
SAILING TOWARD SUSTAINABILITY: LEGAL FOUNDATIONS FOR RESPONSIBLE MARITIME DEVELOPMENT

Monika G, School of Law, Vellore Institute of Technology (VIT) University, Chennai Campus, Vandalur Road, Kelambakkam, Chennai- 600127, India

Vanmathi M, Assistant Professor, Vellore Institute of Technology (VIT) University Chennai Campus, Vandalur Road, Kelambakkam, Chennai- 600127, India

ABSTRACT

The world shipping industry is an integral part of international business; however, it experiences more and more pressure concerning environmental protection and technological innovations. In this regard, the present study explores the use of green technology and autonomous systems in maritime operations as a dual approach towards ensuring both sustainability and efficiency. The report emphasises the necessity of innovation to be able to cope with the challenges posed by the industry, namely, regulation, economy, and technology. Technologies that are used in maritime operations to reduce the environmental footprint include green fuels such as LNG and hydrogen, innovative vessel design and emission reduction systems. All these technologies contribute greatly to achieving international regulations such as IMO 2020 and the Paris Agreement. Therefore, apart from reducing the environmental impact, they also help the maritime industry to comply with the global decarbonization policy. At the same time, autonomous systems based on artificial intelligence and analytics help to improve navigation, port operations, and supply chain management¹.

However, some of the key issues that still exist and need to be tackled are high costs of implementation, risks of technology, and the need for regulation to be harmonized internationally. This paper is going to cover some of the most important areas in the maritime sector which have managed to integrate sustainability concepts in their practices, giving out relevant information regarding the issues mentioned above. It must be stated that the importance of cooperation between states and policy making for sustainability purposes is emphasized in this paper.

Keywords: Maritime Social Sustainability, Ship Flag, Shipping Business, International Survey, Green Technology, Emissions Reduction.²

¹https://www.researchgate.net/publication/386720449_Advancing_sustainability_and_efficiency_in_maritime_operations_Integrating_green_technologies_and_autonomous_systems_in_global_shipping

² <https://www.imo.org/en/OurWork/Environment/Pages/Default.aspx>

1.0 Introduction

One can argue that maritime industry has been extremely important in shaping the way people have developed throughout the history in terms of connections between countries, trading and creation of employment. At the same time, there is a significant impact of maritime activities on the environment because it leads to greenhouse gas emission, marine pollution, overfishing, habitat destruction and influence of climate change on the coasts.

Nowadays, the development of maritime industry should not be viewed only through the prism of growing number of ships, ports, and trade. It should be associated with the sustainable use of marine resources and protection of ocean's ecosystem.³ That is why sustainability has become an important component of the future maritime industry which involves the use of alternative fuels, improvements in energy efficiency, reduction of pollution, improvement of maritime safety and protection of marine biodiversity.

Thus, the sustainable maritime development needs to be achieved by means of joint efforts of governments, industries, science and locals. The help of technological innovations and proper policies will allow to minimize the impact on the environment during the further development. This paper is dedicated to the investigation of the issue of connection between maritime development and sustainability.⁴

2.0 Contemporary Challenges in Maritime Safety and Security

In the dynamic world of marine security and risk assessment, there is need for use of modern technologies, gadgets and sensors which enhance safety measures and surveillance capacities. The integration of Automatic Identification System (AIS) that tracks the position of vessels in order to avoid collisions and radar systems that have the ability to identify vessels and analyse different types of risks in varying weather conditions constitutes the basis of maritime safety standards. CCTV cameras assist in surveillance of the important maritime structures while near shore and satellite imagery cameras help in understanding the movement of the vessels and identification of anomalies. Remote sensing technology such as satellite imagery assists in monitoring the vessels in the sea and identification of any criminal activities. VMS guarantees

³ <https://worldfinancialreview.com/sailing-towards-sustainability-the-role-of-maritime-regulations-in-environmental-and-climate-protection/>

⁴ A sustainable maritime supply chain framework: an overview for academics and practitioners - ScienceDirect

compliance of fishing vessels while GNSS technology enhances navigation and planning of routes. VHF radios make it possible for effective communication between the vessels and maritime officials.⁵

