.e., net zero emissions) by 2050 or thereabouts, taking into account national circumstances. By 2030, greenhouse gas emissions from ships must be reduced by at least 20% compared to 2008. The interim target for 2040 is to reduce emissions by at least 70%.

The 2nd extraordinary session of the IMO's Marine Environment Protection Committee (MEPC/ES.2) was held 14-17 October 2025.The amendments to the MARPOL convention were not adopted, as a majority of 57 member states voted to adjourn the meeting for one year, while 49 voted to continue. Therefore, the decision was to delay adoption of new requirements on greenhouse gas (GHG) fuel intensity, in combination with a pricing and reward mechanism until the meeting in October 2026.

Energy Efficiency Existing Index (EEXI) and Carbon Intensity Indicator (CII) from IMO

The IMO contributes to the global fight against greenhouse gas reduction using the GHG Initial Strategy from 2018, with timelines until 2023, and the follow-up programme from October 2018. Later in 2023, the IMO implemented short-term Greenhouse Gas (GHG) reduction measures, which include the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) regulation. From 1 January 2023, EEXI became mandatory for all ships to calculate their attained energy efficiency and to initiate the collection of data for the reporting of their annual operational carbon intensity (IMO 2025b).

These are both anticipatory measures for reducing emissions by enhancing ship energy efficiency and carbon intensity. EEXI is a technical measure for existing ships (400 GT and above) to meet a specific efficiency standard based on their design (ship type, engine power, DWT and ship reference speed), ensuring they can achieve a target EEXI level. EEXI is a one-time certification, achieved by comparing a ship "attained" EEXI value to a "required" EEXI value, which is set based on the ship's type and size. The CII then provides an operational assessment of a ship's actual carbon intensity over time, with a mandatory rating system and corrective action plan requirements to penalise high-emission vessels.

The purpose of EEXI is to ensure that existing vessels meet minimum energy efficiency standards by calculating their CO_2 emissions relative to their transport capacity. EEXI is the sister regulation to the Energy Efficiency Design Index (EEDI), but while EEDI applies to new builds, EEXI applies to existing ships.

The Carbon Intensity Indicator (CII) regulation is a measure of a ship's actual carbon intensity (CO_2 emissions per transport work) during operation. Ships of 5,000 GT and above are given a carbon intensity rating (A to E) based on their annual reported emissions and transport work. The purpose of CII regulation is to promote operational improvements and encourage ships to reduce their carbon emissions through better performance over time. Ships that receive a poor rating (D for three consecutive years, or E in any year) must develop and implement a corrective action plan to improve their performance.

By combining technical (EEXI) and operational (CII) measures, the IMO addresses energy efficiency from both design and real-world operational perspectives. EEXI focuses on the ship's design, and CII measures the actual operational energy efficiency of the ship and rates its carbon intensity annually.

EEXI and CII are crucial building blocks that provide the data and regulatory framework for developing and implementing future, more rigorous mid-term and long-term GHG reduction measures.

European Union regulations

The European Union has been active in promoting sustainability and a circular economy with a number of regulations, initiatives and policies aimed at reducing the environmental impacts in maritime context.

- **EU Green Deal.** The European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring:
  - no net emissions of greenhouse gases by 2050
  - economic growth decoupled from resource use
  - no person and no place left behind
- **Fit for 55**. Under the European Climate Law, the EU committed to reduce its net greenhouse gas emissions by at least 55% by 2030. The 'Fit for 55' package of legislation ensures all sectors of the EU's economy are fit to meet this target. It sets the EU on a path to reach its climate targets in a fair, cost-effective and competitive way.
- **EU ETS.** EU Emissions Trading System. The EU ETS is being expanded to include shipping, meaning that ships will be required to buy carbon allowances for their emissions, effectively putting a price on CO_2 emissions and encouraging companies to invest in more sustainable technologies.
  - requires polluters to pay for their greenhouse gas (GHG) emissions
  - launched in 2005, it is the world's first carbon market and among the largest globally
  - helps bring overall EU emissions down while generating revenues to finance the green transition
  - covers emissions from the electricity and heat generation, industrial manufacturing and aviation sectors – which account for roughly 40% of total GHG emissions in the EU
  - started covering emissions from maritime transport in 2024
  - operates in all EU countries plus Iceland, Liechtenstein and Norway, and is linked to the Swiss ETS (since 2020)
- **The Renewable Energy Directive (2009/28/EC)** establishes targets for increased renewable energy use, supporting cooperation between EU countries towards this goal. The EU is pushing for the use of renewable fuels for shipping, such as hydrogen, ammonia and biofuels, which have a much smaller carbon footprint than traditional marine fuels.
- **Alternative Fuels Infrastructure Regulation.** In the context of the 'Fit for 55' package, the co-legislators agreed on a new Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure.
- **EU Ship Recycling Regulation.** This regulation ensures that ships are recycled in a sustainable way (1257/2013, 2025/322, 2016/2323, EU Ship Recycling Regulation: Evaluation and list update. 2025). It requires ships that are flagged under EU member states to comply with environmentally safe ship recycling standards. It aligns with the Hong Kong Convention on ship recycling.

