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Technology advancement and international law in marine policy, challenges, solutions and future prospective

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The use of technology and international law in marine policy is becoming increasingly vital as we seek to address the challenges facing our oceans. Technology has revolutionized our ability to monitor, understand, and manage marine ecosystems, providing valuable tools for data collection, analysis, and decision-making. International law, ocean governance ensuring marine environment represented by the frameworks such as the United Nations Convention on the Law of the Sea (UNCLOS), plays a crucial role in governing the use of technology and establishing guidelines for the sustainable management of marine resources. This paper explores the intersection of technology and international law in marine policy, highlighting the transformative impact of technology on our understanding of the oceans and the legal frameworks that shape our approach to marine conservation. It examines the benefits of technology in enabling evidence-based decision-making and fostering international collaboration, while also addressing the legal and regulatory complexities that arise. The paper emphasizes the need for ongoing dialogue and the development of international legal frameworks to adapt to emerging technologies and discourse ethical considerations, and by harnessing the power of technology and international law, we can work towards effective marine policies that ensure the conservation and sustainable use of our oceans for future generations.

KEYWORDS

marine policy, technology, international law, environmental protection, UNCLOS5

1 Introduction

Marine policy plays a crucial role in the sustainable management of the world's oceans, which are vital to the health of our planet and its inhabitants. In recent years, the intersection of technology and international law has emerged as a powerful force in shaping marine policy and addressing the numerous challenges facing our oceans (Baker et al., 2023). The rapid advancement of technology has not only provided new tools and approaches to monitor and understand marine ecosystems but has also posed unique legal and regulatory challenges that require international cooperation. The role of technology in marine policy has been transformative, enabling scientists, policymakers, and conservationists to gather vast amounts of data on marine environments and species. Satellite imagery, remote sensing technologies, and sophisticated underwater monitoring systems have revolutionized our understanding of the oceans and their interconnected ecosystems (Olabi et al., 2023; Subramanian et al., 2023). These technological advancements have facilitated the development of evidence-based policies and management strategies to address issues such as overfishing, habitat destruction, pollution, and climate change (Yu et al., 2023).

Furthermore, technology has fostered international collaboration by enhancing communication and data sharing among nations. Real-time information exchange and collaborative research efforts have become critical in addressing transboundary challenges, such as the conservation of migratory species and the establishment of marine protected areas (Blasiak et al., 2023). Technology has enabled the development of platforms and networks that facilitate dialogue, coordination, and the harmonization of policies and legal frameworks across borders (Quevedo et al., 2023; Sardá et al., 2023). However, the increasing reliance on technology in marine policy also brings forth legal and regulatory complexities. As new technologies emerge, questions arise regarding their ethical use, potential impacts on marine ecosystems, and the need for international governance. Issues such as data ownership, privacy, intellectual property rights, and liability for damages caused by technology-driven activities in the marine environment require careful consideration and international legal frameworks. International law plays a fundamental role in guiding and governing the use of technology in marine policy. Existing legal frameworks, including the United Nations Convention on the Law of the Sea (UNCLOS), provide a basis for cooperation and regulation in areas such as marine pollution, fisheries management, and the protection of marine biodiversity (Olabi et al., 2023). However, as technology evolves, there is a need to adapt and expand these legal frameworks to address emerging challenges. The development of various technologies has significantly impacted marine policy, reshaping regulations and protection efforts. Innovations such as GPS and satellite technology have enabled better tracking and monitoring of fishing vessels, leading to stricter compliance with fishing regulations and curbing illegal fishing practices. Furthermore, sonar and underwater acoustics have revolutionized marine research and exploration, but their potential impact on marine life has prompted the establishment of guidelines to minimize disturbances to marine mammals. Seabed mining technology has raised concerns about environmental damage, necessitating the formulation of new regulations and international agreements to govern deep-sea mining operations responsibly to establish new international agreements and protocols to address the legal and ethical dimensions of technology in marine policy. The regulation of emerging technologies such as deep-sea mining, marine biotechnology, and autonomous vehicles. Additionally, initiatives are being undertaken to strengthen international cooperation and coordination in the use of technologies for monitoring, surveillance, and enforcement in the maritime domain (Guelker, 2023; Pentz and Klenk, 2023).

The role of technology and international law in marine policy is becoming increasingly intertwined and influential. Technology provides valuable tools and data for evidence-based decision-making and promotes international collaboration. However, it also poses legal and regulatory challenges that necessitate ongoing dialogue and the development of international frameworks. By harnessing the power of technology and establishing robust legal mechanisms, striving towards a more effective marine policy that ensures the sustainability and protection of oceans for future generations (Chen et al., 2023). With boundless possibilities, the integration of technology and international law within marine policy stands as a pivotal tool for addressing the ever-evolving challenges of our oceans. However, the successful implementation of technology and international legal frameworks in marine policy is not without obstacles (Moore, 2021). This article explores the key challenges and complexities that arise in the adoption and implementation of technology and international law in marine policy. It examines issues related to data management, legal harmonization, governance gaps, and the need for enhanced international cooperation. The article emphasizes the importance of addressing these challenges to ensure effective and sustainable management of marine resources amidst advancing technology and global environmental threats (Rozwadowski, 2023).

1.2 Impression of the role of technology and international law

Possessing personal impressions or opinions, however, a general assessment of technology and international law in marine policy highlights their undeniable significance and transformative impact on ocean understanding and management. Through satellite technology, remote sensing, and innovative tools like autonomous underwater vehicles (AUVs), monitor ocean conditions, track marine life, and report environmental challenges. This integration of technology and international law establishes frameworks for sustainable ocean management and conservation efforts, facilitating cross-border cooperation (Gullett, 2023).

Technological advancements have provided scientists, policymakers, and conservationists with powerful tools to monitor and study marine ecosystems, leading to more informed decision-making and evidence-based policies. Technologies such as satellite imagery, remote sensing, and underwater monitoring systems have revolutionized data collection and analysis, enabling

us to address pressing issues like overfishing, habitat destruction, pollution, and climate change (Castillo Rodríguez et al., 2023).

Moreover, technology has facilitated international collaboration and cooperation in marine policy. It has bridged geographical barriers, enabling real-time data sharing, communication, and coordination among nations. This increased connectivity and information exchange have been crucial in addressing transboundary challenges and establishing cooperative frameworks for the conservation and sustainable management of marine resources (Stöbener and Gerritsen, 2023). However, the growing reliance on technology in marine policy also raises legal and regulatory complexities. The ever-changing landscape of technology calls for continuous development and adaptation of international legal frameworks to effectively tackle emerging challenges in various domains. that demands particular attention is marine policy, as advancements in technology pointedly impact understanding and management of the Oceans. As new technologies emerge, such as artificial intelligence, big data analytics, and unmanned marine vehicles, there arises a crucial need to ensure that international laws governing marine activities remain relevant. Questions regarding data ownership, privacy, intellectual property rights, and liability for damages caused by technology-driven activities in the marine environment require careful consideration and international cooperation. International law plays a vital role in guiding and governing the use of technology in marine policy. Existing legal frameworks, such as The United Nations Convention on the Law of the Sea (UNCLOS), provide a foundation for cooperation and regulation in various areas related to the oceans. However, there is a need for ongoing efforts to update and expand these frameworks to encompass the rapidly evolving technological landscape and address emerging issues (Kemp et al., 2023a).