Integrating the technologies will help the researchers as well as the other stakeholders involved in maritime industry to improve their capability in terms of monitoring, analysing, and responding for developing a safer and more secured maritime domain in spite of the challenges posed by the conventional and automated ships. The issue of security remains important in terms of maritime piracy as highlighted in the recent Contribution where there was an effort to design a Bayesian network framework for quantifying the hijacking risk. The importance of predicting the number of hijackings together with their impacts through surveillance data, especially, the AIS data is important for improving the accuracy of the models. This demonstrates the effectiveness of the Bayesian network in the field of maritime security.⁶

3.0 Adoption of new technology in the Maritime transport sector

The field of maritime transportation technology keeps advancing and innovations are created to make the process efficient, safe and sustainable. Infrastructure development is required for the development of maritime transportation technology. Innovations usually require improvements in the port and terminal infrastructure. Some examples include the construction of shore power facilities to power vessels and use of autonomous mooring technology to allow ships that can operate independently. The field of marine transportation is highly regulated and innovations have to satisfy certain international and national standards and laws. Adherence to cybersecurity, safety and environmental regulations is of paramount importance for innovative maritime transportation technologies. Reliable communication is important for the transmission of information from ships to ports and other entities involved in the supply chain of maritime transport. Satellite communication and 5G networks provide remote monitoring and control of ships. Innovation integration requires professionals who will be able to operate them.⁷

⁵ https://www.dnv.com/maritime/maritime-forecast/?utm_source=microsoft&utm_medium=paid_display&utm_campaign=ma_26q3_glob_publ_maritime_forecast&utm_id=701bG00000jKA1KQAW&msclkid=7c9f73c4a9f714b2e0fc196063b64492

⁶ Review on Sustainable Development Goals in maritime transportation: current research trends, applications, and future research opportunities | Environmental Science and Pollution Research | Springer Nature Link

⁷ Advancing sustainability and efficiency in maritime operations: Integrating green technologies and autonomous systems in global shipping

Training programs and accreditation programs are very vital in ensuring that the workers within the marine sector, port staffs, and others acquire the required knowledge and skills in using the technologies that are emerging. The adoption of advanced technologies requires lots of investment by the maritime shipping industry. This entails the ship owners, ports, and logistics organizations. There is need for investment to support research, trials, and wide application in order to fast track the adoption of advanced technologies.⁸ There are various organizations that would be required to collaborate in order to adopt advanced technologies in the maritime shipping industry. The organizations include ship operators, ports, logistics firms, technology firms, and regulatory bodies. Collaboration will solve integration challenges as well as facilitate technological advancement. According to the International Council on Clean Transportation, there are various strategies and technologies geared towards enhancing the efficiency of ships, such as wind propulsion, air lubrication, and special ship coating technologies. These are some of the technologies that have the capability to minimize carbon dioxide emissions.⁹

4.0 Legal and Regulatory Environment For Indian Shipping

4.1 The Merchant Shipping Act (1958)

The below mentioned is a specific regulation related to ship registration, maritime safety, seafarer welfare and training, and prevention of marine pollution. The same assists India in ratification of several international maritime conventions.¹⁰

4.2 The Admiralty Act, 2017

This law amended the Indian admiralty law by repealing the earlier British laws, granting admiralty jurisdiction to the high court of coastal states, and providing for maritime liens, ship arrests, claims for damages, charter parties, and towage. The Indian Ports Act of 1908 covers the minor ports while the Major Authorities Act of 2021 modernises the management of ports through decision-making and PPPs.¹¹

⁸ <https://www.mdpi.com/2077-1312/12/10/1728>

⁹ https://ec.europa.eu/clima/policies/transport/shipping_en

¹⁰ <https://maritimeindia.org/legal-and-institutional-challenges-for-ensuring-sustainable-marine-fisheries-in-india/>

¹¹ Review on Sustainable Development Goals in maritime transportation: current research trends, applications, and future research opportunities | Environmental Science and Pollution Research | Springer Nature Link

4.3 Institutional And Regulatory Framework For Maritime Governance In India.

A structure of institutions in charge of carrying out the functions in marine administration exists in addition to the legislative actions. The institutional framework will guaranty that Indian laws and policies are developed in compliance with international norms. The essay that follows makes an effort to go over a few facets of the Indian maritime institutions system.¹²