Climate targets

The European Union (EU) legislative package is established in line with the Paris Agreement temperature goals to achieve significant CO_2 reductions by 2050: The EU aims to be climate neutral. The EU follows and strengthens international regulations established by the IMO. The Fit For 55 package includes the Emission Trading System, Renewable Energy Directive and Alternative Fuels Infrastructure Regulation.

- **The EU Emissions Trading System (ETS)** is a comprehensive legal framework designed to reduce greenhouse gas (GHG) emissions through a "cap and trade" mechanism: a cap is set on the total amount of greenhouse gases that can be emitted. In addition, it requires polluters to pay for their greenhouse gas (GHG) emissions.

  The world's first carbon market, ETS, was launched in 2005. The aim of the ETS is to cut overall EU emissions and generate revenues to finance the green transition. The ETS is applied to the electricity and heat generation industry, industrial manufacturing and aviation sectors, which account for roughly 40% of total GHG emissions in the EU. Maritime transport emissions were included into the ETS system in 2024. The ETS is applied in all EU countries and in Iceland, Liechtenstein and Norway, and it is linked to the Swiss ETS (since 2020) (IVR 2025).

  The ETS is being expanded to include shipping, meaning that ships will be required to buy carbon allowances for their emissions, effectively putting a price on CO2 emissions and encouraging companies to invest in more sustainable technologies.

  The concept of "proactive law" is demonstrated by the ETS's iterative legal revisions and the establishment of a separate ETS2 for buildings and road transport, reflecting the EU's commitment to continuously adapt its climate policy to achieve evolving emission targets and promote cost-effective emission reductions.

  The EU ETS serves as an example of proactive law because of the following: 1) It establishes a market-based incentive for emissions reduction: The core "cap and trade" principle empowers companies to find the most cost-effective ways to reduce their emissions by setting a limit on total allowances and allowing companies to buy or sell them. 2) The system is dynamic as it Is subject to constant revision: The system has undergone numerous revisions to align with the EU's broader climate targets, such as the ambitious goal of reducing net GHG emissions by 55% by 2030, compared to 1990 levels, as outlined in the European Climate Law. It has also expanded its scope by progressively broadening its coverage to include more sectors and gases. A prime example of its proactive evolution is the introduction of ETS2, which will cover emissions from fuel for buildings and road transport, starting in 2027.

  The dynamic nature of the ETS is also created by a goal-based governance method: According to Kotzampasakis and Woerdman (2024), goal-orientation is built in Article 1 of the ETS Directive, in which there is "an obligation of result rather than an obligation of conduct, as it aims for a concrete outcome that contributes to the achievement of the EU's domestic and international emissions reduction commitments". Secondary (sub-)goals include, among others, cost-effectiveness and economic efficiency, protecting economic development and employment, preserving the integrity of the internal market and competition, as well as promoting technological improvements.

- **The Renewable Energy Directive (2009/28/EC)** establishes targets for increased renewable energy use, supporting cooperation between EU countries towards this goal. The EU

is pushing for the use of renewable fuels for shipping, such as hydrogen, ammonia and biofuels, which have a much smaller carbon footprint than traditional marine fuels.
The Renewable Energy Directive (RED) is a proactive law instrument because it sets binding targets (e.g., OECD 2025) and establishes a comprehensive framework for the promotion of renewable energy across the EU, addressing climate change, energy security and economic growth before these become critical crises. By introducing measures like streamlining permitting, establishing prosumer rights (Roberts 2016, Ritzel et al. 2022), and promoting sustainable energy in sectors like transport and industry, the RED proactively guides the EU's energy transition towards a greener future, aiming to prevent future energy-related issues through long-term strategic planning.