The United Nations Convention on the Law of the Sea (UNCLOS) is a significant international agreement that provides legal guidelines for using and protecting the oceans and seas of the world. It was enacted in 1982, and it became effective in 1994. Regarding the exploitation of marine resources, defining maritime boundaries, and protecting the environment, UNCLOS outlines the different rights and obligations of nations (Kwiatkowska, 1995). The continental shelf, exclusive economic zones (EEZs), territorial sea limitations, and freedom of navigation are a few examples. Through learning more about UNCLOS (Rothwell, 1994). The role of international law is not only to provide regulations and guidelines but also to foster collaboration and consensus among nations. The establishment of new international agreements and protocols is essential to address the legal and ethical dimensions of technology in marine policy effectively. Discussions are underway to regulate emerging technologies, develop guidelines for their use, and strengthen international cooperation in monitoring, surveillance, and enforcement in the maritime domain (Bender et al., 2022; Liu et al., 2023). It is evident that technology and international law play a multidimensional role in maritime policy. The development of new technologies has greatly improved the capacity to study and control marine environments. At the same time, international law plays a pivotal role by setting the stage for collaborative efforts toward regulation and governance of marine-related issues. While technology brings immense benefits, it also presents legal and regulatory challenges that require ongoing dialogue and the development of international frameworks. By leveraging technology responsibly and strengthening international cooperation, we can work towards more effective marine policies that ensure the protection and sustainability of our oceans (Hung et al., 2022; Roessger et al., 2022). The remainder of this paper is organized as follows: Section 2 Methods and Materials, Section 3: Literature review, technologies Section 4 discussion and analysis provides findings on improving Role of International Law in Marine Policy, Section 5 offers conclusions, recommendations and future policies for implementation of technology in Marine Policy and law.

2 Materials and methods

This methodology section outlines the approach and methods employed to investigate the role of technology and international law in marine policy. The study aims to examine how advancements in technology and international legal frameworks contribute to the development and implementation of effective marine policies. The study involves a combination of research methods to gather data, analyze relevant literature, and draw conclusions. Literature review, and an extensive review of academic journals, books, reports, and relevant policy documents was conducted to gather a comprehensive understanding of the role of technology and international law in marine policy. In-depth case studies of specific marine policy initiatives were conducted to examine the practical applications of technology and international law. Thematic analysis was applied to the collected qualitative data, such as interview transcripts and policy documents, to identify key themes, patterns, and relationships. Measures were taken to ensure the anonymity and confidentiality of participants' identities and sensitive information, and the research was adhered to ethical guidelines and regulations. The research was conducted within a specific timeframe, which may limit the scope and depth of the study. Access to comprehensive and up-to-date on specific marine policy initiatives and technological advancements may pose challenges.

To investigate the role of technology and international law in marine policy, can utilize various materials and sources. Academic journals and articles, books and book chapters, reports and policy documents, case studies, official websites, and these materials, encompassing academic research, legal frameworks, case studies, expert opinions, and official reports provide a comprehensive foundation for examining the role of technology and international law in marine policy. This methodology provides a systematic approach to investigating the role of technology and international law in marine policy, by employing a mixed-methods research design and considering ethical considerations, the study aims to generate valuable insights into the interactions between technology, international law, and effective marine policy development and implementation. The findings contribute to the existing body of knowledge on marine governance and inform policymakers, legal experts, and relevant stakeholders in making informed decisions to

address current and future challenges in marine policy, (see Figure 1 below). For example, how should drones be regulated for use in marine surveys and inspections? What are the legal implications of using artificial intelligence to make decisions about marine resource management? These are just some of the questions that marine policy makers need to address in the coming years.

3 Literature review

The role of technology and international law in marine policy has evolved significantly in the past five years. New technologies, such as drones, artificial intelligence, and underwater robotics, have the potential to revolutionize marine resource management and conservation. However, these technologies also raise new legal challenges, as they blur the lines between traditional maritime boundaries and jurisdictions. One of the most significant challenges facing marine policy makers is how to regulate the use of new technologies in the marine environment. Another challenge facing marine policy makers is how to ensure that international law keeps pace with technological change. The United Nations Convention on the Law of the Sea (UNCLOS) is the cornerstone of international law governing the oceans. However, UNCLOS was drafted in the 1970s, and it does not explicitly address many of the new technologies that are now being used in the marine environment. This has led to some uncertainty about how these technologies should be regulated under international law. Despite these challenges, there is a growing recognition of the importance of technology and international law in marine policy are presented in Figure 2. The United Nations General Assembly adopted a resolution on the "Sustainable Use of Marine Technology on December 7 1994." The resolution calls for the development of new international law and standards to regulate the use of marine technology. It also encourages states to cooperate in the development and use of marine technology for sustainable development. The role of technology and international law in marine policy is likely to continue to evolve in the coming years. As new technologies emerge, marine policy makers need to find ways to regulate them in a way that is both effective and sustainable. At the same time, they need to ensure that international law keeps pace with technological change (Nõmmela and Kõrbe Kaare, 2022).

3.1 Challenges in implementing technology and international law in marine policy

Implementing technology and international law in marine policy presents several significant challenges that need to be overcome to ensure their successful integration, and these challenges include.

3.1.1 Data management challenge

The vast amount of data generated by technological tools, such as remote sensing and underwater sensors, can overwhelm existing data management systems. This is because the data is often very