4.4 Ministry of Ports, Shipping, and Waterways (MOPSW)

Ministry of Ports, Shipping and Waterways (MoPSW) was formerly titled as Ministry of Shipping, and is the administration responsible for the development of national maritime policy. It plays an important role in the development of port facilities, expansion of terrestrial and coastal marine traffic and standard adherence of international shipping rules.¹³

4.5 The Director General of Shipping (DGS)

The main regulating body responsible for managing the waters comes through the Directorate General of Shipping under the MoPSW. The Director General of Shipping (DGS) located at Mumbai is responsible for enforcement of maritime agreements, and managing Indian ships.¹⁴

5.0 Role of Governments and International Organizations

Governments and international organizations try to ensure the sustainable development of the maritime industry through the introduction of legislation and regulations concerning such aspects of ship operations as safety of the ship, environmental protection, waste management, employment, and conservation of the marine species. It is important to cooperate internationally as the ships sail from one country to another and also in the international water area.

It is necessary to set policies focused on the green technologies application, control, ports construction, and sanctions for pollution of the sea. Governments must allocate money for research and development, encourage green technologies financially, and train specialists.

¹² https://commons.wmu.se/cgi/viewcontent.cgi?article=1093&context=lib_reports

¹³ Advancing sustainability and efficiency in maritime operations: Integrating green technologies and autonomous systems in global shipping

¹⁴ The Way Towards Sustainable Oceans – Centre for Maritime Law

6.0 Social and Economic Benefits

Sustainable development of the maritime industry can create prospects for economic development in the future. Modernization of ports and ships can increase the efficiency of shipping and provide job opportunities in such sectors as engineering, renewable energy, logistics, environmental conservation, and marine research.

Sustainable development is beneficial for coastal societies. Sustainable fishing, marine tourism, and coastal conservation will bring profits without harming the environment. Protection of labour rights and safety are also important aspects since seafarers and port workers often work under difficult conditions.

7.0 Primary Responsibilities:

- Ship registration, inspection and certification.
- Licensing, welfare and dispute settlement in the maritime industry.
- Implementation of SOLAS, MARPOL, STCW and other conventions.
- Guidelines concerning shipping safety, pollution prevention and maritime training institutions.
- Ship construction standards and audit.¹⁵

8.0 Green technologies in maritime shipping

8.1 Alternative Fuels

Alternative fuels are now being considered as a solution for lowering GHG emissions and achieving sustainability goals. Traditional fuels used in shipping such as heavy fuel oil [HFO] lead to serious environmental pollution, releasing huge amounts of CO₂, sulfur oxides [SO_x] and nitrogen oxides [NO_x]. Alternative fuels like liquefied natural gas [LNG], hydrogen, and biofuels provide more environmentally friendly and efficient solutions, though they are

¹⁵ <https://www.tandfonline.com/doi/full/10.1080/15487733.2025.2472466#d1e354>

associated with several difficulties.

8.2 Liquefied Natural Gas [LNG]

LNG is currently one of the most popular alternative fuels in the maritime industry. It allows reducing SOx emissions by 99%, NOx emissions by 85–90%, and CO₂ emissions by 25% compared to HFO. LNG-fuelled vessels, for instance, CMA CGM's ships prove that LNG can be effectively used in order to lower the number of emissions. At the same time, the use of LNG raises several problems, among which methane slip, a powerful GHG.¹⁶

8.3 Hydrogen

Hydrogen is used to demonstrate how a clean energy source such as hydrogen can be adopted to replace polluting sources of energy such as fossil fuels. Since burning hydrogen results in water vapour formation, it makes the process useful in the attainment of decarbonization goals. For example, the ferry project in Norway is one of the instances in which hydrogen is put into practice.

8.4 Biofuels

Biofuels that are obtained from living organisms such as algae, used oils, and agricultural wastes offer an alternative that is renewable and easily available. Such fuels can be applied in current engines without major changes, thus avoiding expensive conversions. Additionally, biofuels provide reductions in greenhouse gases on a lifecycle basis, depending on the process of production. Nevertheless, their limited availability is due to competition with food production.