As a governance instrument, the RED sets mandatory targets for the share of renewable energy in the EU's energy mix, compelling member states to act and driving investment in renewable technologies. The directive encourages forward-looking planning by establishing rules and mechanisms for the expansion of renewable energy, including strategic planning for energy infrastructure. It promotes the use of renewables across various sectors, including electricity, heating, cooling, transport and industry, ensuring a comprehensive and integrated approach.

In addition, RED II includes provisions to empower "prosumers" (consumers who also produce energy) and improve consumer rights, increasing autonomy and facilitating the integration of renewables. By creating a stable and predictable legal framework, the RED provides the certainty that businesses and investors need to make long-term commitments to renewable energy projects.

Addressing Future Challenges:

The RED aims to pre-empt future challenges related to energy dependency, climate change and environmental degradation by promoting sustainable practices and energy efficiency. Examples of proactive measures include, e.g., streamlined permitting: The latest version (RED III) introduces mechanisms to streamline permitting procedures for renewable energy projects, which is a key barrier to faster expansion. The directive also highlights the importance of energy efficiency, a crucial element in reducing overall energy demand and ensuring a sustainable energy system. RED III also includes measures to promote the use of advanced biofuels and renewable fuels of non-biological origin, such as green hydrogen, anticipating future fuel needs.

- In the context of the 'Fit for 55' package, the co-legislators agreed on a new Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure. **The Alternative Fuels Infrastructure Regulation (AFIR)** is an EU law (Regulation (EU) 2023/1804) that sets binding targets for Member States to deploy electric vehicle charging and hydrogen refuelling infrastructure by 2030. A proactive national law, such as Finland's proposed Act on the Distribution of Alternative Fuels for Transport, provides the framework for implementing AFIR's requirements at the national level by defining administrative responsibilities, supervising infrastructure and establishing user-friendly standards for charging and payment.
The EU Regulation (AFIR) purpose is to ensure a sufficiently dense and interoperable network of alternative fuel infrastructure across the EU to support the transition to sustainable transport and achieve the 2050 climate neutrality goal. AFIR sets specific, binding national targets for deploying fast-charging stations for cars and vans, charging points for heavy-duty vehicles and hydrogen refuelling stations. AFIR sectoral coverage includes requirements for charging stationary aircraft at airports and provides shore-side electricity for ships and inland waterway vessels at ports.

  AFIR standards are user-friendly as they require clear pricing, user-friendly payment methods (like contactless payment), and access to data at charging and refuelling points. The implementation phase has proactive elements: AFIR promotes interoperability of infrastructure through the adoption of technical specifications and standards for data sharing, which removes implementation barriers. AFIR has been applicable since 13 April 2024, repealing the previous directive.

Recycling regulation

From a material perspective, especially the regulation focusing on the dismantling phase of a vessel, the recycling targets are interesting and important.

The EU Ships Recycling Regulation (SRR) ensures that ships are recycled in a sustainable way. It requires ships that are flagged under the EU member states to comply with environmentally safe ship recycling standards. It aligns with the Hong Kong Convention on ship recycling (COM 2025/322).

The EU Ship Recycling Regulation is a proactive law that prevents, reduces and eliminates the negative impacts of ship recycling on human health and the environment by requiring EU-flagged ships to be recycled in safe and sound facilities, managing hazardous materials on board through an Inventory of Hazardous Materials (IHM), and establishing a list of approved recycling yards. It builds upon the Hong Kong Convention by adding stricter requirements and serves as a globally recognised framework, establishing the foundation for responsible ship dismantling.