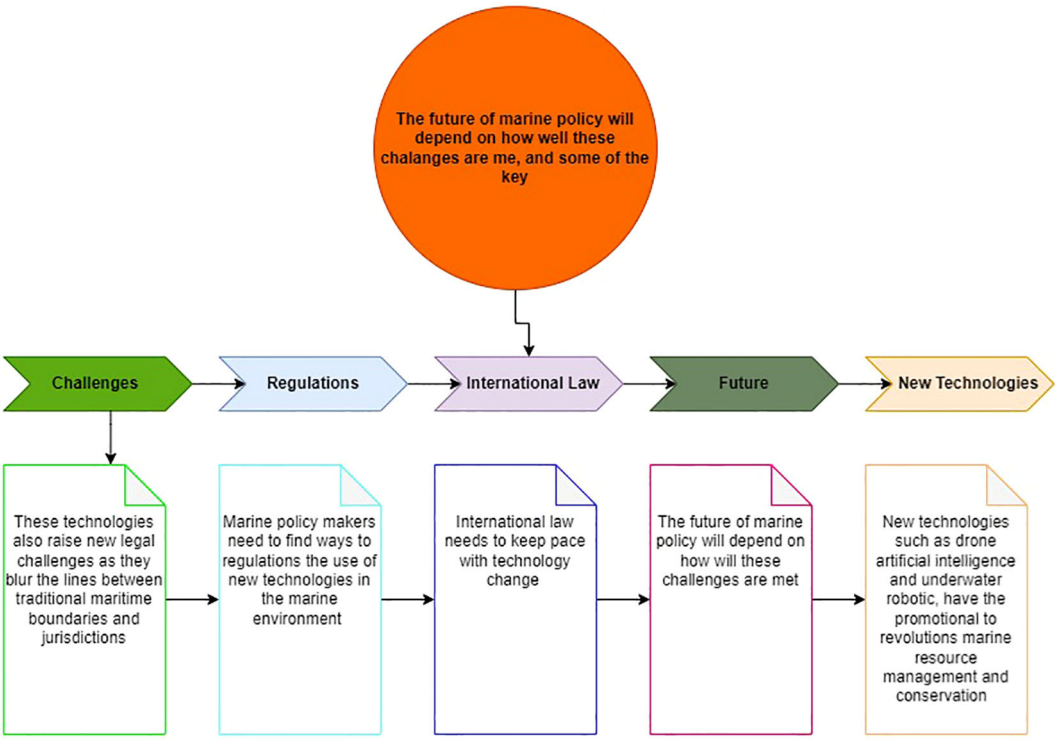

FIGURE 1
This model was created by authors opening about the Key findings on the future of marine policy.

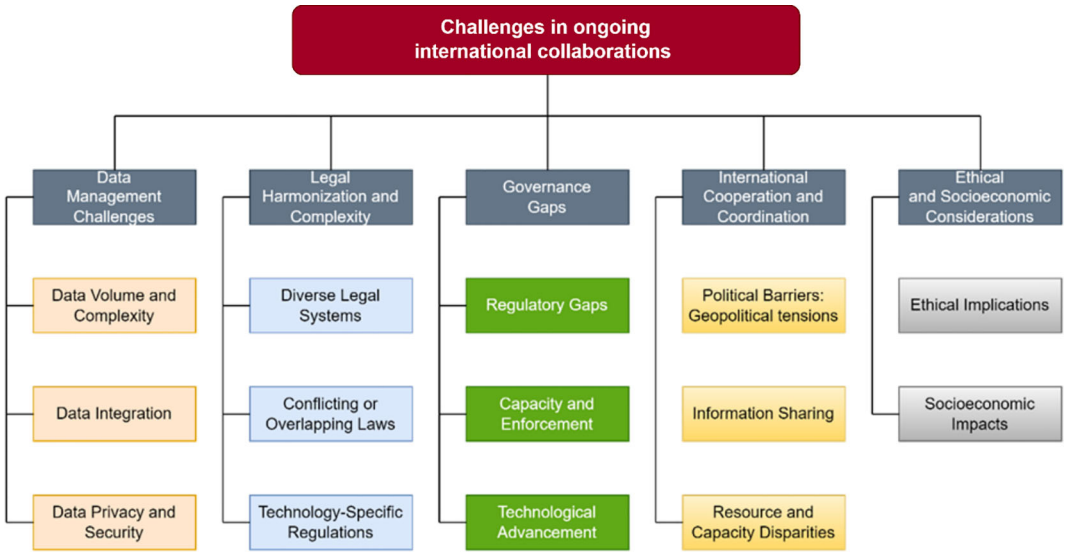

FIGURE 2
This model was created by the authors idea about technological advancements and emerging marine issues under legal frameworks.

large and complex, and it can be difficult to store, process, and analyse efficiently. (Wang et al., 2023b).

Data integration, integrating data from diverse sources and formats, ensuring interoperability, and maintaining data quality standards is a complex task that requires effective data management frameworks (Luecken et al., 2022; Mobashir et al., 2022).

Data privacy and Security, safeguarding sensitive data, protecting privacy rights, and mitigating cybersecurity risks are critical challenges in the context of technology implementation, particularly when multiple stakeholders are involved (Shen et al., 2022).

3.1.2 Legal harmonization and complexity

Diverse legal systems, different countries have varying legal frameworks and approaches to marine policy, leading to discrepancies and inconsistencies that need to be harmonized to enable effective international cooperation (Cox and Van Nostrand, 2023; Gutowski et al., 2023).

Conflicting or overlapping laws, overlapping jurisdictional claims, differing interpretations of international law, and conflicting regulations at regional and national levels can impede the harmonization of legal frameworks (Annisa and Wisnaeni, 2023; Santy, 2023).

Technology-specific regulations, the rapid advancement of technology often outpaces the development of corresponding regulations, resulting in legal gaps and challenges in adapting existing legal frameworks to address emerging marine technologies (McDonald et al., 2023).

3.1.3 Governance gaps

Regulatory gap, existing international governance frameworks, such as UNCLOS, may not comprehensively cover emerging technologies or adequately address evolving marine challenges, necessitating the development of new regulations and governance mechanisms (Hussain and Bhatti, 2023; Kostruba et al., 2023; Moshiul et al., 2023).

Capacity and enforcement, limited capacity to enforce regulations, monitor compliance, and address violations can undermine the effectiveness of technology and international law implementation in marine policy (Assunção et al., 2023; Langlet and Vadrot, 2023).

Technological advancement, The dynamic nature of technology requires agile governance structures capable of adapting to rapidly evolving advancements, ensuring that regulations remain relevant and effective (Baker, 1978; Kemp et al., 2023b).

3.1.4 International cooperation and coordination

Political barriers and geopolitical tensions, conflicting national interests, and divergent priorities among nations can hinder effective international cooperation, making it challenging to establish unified marine policies (Scheelhaase et al., 2019).

Information sharing, balancing the need for open data sharing and collaboration with concerns over data security, intellectual property rights, and national sovereignty poses challenges in promoting transparent and inclusive decision-making processes (Rukanova et al., 2023).

Resource and capacity disparities, unequal access to technology, financial resources, and technical expertise among nations can hinder effective collaboration, exacerbating the challenges in implementing technology and international law in marine policy (Awad et al., 2023; Wang et al., 2023a).

3.1.5 Ethical and socioeconomic considerations

Ethical implications, and the use of technology in marine policy raises ethical concerns related to privacy, equity, consent, and the potential unintended consequences on marine ecosystems and communities (What's in a name? : the ethical implications and

opportunities in diagnosing an infant with neonatal abstinence syndrome (NAS) | Western Sydney University ResearchDirect, n.d.).