8.5 Advantages and Disadvantages

Using alternative fuels comes with many advantages, including the fact that it helps comply with environmental laws, decreases dependence on fossil fuels, and supports the general decarbonization trend across the globe. However, the maritime sector is confronted with challenges associated with using these fuels, including the high cost of initial investment,

¹⁶ <https://nititantra.com/wp-content/uploads/2025/06/Indias-Blue-Economy-and-Maritime-Law.pdf>

regulatory risks, and the development of the infrastructure required.¹⁷

9.0 Supply Chain Integration

The application of autonomous technologies is becoming critical in supply chain integration processes, facilitating efficiency, transparency, and stock management. Maritime logistics are thus integrated into supply chain operations through these technologies to facilitate efficient collaboration among various modes of transport contribution of Autonomous Technologies to Logistics AI platforms, robotics, IoT devices, and other autonomous technologies have helped simplify logistics operations through automation and provision of timely information. Some of the applications include the use of robotic systems in automated warehouses for efficient stock management and the use of AI in predicting demand patterns. In maritime logistics, autonomous ships and intelligent ports help in the efficient delivery of goods.¹⁸

10.0 Transparency and Traceability

Another critical advantage of autonomous technologies is their increased level of transparency. Blockchain technology combined with IoT devices ensures traceability of cargo movements through maintaining an immutable record that allows for real-time monitoring and holds people accountable. For instance, Maersk's TradeLens platform applies blockchain technology for document automation and increasing transparency in the supply chain. It minimizes the probability of errors, fraud, delays and helps to establish trust between the parties.¹⁹

11.0 Inventory Management

In addition, autonomous systems provide an opportunity for improved inventory management due to more accurate data on the stock levels and changes in demand. Through the use of AI-based platforms, businesses can better predict demand patterns and manage their inventories accordingly. For instance, the way Amazon uses autonomous robots and AI for inventory management serves as a benchmark for logistics efficiency. From the point of view of shipping companies, these technologies enable them to operate based on the customer's needs.

¹⁷ A sustainable maritime supply chain framework: an overview for academics and practitioners - ScienceDirect

¹⁸ doc20251215731201.pdf

¹⁹ <https://sinay.ai/en/maritime-sustainability-policies-and-global-initiatives-for-a-greener-future/>

12.0 Pros and Cons

Autonomous technologies applied to supply chains provide a number of advantages, which include lower costs of operations, high level of customers' satisfaction, and better sustainability. At the same time, there are issues that should be solved such as expensive implementation, cybersecurity issues, and regulatory issues. The complexity of working with different stakeholders and systems requires the use of standardized approaches and collaborative work. With the continuous development of autonomous technologies, their role in supply chain integration will become even greater. Thus, maritime industry may find itself at the forefront of new logistics system.²⁰

13.0 Recommendations for Policy and Collaboration

For a sustainable and autonomous maritime sector to be realized, appropriate policy structures and collaboration on an international level are important. There needs to be a collaboration between governments, industry players, and regulatory agencies to come up with a roadmap for green and autonomous technologies.²¹

14.0 Strategies for Facilitating International Collaboration

The main challenges facing the realization of green and autonomous shipping include regulatory fragmentation, technological challenges, and differences in infrastructure. Institutions such as the International Maritime Organization [IMO] need to continue playing a pivotal role in international collaborations. The Global Industry Alliance [GIA] for Low Carbon Shipping serves as a platform for such cooperation in order to share ideas and invest jointly in green technologies. Also, regional collaborations have a great role to play in achieving sustainability. An example is the European Green Deal, which provides for maritime sustainability measures. Such frameworks should be expanded to cover developing countries as well.

15.0 Policy Frameworks for Encouraging Sustainability and Adoption of Technologies

In order to encourage companies in adopting sustainable practices, governments should design

²⁰ Sustainability Challenges in Maritime Transport and Logistics Industry and Its Way Ahead

²¹<https://www.bing.com/search?q=MARITIME+PROGRESS+AND+SUSTAINABILITY&form=ANNT11&refig=6aa17d3edcf54248acfd90c2e3cb6493&pc=SCOODB&ucpdpc=UCPD>

policy frameworks to encourage the use of green technologies and automation. Governments may offer tax breaks and subsidies to the companies for the implementation of alternative fuels, renewable energy systems, and digitization. For example, Japan's Green Innovation Fund offers financial support to the projects related to hydrogen and ammonia propulsion, and it can serve as an example to the rest of the world. The mandatory emission reporting and carbon pricing mechanism, such as Emissions Trading System in the EU, may also serve as the incentive for innovation.²²