The ship recycling regulation applies to all ships flying the flag of an EU country and to non-EU-flagged vessels calling at EU ports or anchorages. Exceptions include warships, non-commercial government service vessels and ships below 500 gross tonnes. (EU SRR 2025; Regulation (EU) No 1257/2013)

Hazardous Materials Management is at the core of the regulation, as the regulation mandates the prohibition and restriction of certain hazardous materials on ships. It also requires an Inventory of Hazardous Materials (IHM) for every new ship, detailing the hazardous materials onboard. The SRR provides a list of compliant ship recycling facilities, both within and outside the EU, that meet stricter requirements for safe and environmentally sound practices. (EU SRR 2025; Regulation (EU) No 1257/2013)

Ship owner responsibilities require ensuring that their vessels are dismantled in an approved facility and for providing necessary information about the vessel, including its IHM and the relevant ship recycling plan. (EU SRR 2025; Regulation (EU) No 1257/2013)

The SRR is considered proactive, because it aims to prevent harm from occurring, rather than simply reacting to it. It focuses on the entire lifecycle of a ship to ensure safety and environmental protection. The regulation complements and helps accelerate the ratification of the International Maritime Organization's (IMO) Hong Kong Convention, which provides a global standard for ship recycling. The Hong Kong Convention is aimed at ensuring that ships, when being recycled after reaching the end of their operational lives, do not pose any unnecessary risk to human health and safety or to the environment.

The SRR is proactive, because it shifts the focus from managing waste after a ship is scrapped to prevent hazards and ensure safe practices throughout the ship's design and operational life, ultimately leading to responsible recycling. It also sets a high standard that encourages other regions to adopt similar measures for global ship recycling.

Directives in the national legislation

Member States must transpose the directive into national legislation. In Finland, the national authority, the Finnish Transport and Communications Agency (Traficom), supervises compliance with AFIR requirements by establishing consequences for non-compliance with the regulation. User focus is prioritised: payment terminals, digital interfaces and information provided to users ease the implementation and compliance. Old laws are repealed, such as Finland's Act on the Distribution of Alternative Fuels for Transport.

A few mentions about voluntary guidance instruments

The article *"Environmental Certifications: Towards a More Responsible Marine Shipping Industry"* gives an overview of the environmental standards and certification programmes aimed at encouraging ship owners and operators, industry providers and port authorities to adopt sustainable practices and reduce their environmental footprint. (ClearSeas, 2025)

Listed below are a few of the most important voluntary instruments:

- **EU Ecolabel.** The official European Union voluntary label for environmental excellence. The EU Ecolabel is a world-renowned, voluntary scheme promoting goods and services that clearly demonstrate environmental excellence, based on standardised processes and scientific evidence. How the EU Ecolabel works is set out in the official regulation (EC/66/2010). It is managed by the European Commission and Member States according to the priorities established in the Strategic EU Ecolabel Work Plan (2023).
- **Green Certifications**.
  - **EECS.** Each EECS® certificate is uniquely identifiable, transferable and, therefore, tradable. Each contains standard information on the source of the energy and its method of production.
  - **ISO 14001.** ISO 14001 is the internationally recognised standard for environmental management systems (EMS).

Market Competitiveness and Customer Demand

As sustainability becomes an increasingly significant concern for both consumers and corporate clients, companies that adopt green technologies early are likely to gain a competitive advantage (Pajunen, 2015). Several shipping companies have already positioned themselves as eco-friendly operators, aiming to attract environmentally conscious clients, particularly in sectors such as supply chain logistics and tourism (e.g., cruise lines). However, concerns regarding 'greenwashing' are growing; therefore, all sustainability claims, including those related to eco-friendliness, must be substantiated with verifiable evidence.

Many shipping lines are pursuing environmental certifications—such as Green Marine, ISO 14001 or the EU Ecolabel—to demonstrate their commitment to sustainability. While these certifications can enhance market appeal among eco-conscious clients, obtaining and maintaining them entails additional costs and operational adjustments.

Furthermore, numerous multinational corporations are setting ambitious sustainability targets and actively seeking partners that meet their environmental criteria. For instance, companies selecting shipping providers for logistics increasingly require their partners to reduce carbon footprints. This trend may become a major market differentiator and drive demand for green-certified vessels.

Sustainability regulations in practice

The shift towards sustainable shipbuilding, based on the present and future related regulations in the EU, has wide-ranging effects on shipbuilding and the shipping companies' operations, both in the short and long term. In practice, there is a need for the companies to either design new ships with eco-friendly features or retrofit existing vessels to meet energy efficiency and emission standards.

The shipyards and shipbuilders are embracing eco-design principles and lifecycle assessments to minimise environmental impact from construction through decommissioning. This includes using lighter and recyclable materials, such as advanced composites and recycled steel, which reduce vessel weight and fuel consumption.