Socioeconomic impacts, implementing technology-driven policies should consider potential socioeconomic disparities, ensuring equitable access to benefits, mitigating negative impacts on local communities and traditional practices, and addressing potential economic disruptions (Reducing environmental impacts through socioeconomic transitions: critical review and prospects | SpringerLink, n.d.). Talking these challenges requires ongoing international collaboration, knowledge sharing, capacity building, and the development of robust legal frameworks that can keep pace with technological advancements and emerging marine issues (Hussain and Bhatti, 2023; A Review Article on an Appraisal of Maritime Laws as a Mechanism of Community Governance for Sustainable Development Goals | Pakistan Journal of Humanities and Social Sciences, n.d.). By overcoming these challenges, the effective integration of technology and international law can contribute to sustainable marine policies that promote the conservation and preservation of our oceans for future generations (Narayanan et al., 2023).

3.2 Technology

3.2.1 Technology and international marine policy

Technology plays a crucial role in shaping international marine policy and addressing the complex challenges faced by our oceans. The advancement of technology has significantly improved our ability to monitor, manage, and protect marine resources. For instance, satellite-based remote sensing and tracking systems provide real-time data on ocean temperatures, currents, and the movement of marine species (Pyć, 2023). This information helps policymakers make informed decisions regarding conservation measures, fisheries management, and the establishment of marine protected areas. Moreover, technological innovations have greatly enhanced our understanding of the impacts of human activities on the marine environment. Advanced underwater robots, known as remotely operated vehicles (ROVs), enable scientists to explore and document previously inaccessible ocean depths, studying marine ecosystems and identifying areas of vulnerability (Mori et al., 2023). Additionally, advanced modelling and simulation tools help policymakers assess the potential consequences of different policy options, such as the implementation of offshore renewable energy projects or the introduction of new shipping routes (Stoll et al., 2023).

International collaboration and cooperation are essential in developing effective marine policies, and technology plays a vital role in facilitating such efforts. Communication and information-sharing technologies enable scientists, policymakers, and stakeholders from different countries to collaborate and exchange knowledge and data on a global scale. This collaboration allows for the development of coordinated policies and strategies to address transboundary issues such as overfishing, pollution, and climate change. Furthermore, emerging technologies like blockchain offer opportunities for improved transparency and traceability in global seafood supply chains, helping combat illegal, unreported, and unregulated fishing practices. Technology and international marine policy are deeply intertwined. Technological advancements provide crucial tools for monitoring and understanding the marine environment, supporting evidence-based decision-making processes. Furthermore, technology facilitates international collaboration and cooperation, enabling countries to work together in protecting and sustainably managing our oceans (Lubchenco and Haugan, 2023). As we continue to face environmental challenges, the responsible and innovative use of technology plays a pivotal role in shaping effective and forward-thinking marine policies.

3.2.2 Types of technology used in marine policy

Various types of technology are utilized in marine policy to address environmental challenges, promote sustainable practices, and protect marine ecosystems (Lee and Zhang, 2023). These technologies enable policymakers to gather data, monitor activities, and implement effective measures, and blue color are some examples of technology commonly used in marine policy (see in the Figure 3).

Remote sensing and satellite imaging, satellite-based remote sensing systems provide valuable data on ocean parameters such as sea surface temperature, chlorophyll levels, and ocean currents. This information helps monitor changes in the marine environment, track the spread of harmful algal blooms, identify fishing hotspots, and detect illegal activities such as illegal fishing or oil spills (Oloruntobi et al., 2023).

Underwater robotics and autonomous vehicles, and remotely operated vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) allow scientists to explore and collect data from the deep sea and other inaccessible areas (JMSE | Free Full-Text | Estimation and Control of a Towed Underwater Vehicle with Active Stationary and Low-Speed Maneuvering Capabilities, n.d.). These robotic systems are equipped with sensors and cameras that provide detailed insights into marine ecosystems, helping assess biodiversity, habitat health, and the impacts of human activities.

Acoustic monitoring and telemetry, acoustic technologies, such as hydrophones and passive acoustic monitoring, are used to track the movements and behavior of marine species. This information aids in understanding migration patterns, reproductive behaviors, and the impact of noise pollution on marine life (Sanderson et al., 2023). Telemetry systems, including tags and sensors attached to marine animals, provide real-time data on their movements, feeding habits, and habitat preferences.

Geographic information systems (GIS), GIS technology combines spatial data with analytical tools to visualize and analyze marine data. It helps policymakers identify vulnerable areas, plan marine protected areas, and assess the potential impact of development projects on marine ecosystems. GIS also facilitates the integration of various datasets, allowing for a comprehensive understanding of complex marine processes (Zhao et al, 1997).

Oceanographic monitoring systems, these systems include buoys, floats, and gliders equipped with sensors that measure parameters such as temperature, salinity, pH, and nutrient levels in the ocean. These real-time data sources provide critical information for understanding climate change, ocean acidification, and the health of marine ecosystems (Schwing, 2023).

FIGURE 3
These are just a few examples of the wide range of technologies employed in marine policy. Continued advancements in technology hold great potential for enhancing our understanding of the marine environment and improving the effectiveness of policies aimed at sustainable marine resource management (Shi et al., 2023).

Data management and modeling, advanced data management and modeling techniques are essential for analyzing and interpreting vast amounts of marine data. These technologies help policymakers simulate and predict the effects of policy interventions, such as fishing restrictions or the establishment of marine reserves, on ecosystems and fisheries (Dudayev et al., 2023).

3.2.3 Benefits of technology in marine policy

The benefits of technology in marine policy on a global scale are numerous and significant, and explained are some key advantages (See in Figure 4)

Technology enables the collection of extensive and accurate data on various aspects of the marine environment, including water quality, species abundance, and habitat health. This data provides a solid foundation for evidence-based decision-making and policy formulation (Sk, 2023). It allows policymakers to identify emerging trends, monitor the effectiveness of management measures, and assess the impact of human activities on marine ecosystems. Advanced technologies such as underwater robotics, satellite imaging, and acoustic monitoring provide scientists and policymakers with unprecedented access to marine environments. This enhanced understanding of marine ecosystems helps identify vulnerable species, detect habitat degradation, and uncover ecological interactions (Subsurface Science and Search for Life in Ocean Worlds - IOPscience, n.d.). With a more comprehensive understanding, policymakers can develop targeted and effective policies to protect marine biodiversity and promote sustainable resource use. Technology has greatly facilitated international collaboration and cooperation in marine policy. Through communication and information-sharing technologies, scientists, policymakers, and stakeholders from different countries can connect, exchange knowledge, and collaborate on a global scale. This collaboration leads to the development of coordinated strategies and policies to address transboundary issues, such as overfishing, marine pollution, and climate change (Hongdao et al., 2019). Technology also enables the sharing of best practices, lessons learned, and scientific research, fostering a collective global effort to protect and sustainably manage our oceans.