16.0 Standardization and Cybersecurity

In order to ensure a rapid implementation of technologies globally, it is necessary to pay attention to the standardization of technologies and protocols. It will make it easier to implement green and automation technologies and comply with regulations. The cybersecurity framework is essential in the protection of sensitive data. Thus, addressing these issues will help the maritime industry become sustainable and automated, and therefore stay as an important part of international trade.²³

17.0 Approach to Sustainable Maritime Development by Law

Legal approach to sustainable maritime development would entail the use of an equilibrium in respect of economics, environment, maritime safety and seafarers' welfare. Law of the sea would become the most important law in respect of regulation of vessels, vessel porting, pollution and allocation of responsibilities of the stakeholders. The Indian law that regulates such matters as ship registration, maritime safety, seafarers' rights and maritime pollution is the Merchant Shipping Act of 1958. Another important legislation in this context is the Admiralty (Jurisdiction and Settlement of Maritime Claims) Act, 2017.²⁴

Legal aspect of environmental sustainability is also quite relevant in the context of maritime law. Maritime authorities of India should implement international maritime regulations in the sphere of safety, pollution prevention, training of crews and environmental protection. The use of international conventions in the national maritime laws demonstrates the importance of international maritime law for the domestic shipping laws and practice. These conventions

²²<https://www.pib.gov.in/PressReleasePage.aspx?PRID=2105136>

²³ Press Release Page | Press Information Bureau

²⁴ <https://nititantra.com/wp-content/uploads/2025/06/Indias-Blue-Economy-and-Maritime-Law.pdf>

include the International Convention for the Safety of Life at Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW).²⁵ The last issue concerning the modern developments in the maritime field refers to the development of green technologies and autonomous vessels, which creates a number of new legal problems. Such problems as liability in case of accident with autonomous system, cyber security issues, environmental liabilities, safety requirements, data protection, and responsibilities for making decisions in autonomous systems need to be regulated by law. As was mentioned above, one of the main barriers to the safe implementation of maritime autonomous technologies is cybersecurity threat and absence of corresponding regulations. Therefore, it is crucial that maritime law should be developed.

It can safely be said that for sustainable future maritime practices, it will not only be about the technology but will also have something to do with the implementation of the regulations concerning the laws. It becomes very important for the government and maritime organizations to modify the laws according to the technological developments, otherwise, the technology may adversely affect the environment.²⁶

Conclusion

The marine industry is at a critical crossroads affected by the needs for sustainability and innovation. This particular article reviewed the significance of green technologies and autonomous systems for tackling the environmental and operational challenges faced by the marine industry. Moving from the use of alternative fuels and environmentally friendly designs of ships to the use of AI-based autonomous systems and intelligent ports, the marine industry proves that it is ready to change its future through innovations. The key findings demonstrated the need for significant investment in alternative fuels like hydrogen, ammonia, methanol which would ensure that the industry operates more efficiently than before due to less environmental impact compared to traditional fossil fuels. Autonomous systems have revolutionised the maritime logistics industry in terms of efficiency and safety. Navigation systems that utilize AI, predictive analytics and blockchain to provide supply chain visibility and improve customer satisfaction by minimising delays and resource management are among

²⁵ <https://www.ljmu.ac.uk/study/courses/postgraduates/2026/37093-international-maritime-law-and-sustainability-llm>

²⁶ Sustainability in the Maritime Industry—More than “Life Below Water” – Clear Seas

those revolutionary innovations that are changing the face of this industry. Not only do these innovations solve the current challenges within the industry, but also make it one of the pioneers of innovations in the world. Creating appropriate policy frameworks, working together internationally, investing in infrastructure and education will be essential to ensure sustainable development and the transition of the industry into an industry of the future. The incorporation of sustainability and innovation is becoming inevitable in the coming decades and it is recommended that all stakeholders consciously decide to embrace this change to introduce innovations and collaboration in the industry.²⁷

²⁷ Sustainability Challenges in Maritime Transport and Logistics Industry and Its Way Ahead