Decisions promoting sustainability from different perspectives, such as optimised hull forms, high-performance insulation and glare-control glazing, are part of implementing the new requirements. Many shipyards have also invested in green infrastructure, renewable energy for manufacturing and waste-reduction systems. Additionally, sustainability certifications, for example ISO 14001, are becoming standard, signalling compliance and enhancing market reputation.

Retrofitting ships for compliance with IMO regulations and EU regulations require advanced engineering, often leading to longer dry-docking times and operational disruptions. However, such investments will improve fleet sustainability and keep companies competitive in the long term and quite often are the necessity to stay in a market.

Beyond technical measures, collaboration and innovation are central to meeting regulatory demands. Companies are participating in the R&D projects, for example piloting zero-emission vessels, assessing environmental impacts, and developing circular economy solutions into the industrial supply chain. These efforts align with broader ESG commitments, which now influence financing and chartering decisions.

The adoption of sustainable practices and the shift to greener technologies can also position shipping companies for long-term success. As regulations continue to tighten globally, particularly in the EU, being ahead of the curve will offer a strategic advantage. It may also help to future-proof the business against any sudden changes or tougher restrictions on emissions. In addition, transparent reporting practices are vital for the companies where demand of sustainability is increasing from the customer side. Furthermore, companies need to continuously invest in R&D to stay ahead of evolving environmental regulations. Innovations in fuel technology, propulsion systems, energy efficiency and digitalisation will be key to remaining competitive in a greening marine sector.

After the initial investment, fuel savings from energy-efficient technologies can be significant. Moreover, lower emissions might help companies avoid future carbon pricing increases or penalties. In addition, ships that are built with sustainability in mind or are retrofitted to be more energy-efficient may have a higher resale value. These vessels are less likely to be scrapped early, and their compliance with future regulations may make them more attractive on the secondary market.

From the perspective of subsidies and incentives, governments and international bodies provide subsidies, incentives and financial support to promote the transition to sustainable practices. For example, the European Investment Bank (EIB) offers financing options for green projects, such as sustainable shipbuilding and retrofitting. (EIB, 2025)

From the perspective of maritime transport, the adaptation of sustainability regulations to daily operations to reduce emissions and increase efficiency in the operation phase of a ship means changes and measures, which include the following:

- Route Optimisation. Companies are adopting more advanced digital systems that use AI and big data to optimise shipping routes for fuel efficiency. This includes adjusting weather patterns, sea currents and the most efficient paths between ports.
- In response to emission reductions requirements, many shipping lines are adopting slow steaming practices, where ships sail at lower speeds. This reduces fuel consumption and lowers emissions but also impacts turnaround times.
- By maximising cargo load and reducing underutilised trips, shipping companies can improve fuel efficiency and reduce carbon emissions per tonne of cargo shipped.
- Some companies have begun positioning themselves as environmentally responsible carriers or cruise ships. These companies are investing heavily in sustainable technologies to achieve, for example, net zero goals.
- Customers can also require their logistics partners, or from the passenger ships, to meet specific sustainability standards. Companies that fail to comply may lose business to those that have invested in cleaner technologies. This has resulted in increased demand for green shipping services.
- Ports are crucial collaborative partners for shipping companies. Some ports in the EU are creating green corridors, which are designated routes where vessels can use low-emission

technologies, like LNG bunkering stations. Shipping companies that operate in these corridors benefit from reduced emissions and often financial incentives.

Companies that are early adopters of green technologies may be able to capture new business from sustainability-conscious customers, where customers increasingly demand greener shipping solutions.

Adopting sustainability regulations significantly reshapes the economics and businesses of shipbuilding. Compliance with IMO and EU frameworks, such as the Carbon Intensity Indicator (CII), Energy Efficiency Existing Ship Index (EEXI) and the EU Emissions Trading System, introduces new cost structures. Carbon pricing under the EU ETS, for example, can add hundreds of thousands to millions of euros annually for large vessels, making emissions a direct financial liability. This drives shipyards to invest in energy-efficient designs, alternative fuel compatibility (LNG, methanol, ammonia) and green technologies early in the build process to maintain competitiveness and avoid costly retrofits.