Technology plays a crucial role in enforcing marine regulations and combating illegal activities. Satellite-based monitoring systems, electronic surveillance, and real-time tracking tools help authorities detect and prevent illegal fishing, poaching, and other unauthorized activities in marine protected areas and exclusive economic zones (Aprilia et al., 2023). These technologies provide valuable evidence

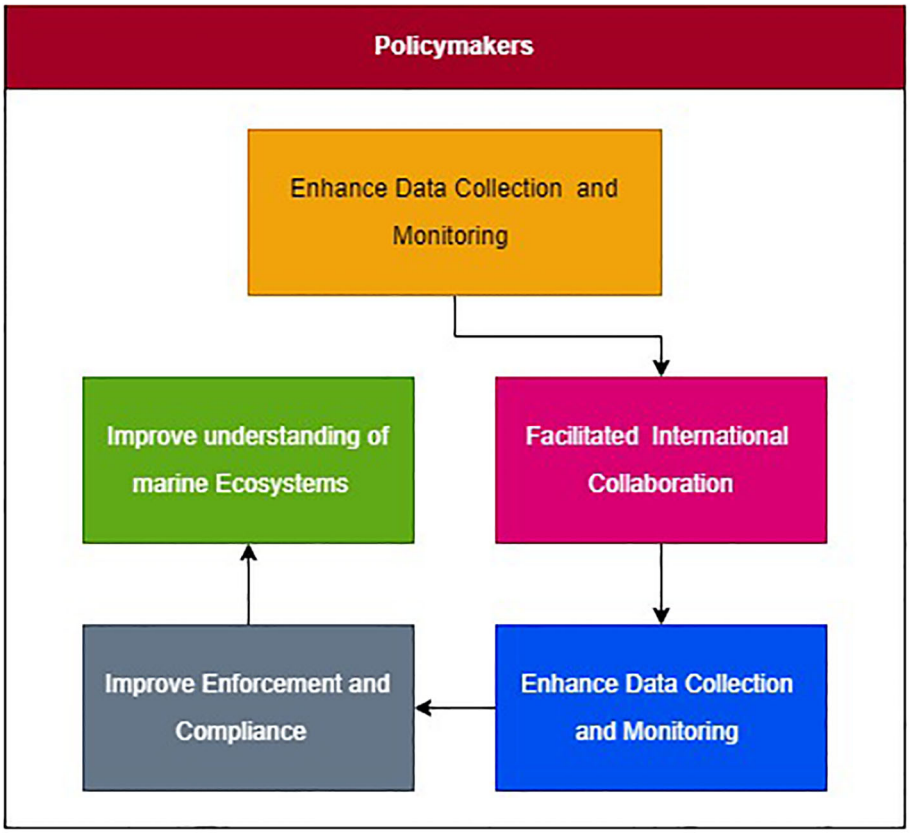

FIGURE 4
The benefits of technology in marine policy are far-reaching and have the potential to drive positive change worldwide, by harnessing the power of technology, policymakers can make informed decisions, protect marine ecosystems, and ensure the sustainable use of marine resources for future generations (Wang et al., 2022).

for prosecution, act as deterrents, and contribute to the sustainable management of marine resources (Ao et al., 2023). Technology drives innovation in marine policy by introducing new solutions and approaches. Emerging technologies, such as blockchain and artificial intelligence, offer opportunities for improved traceability, transparency, and accountability in seafood supply chains. They enable the verification of sustainable fishing practices and support efforts to combat illegal, unreported, and unregulated fishing. Additionally, advancements in renewable energy technologies, such as offshore wind and wave power, contribute to the transition to a more sustainable and low-carbon blue economy (Illia et al., 2023).

4 Discussion and analysis

4.1 International maritime law

International maritime law, also known as admiralty law or the law of the sea, is a body of legal principles, conventions, and treaties that govern activities and relationships on the world's oceans and other navigable waters. It provides a framework for regulating various aspects of maritime affairs, including navigation, shipping, marine resources, environmental protection, and international trade (Ehrhart, 2023). International maritime law encompasses both customary international law, which is derived from longstanding practices and accepted norms among nations, as well as international treaties and conventions that have been adopted by countries to establish specific rules and regulations. The United Nations Convention on the Law of the Sea (UNCLOS), adopted in 1982 and ratified by most countries, is the primary treaty that governs maritime affairs and serves as the cornerstone of international maritime law (García-Carriazo, 2023), key areas covered by international maritime law include (see to Figure 5).

It establishes the sovereignty of coastal states over a belt of water extending from their shores, typically up to 12 nautical miles. Within these waters, coastal states have the authority to enforce their laws and regulations, including customs, immigration, and environmental regulations (Falahzadeh et al., 2023). The EEZ extends up to 200 nautical miles from a coastal state's baselines and provides the state with exclusive rights to explore, exploit, and manage the natural resources, both living and non-living, within that zone. Coastal states also have jurisdiction over activities such as marine scientific research and environmental protection within their EEZ (Wiraputra et al., 2022).

The International Maritime Organisation (IMO) is a specialised UN body in charge of overseeing maritime shipping. It was founded in 1948 and seeks to ensure safe, secure, and ecologically friendly

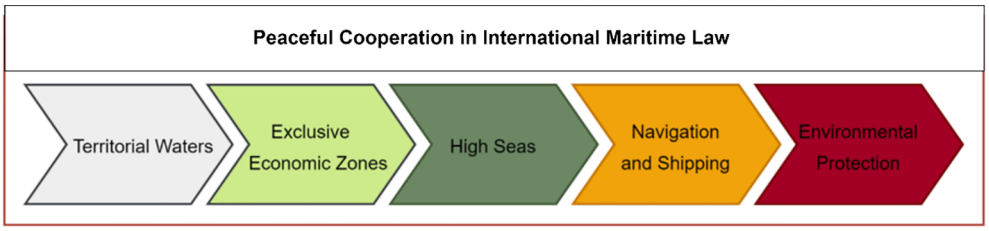

FIGURE 5
The primary objective of international environmental law is to promote environmental protection and sustainable development at the global level. By establishing common standards and frameworks, it fosters cooperation, knowledge sharing, and collective action to address pressing environmental issues that transcend national boundaries (Soininen and Romppanen, 2022). The implementation of international environmental law requires the active participation and collaboration of governments, international organizations, non-governmental organizations, and other stakeholders to achieve effective environmental governance on a global scale.

shipping throughout the world (Peters et al., 2012). The IMO creates and upholds a broad range of laws addressing topics like shipbuilding, crew training, pollution prevention, and maritime security, and readers a better grasp of how the IMO affects maritime policy and practises thru elaborating on the organisation's mission and duties (Brief History of IMO, n.d.).

The high seas refer to areas beyond national jurisdiction, where no state has sovereign rights. International maritime law governs activities on the high seas, including freedom of navigation, piracy suppression, marine scientific research, and conservation of marine resources (Zupruk, 2022). International maritime law regulates the rights and obligations of vessels and seafarers, including rules on vessel registration, safety standards, crew qualifications, collision avoidance, and liability for maritime accidents (Osaloni and Ayeni, 2022). The International Maritime Organization (IMO), a specialized agency of the United Nations, plays a central role in establishing and promoting international standards in shipping.

International maritime law addresses environmental issues, such as pollution prevention, control of vessel-source pollution (e.g., oil spills), and the protection of marine ecosystems. It includes regulations on ballast water management, disposal of waste, and the conservation of marine biodiversity (Dong et al., 2022). International maritime law is crucial for promoting peaceful cooperation, ensuring the sustainable use of ocean resources, and resolving disputes between nations. It provides a legal framework that balances the rights and interests of coastal states, flag states, and the international community, aiming to safeguard the marine environment and promote the safety and efficiency of maritime activities (Coelho and Rogers, 2023).

4.2 International environmental law

International environmental law refers to the body of legal principles, treaties, conventions, and agreements that aim to address environmental challenges at the global level. It provides a framework for cooperation and coordination among nations to protect and conserve the environment, prevent pollution, and promote sustainable development. International environmental law encompasses a wide range of issues, including climate change, biodiversity conservation, marine pollution, air pollution, hazardous waste management, and the protection of natural resources (Andreone, 2022; Yan et al., 2022 1), there some key characteristics of international environmental law include in (See the Figure 6).

International environmental law relies on multilateral cooperation among nations. It involves the negotiation and adoption of international treaties and conventions, where countries agree on common goals, principles, and standards to address global environmental challenges (Hassanali, 2022). Examples include the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Legal Lamination to Transboundary Movement of Plastic Pollutants - IOS Press, n.d.). The principle of common but differentiated responsibilities recognizes that all countries have a shared responsibility to protect the environment but acknowledges that developed and developing countries have different capacities and historical contributions to environmental issues. This principle allows for differentiated obligations and commitments based on countries' respective capabilities and circumstances (Pata and Balsalobre-Lorente, 2022). International environmental law includes mechanisms for monitoring compliance with environmental obligations and enforcing their implementation. These mechanisms can involve reporting obligations, monitoring programs, dispute settlement procedures, and sanctions for non-compliance (Koh et al., 2022). International organizations, such as the United Nations Environment Programme (UNEP) and regional bodies, play a role in facilitating compliance and enforcement efforts (Baste and Watson, 2022; Qalati et al., 2022).

Technological advancement refers to the relentless progression of innovations and improvements in various fields, driven by human ingenuity and research, and constant growth of inventions and advancements across a range of industries, motivated by human intellect and study, is referred to as technological advancement. It includes innovations in automation, medicine, and other fields that influence communities and economy. These developments have altered the way we live, work, and interact, from the introduction of the internet to artificial intelligence. Questions about ethics, sustainability, and equitable access are raised as technology advances. To ensure that these developments improve

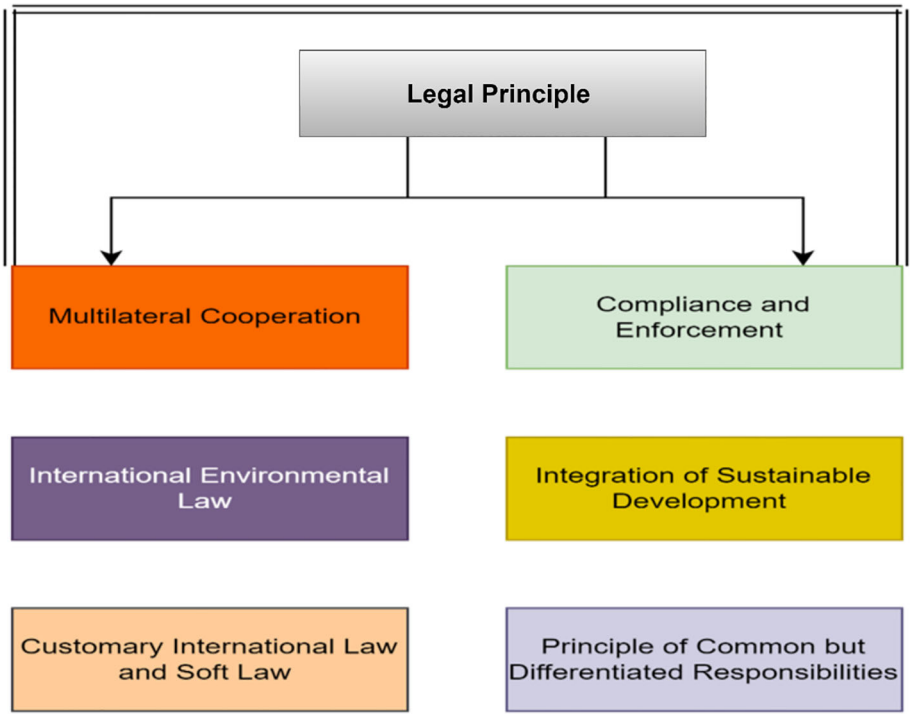

FIGURE 6
The body of International environmental law encompasses a wide range of issues, including climate change and International law.

human well-being, address global concerns, respect ethical boundaries, and protect the future, growth and responsible development must be balanced.

International environmental law seeks to integrate environmental concerns with social and economic development. It recognizes the interdependence of environmental protection and sustainable development, aiming to balance environmental conservation with the needs and aspirations of present and future generations (Sand and McGee, 2022). In accumulation to legally binding treaties and conventions, international environmental law may also include customary international law, which arises from established state practices and accepted norms. Soft law instruments, such as declarations, guidelines, and non-binding agreements, can also contribute to the development and implementation of environmental norms (Nyekwere et al., 2022).

4.3 Role of international law in marine policy

International law plays a crucial role in shaping and guiding marine policy at the global level. It provides a legal framework and establishes rules, principles, and standards that govern the use, conservation, and management of the world's oceans and marine resources (Hassanali and Mahon, 2022). The role of international law in marine policy can be seen in several key aspects, (See in the Figure 7).

International law, particularly the United Nations Convention on the Law of the Sea (UNCLOS), serves as the primary legal instrument for governing maritime activities. UNCLOS provides a comprehensive framework that sets out the rights and responsibilities of states in their use and protection of the oceans. It defines maritime boundaries, establishes rules for navigation, regulates exploitation of marine resources, and sets forth principles for environmental protection (Barnes, 2022). By providing a clear legal framework, international law helps ensure consistency, predictability, and stability in the development and implementation of marine policies.

International law plays a vital role in the conservation and sustainable use of marine biodiversity. The Convention on Biological Diversity (CBD) sets forth principles and guidelines for the conservation and sustainable management of marine and coastal ecosystems. It promotes the establishment of marine protected areas, the conservation of endangered species, and the sustainable utilization of marine genetic resources. International legal instruments also address specific issues such as the protection of migratory species, the prevention of marine pollution, and the regulation of activities that may harm marine habitats (Dobush et al., 2022).