Failure to comply with regulatory requirements may result in diminished charter rates, reduced asset resale values, exclusion from ESG-sensitive markets and reputational harm. Conversely, proactive compliance can facilitate access to green financing, government subsidies and premium contractual opportunities, thereby positioning firms as strategic partners in the transition toward a decarbonised maritime economy.

Sustainability compliance demands novel expertise. Shipyards must integrate multidisciplinary knowledge, covering alternative propulsion systems, fuel-flexible engines, lifecycle environmental assessments and advanced materials engineering. Skills in digitalisation (e.g., digital twins for performance modelling), emissions monitoring and ESG reporting are now essential.

Workforce training in sustainable shipbuilding practices, hazardous material handling and ISO standards is critical. Collaboration with technology providers and classification societies has become a strategic necessity to ensure compliance and minimise retrofit costs. In short, sustainability regulations are transforming shipbuilding from a traditional engineering domain into a high-tech, environmentally driven industry, requiring continuous innovation and specialised talent.

Preparing for future sustainability legislation

The EU Green Deal, IMO regulations and other evolving global and regional frameworks will shape the future of shipbuilding. Preparing for compliance will require anticipating changes and understanding the regulatory landscape.

Preparing for future sustainability regulations is crucial for shipbuilding companies, as the maritime industry undergoes rapid transformations due to stricter environmental regulations and the growing pressure to reduce carbon emissions. In addition, the pressure and customers' demand for sustainability are also likely to increase in the near future.

Actions:

- Set up a dedicated team or task force to monitor changes in maritime environmental regulations (such as the IMO 2050 carbon reduction targets, EU ETS and MARPOL amendments). This team should stay informed about evolving legislation and begin working on compliance strategies.
- Evaluate existing fleet and establish a plan for how the company will meet the upcoming Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) regulations. For new vessels, ensure they exceed minimum regulatory standards.
- Pursue certifications, such as ISO 14001 (Environmental Management Systems) or Green Marine Certification for the shipyard. This not only prepares the company for regulation but also helps with branding and marketing.
- Develop reporting systems for carbon emissions, fuel consumption and other sustainability metrics to meet EU monitoring, reporting and verification requirements. Being ahead of the compliance curve will reduce the administrative burden later.

To stay competitive and comply with future regulations, the company needs to be proactive and start investing in R&D to develop the next generation of sustainable technologies. This is crucial, not only for meeting future regulations but also for positioning the company as an industry leader. This will also ensure they are ahead of the curve in terms of innovation and reputation. This is a huge business opportunity when stricter legislation is expected to be implemented in the near future. The companies which start the development work for more sustainable business now are the forerunners and can achieve the benefits of the transition.

Actions:

- Start designing vessels for sustainability, where the vessels are optimised for low emissions, energy efficiency and alternative fuel usage (such as LNG, hydrogen, ammonia and biofuels). Even if technology is not mainstream yet, being a pioneer will create a competitive advantage. As an example of hybrid propulsion systems (battery + fuel) and wind-assisted propulsion technologies (like sails or rotors). In addition, renewable energy integration (e.g., solar panels, wind energy) for auxiliary power will be more viable in the future.
- Develop ships with retrofit potential in mind. This means designing vessels that can easily be upgraded with future technologies, like green fuel systems (hydrogen, ammonia), advanced batteries or carbon capture systems, without requiring major overhauls.
- Partner with universities, maritime research labs and organisations like the European Maritime Safety Agency (EMSA) to explore new technologies. Collaboration can help reduce R&D costs and speed up the development of innovative solutions.

As the market for shipping shifts toward greener technologies, the company must be prepared to manage both risks and opportunities. A comprehensive business strategy is essential to navigate this transition.

Actions:

- Use scenario planning to model how different regulatory outcomes could affect your business.
- Prepare for potential supply chain disruptions.
- Develop a financial plan for transitioning to more sustainable shipbuilding. This includes setting aside capital for R&D, retrofitting and new technologies, but also considering new funding mechanisms, like green bonds or EU subsidies, for eco-friendly projects.
- Explore sustainable financing options, such as green loans, which offer favourable interest rates for companies investing in sustainable technologies.
- Regularly conduct cost-benefit analyses of implementing sustainability measures. For example, while retrofitting ships to meet future regulations might be expensive, doing so early can prevent larger fines or penalties and open up new revenue streams from environmentally conscious clients.
- Sustainability is not just about the ships themselves; it also involves the entire supply chain. As regulations and customer demands shift, your company's suppliers and partners must also be aligned with sustainability practices.
- Source sustainable materials for shipbuilding, such as low-emission steel, non-toxic paints and eco-friendly insulation materials. Establish long-term relationships with suppliers who are committed to sustainability.
- Ports are central to the decarbonisation of the shipping industry. Collaborate with EU ports that are investing in sustainability.
- Join industry groups such as the Clean Shipping Coalition. Collaboration with other shipbuilders and key stakeholders (port authorities, fuel providers) will help share knowledge, reduce costs and create a more unified approach to sustainability.

As the industry transitions, your workforce needs to be equipped with the skills to handle new technologies and regulatory demands.

Actions:

- Offer training programmes focused on sustainable ship design, alternative fuel systems and green technologies. This will ensure your team is ready to execute new projects and adapt to regulatory changes.
- As the maritime industry becomes more tech-driven, attracting top talent will be crucial. Invest in engineering education and green innovation teams to ensure the company can take on R&D projects and lead the way in sustainable shipbuilding.

Sustainability is increasingly becoming a key differentiator for customers, so it's vital that the company communicates its efforts effectively.

Actions:

- Position your company as an eco-friendly leader in the industry. Use your certifications, sustainable designs and achievements in compliance with green regulations as part of your branding. Be sure that you are not greenwashing, instead everything you say is based on real facts.
- Educate customers on the environmental benefits of your ships and technologies. Highlight the long-term cost savings, such as fuel efficiency and lower maintenance costs, which come with sustainable designs.

By taking these proactive steps, shipbuilding companies can not only ensure they meet future legislation but also gain a significant competitive advantage in the growing green maritime market.

Summary

In this report, we have presented regulatory instruments related to sustainable shipbuilding. As is known, shipbuilding is a complex domain and global industrial sector; because of this, the legislation is wide and multifaced as well. The maritime sector is also shaped by various international agreements, standards and voluntary measures. In addition, economic incentives and informational guidance likewise play a significant role in advancing sustainability objectives.

Policies and regulations promoting the sustainability of transition are continuously evolving within the European Union. The purpose of this report was to provide ship designers, engineers, subcontractors and shipbuilders with an overview of legislation and international agreements related to sustainable shipbuilding. As the regulatory environment is in constant flux, this report provides only a snapshot of the current situation.

The S4M research project focuses on the design and construction phases of ships. The project focuses especially on interior materials and products and is carried out in collaboration with companies that manufacture these products. These companies are interested in advancing their operations and exploring how sustainability can be more effectively integrated into design and shipbuilding processes.

Discussion

The sustainability crisis, encompassing climate change and biodiversity loss, already necessitates not only efforts to halt these developments but also measures for adaptation. The consequences of climate change are already evident in maritime transport. Intensifying storms and sudden weather fluctuations must be considered in ship design and construction, as well as in the organisation of maritime operations.

The sustainability transition requires systemic changes across all sectors of society, including shipbuilding and the global organisation of maritime transport. This transformation is accelerated by various international agreements and regulatory instruments.

The European Parliament and Council have emphasised the need to accelerate the sustainability of transition, implement circular economy practices, enhance material circulation and security of supply, and update related legislation. Maritime transport, ship design and shipbuilding are governed by a complex framework of international agreements and legislation.

From a regulatory perspective, ensuring maritime safety remains the primary objective. In the context of the sustainability transition, the most significant regulatory action focuses on the reduction of emissions from maritime transport. Therefore, this is also the principal area of development for shipping companies in their R&D efforts.

Given the global situation, there is also growing interest in improving material circularity. Securing access to raw materials will remain critical in the future. Ships, as large-scale products, are increasingly viewed as material banks. It is anticipated that, perhaps in the near future, measures will be taken to ensure that valuable recyclable materials recovered from ships remain within the European Union.

From a business perspective, the sustainability transition should be approached as an inevitable process. Regulatory measures will continue to be tightened, and new requirements are expected. Leadership in developing sustainable solutions can create substantial business opportunities in the future. Moreover, customer-driven pressure of adopting sustainable practices is increasing. In the near term, sustainable operations may become a prerequisite for remaining competitive and maintaining market presence.

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