International law provides a framework for regulating various maritime activities, including shipping, fishing, offshore oil and gas exploration, and marine scientific research. Treaties and conventions establish rules and standards to ensure safety at sea, protect the marine environment, prevent pollution, and promote responsible practices. For example, the International Maritime Organization (IMO) develops and enforces international regulations on maritime safety, security, and environmental protection (Karim, 2022). These legal instruments help harmonize

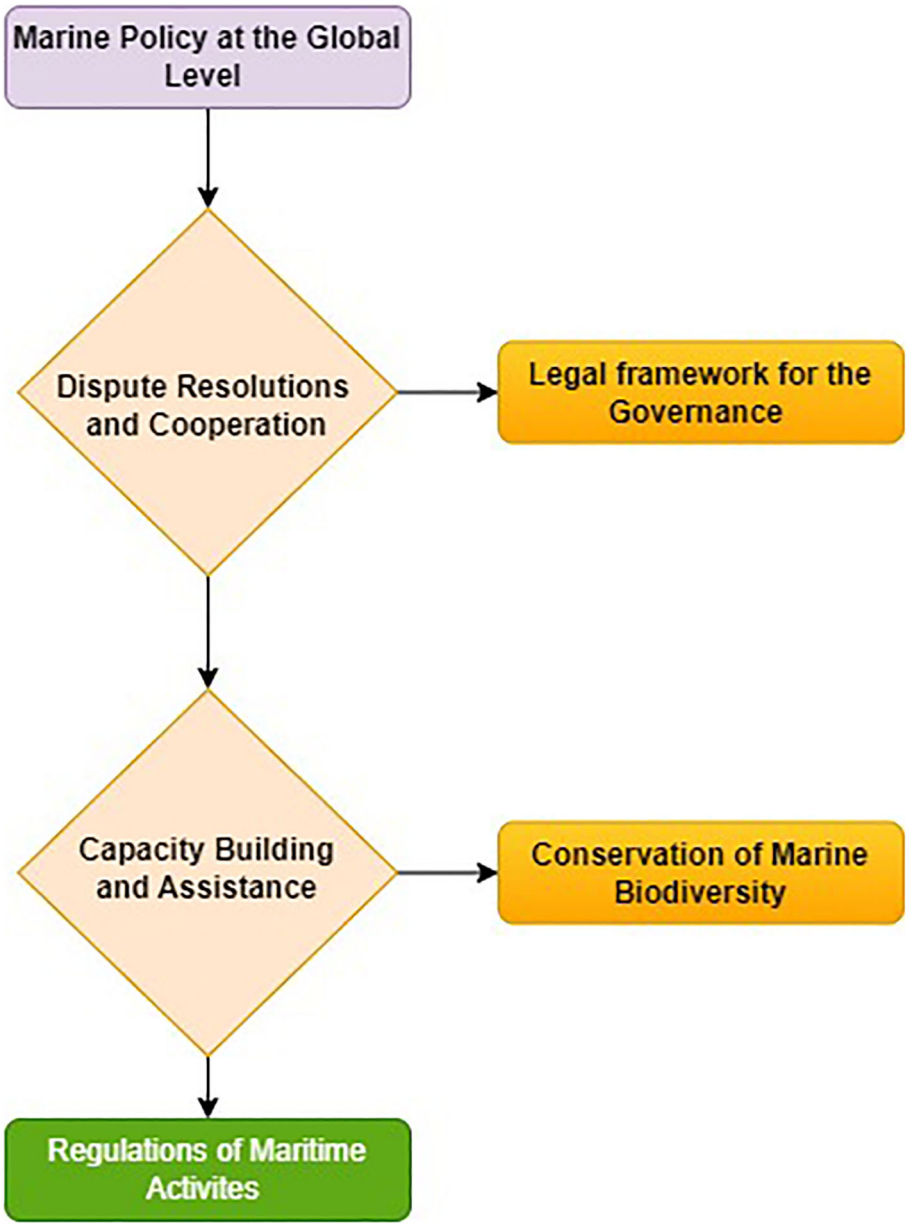

FIGURE 7
International law plays a pivotal role in marine policy by providing a legal framework, establishing rules and standards, facilitating cooperation, and promoting the conservation and sustainable use of marine resources. It provides a foundation for harmonizing national policies, resolving disputes, and fostering global efforts to protect and sustainably manage the world's oceans for present and future generations (Krabbe, 2022).

national policies and practices, promote cooperation, and address common challenges in marine industries.

International law provides mechanisms for the peaceful resolution of disputes among states regarding marine issues. It establishes procedures for the settlement of disputes, such as arbitration or adjudication through international tribunals. Notably, the International Tribunal for the Law of the Sea (ITLOS) provides a forum for resolving disputes related to the interpretation and application of UNCLOS. Additionally, international law fosters cooperation among states by promoting dialogue, negotiation, and collaboration in addressing shared challenges, such as the sustainable management of fish stocks or the response to marine pollution incidents (Fahy, 2022).

International law promotes capacity building and technical assistance to help states implement and comply with marine policies (Harden-Davies et al., 2022). International organizations and programs, such as the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF), support developing countries in building their capacity to implement international marine law and strengthen their national policies and institutions.

4.4 Challenges in implementing and maintaining technology

Implementing and maintaining technology can present several challenges, particularly in the context of marine policy, and we discuss challenges below.

Technology implementation often involves significant costs, including the purchase of equipment, software, and infrastructure, as well as ongoing maintenance and operational expenses. Limited financial resources can pose a challenge, especially for developing countries or organizations with constrained budgets. Securing funding and allocating resources for technology implementation and maintenance can be a hurdle, requiring careful planning, prioritization, and long-term sustainability strategies (Chen and Popovich, 2003). Effective technology implementation requires skilled personnel with expertise in operating and maintaining the chosen technologies. Training and capacity-building efforts are essential to ensure that users possess the necessary technical skills. In some cases, specialized knowledge may be required for complex systems such as underwater robotics, satellite data analysis, or data modeling (Amini and Jahanbakhsh Javid, 2023). Acquiring and retaining qualified staff, as well as addressing the technology skills gap, can be challenging, particularly in regions with limited access to training programs or a shortage of skilled professionals.

Technology generates vast amounts of data, and effective management and integration of this data pose challenges. Handling large datasets, ensuring data quality and integrity, and establishing protocols for data sharing and interoperability are essential. Integrating data from various sources and platforms can be complex, requiring compatibility and standardization. Additionally, addressing data privacy and security concerns is crucial to protect sensitive information and ensure compliance with applicable regulations (Francolini et al., 2023). Implementing and maintaining technology requires skilled personnel who can operate and manage the technology effectively. Building and maintaining the necessary technical skills and knowledge among staff members can be a challenge, particularly in regions or sectors where there is a shortage of trained personnel (Chuah et al., 2023). Continuous training and capacity-building efforts are essential to ensure that users can leverage the full potential of the technology.

Technology evolves at a rapid pace, and what may be cutting-edge today can become outdated in a short period. This presents challenges in terms of keeping up with technological advancements, ensuring compatibility with newer systems, and managing the lifecycle of technology. Regular updates, upgrades, and replacement of outdated technology can be necessary but may also incur additional costs (Kucharski, 2021). Introducing new technology and integrating it into existing workflows and processes may encounter resistance from stakeholders. Individuals or organizations may be reluctant to change established practices or may perceive technology as a threat to their roles or job security (Hegab et al., 2023). Overcoming resistance to change and fostering a culture of technological innovation and adoption can be challenging. Technology in marine policy raises ethical and legal considerations, such as privacy concerns, data protection, and potential misuse of technology. Adhering to ethical principles, ensuring compliance with legal frameworks, and addressing potential risks and vulnerabilities are critical to maintain trust, credibility, and the responsible use of technology (Pagallo et al., 2023). These challenges require a comprehensive approach that includes strategic planning, adequate funding, capacity building, stakeholder engagement, and ongoing evaluation and adaptation of technology initiatives. Collaborative efforts between policymakers, technology experts, and end-users are necessary to overcome these challenges and maximize the benefits that technology can bring to marine policy (Aghabalayev and Ahmad, 2023; Bennett et al., 2023).

4.5 Challenges in applying and enforcing international law

Applying and enforcing international law can present several challenges due to the complex nature of the international legal system and the diverse interests and perspectives of states.

Sovereignty and Consent: International law relies on the consent and cooperation of states to be effectively applied and enforced. States have the sovereign right to accept or reject international legal obligations, which can hinder the universal application of certain laws and treaties. In cases where states do not recognize the jurisdiction of international courts or tribunals, enforcing international law becomes challenging (Väyrynen, 2022). Non-compliance with international law is a significant challenge. States may choose not to comply with their obligations due to various reasons, including conflicting domestic laws, political considerations, resource constraints, or a lack of enforcement mechanisms. The voluntary nature of international law often limits the effectiveness of enforcement measures and may lead to a culture of non-compliance among some states (Brauers and Oei, 2020).

Power imbalances among states can impact the application and enforcement of international law. Powerful states may exert influence or selectively apply international law to suit their interests, while smaller or less influential states may face challenges in holding powerful states accountable (Simó-Soler and Peña-Asensio, 2022). This can undermine the universality and impartiality of international law and weaken its effectiveness. International legal instruments are subject to interpretation, which can lead to divergent understandings and conflicting interpretations among states. Disputes over the interpretation and application of international law can arise, requiring resolution through international courts or tribunals. However, the limited jurisdiction of these bodies and the consent of the parties involved can pose challenges to achieving binding resolutions (Munim et al., 2021).

Unlike domestic legal systems, international law often lacks strong enforcement mechanisms. While some international courts and tribunals can issue judgments, their ability to enforce those judgments can be limited (Hongdo et al., 2019). Reliance on state cooperation, diplomatic pressure, economic sanctions, or collective action by the international community can be challenging to

mobilize, resulting in a gap between legal norms and their enforcement. International law traditionally focuses on regulating the behavior of states. However, the involvement of non-state actors, such as multinational corporations, non-governmental organizations, and individuals, in global affairs poses challenges for applying and enforcing international law. Non-state actors may not be bound by the same legal obligations as states, making it difficult to hold them accountable for violations of international law (Pappa, 2019).

The international legal system often struggles to keep pace with rapidly evolving and emerging issues, such as cyber warfare, climate change, and emerging technologies (Filbee-Dexter and Smajdor, 2019). Adapting existing legal frameworks or developing new norms and rules to address these complex and dynamic challenges can be a slow and arduous process, resulting in gaps in international law's effectiveness and relevance. These challenges require strengthened international cooperation, enhanced compliance mechanisms, increased capacity building, and continued efforts to promote the universality, transparency, and accountability of international law. Engaging in dialogue, promoting the rule of law, and reinforcing the mechanisms for dispute resolution and peaceful settlement of disputes are essential for the effective application and enforcement of international law (Pickering et al., 2020).

5 Conclusions

The technology and international law play crucial roles in shaping and advancing marine policy at the global level. Technology offers numerous benefits, including improved data collection and analysis, enhanced surveillance and monitoring capabilities, and increased efficiency in managing marine resources. It enables better decision-making, promotes sustainable practices, and strengthens collaboration among stakeholders. However, challenges such as cost constraints, technical complexity, and data management must be overcome to ensure successful implementation and maintenance of technology in marine policy. International law provides the legal framework and principles necessary for effective governance and cooperation in marine affairs. It establishes rules and standards for navigation, resource exploitation, environmental protection, and dispute resolution. International environmental law specifically addresses the conservation and sustainable use of marine resources, promoting biodiversity conservation and pollution prevention. International maritime law governs activities on the seas, including navigation, shipping, and territorial rights. However, challenges in applying and enforcing international law, such as sovereignty issues, non-compliance, and power imbalances, must be addressed to ensure its effective implementation (Majid et al., 2023). In combination, technology and international law have the potential to create a powerful synergy in marine policy. Technology provides tools and solutions to address complex challenges, improve compliance monitoring, and enhance enforcement efforts. International law provides the legal framework and principles that guide the responsible and sustainable use of technology, ensuring that its benefits are harnessed for the collective good. By leveraging technology within the framework of international law, governments, organizations, and stakeholders can work together to safeguard marine ecosystems, protect resources, and promote the long-term health and sustainability of our oceans.

5.1 *Recommendations and future policies for implementation in marine policy and law*

Improving the implementation of technology and international law in marine policy requires concerted efforts and collaboration among various stakeholders. Here are some suggestions to enhance their effectiveness. Invest in training programs and capacity-building initiatives to enhance the technical skills and knowledge of personnel involved in marine policy implementation. This includes training in technology usage, data management, legal expertise, and policy implementation. Through equipping individuals with the necessary skills, they can effectively leverage technology and navigate international legal frameworks. Facilitate collaboration among governments, international organizations, academia, and industry to share best practices, experiences, and lessons learned. Establish platforms for knowledge sharing, such as workshops, conferences, and online forums, to promote dialogue and exchange of information. Collaborative initiatives can enhance the understanding and implementation of technology and international law in marine policy. Develop clear and comprehensive regulatory frameworks that govern the use of technology in marine policy. These frameworks should address issues such as data management, privacy, security, and accountability. Thru establishing transparent and consistent regulations, stakeholders can confidently adopt and implement technology solutions while ensuring compliance with international legal obligations. Implement robust data management systems that ensure the collection, storage, analysis, and sharing of high-quality data. This includes establishing data standards, protocols, and infrastructure that facilitate interoperability and accessibility. Efficient data management enables evidence-based decision-making, enhances monitoring and enforcement efforts, and supports compliance with international reporting requirements.

Strengthen international cooperation and coordination mechanisms to address transboundary marine challenges effectively. Encourage information exchange, joint research initiatives, and collaborative projects among nations to tackle shared issues. International partnerships can foster innovation, promote technology transfer, and enhance the implementation of international law in marine policy. Promote public awareness and stakeholder engagement as a raise public awareness about the importance of technology and international law in marine policy. Foster stakeholder engagement through public consultations, involvement of non-governmental organizations, and partnerships with local communities. Encouraging public participation and inclusivity can improve policy implementation, enhance

accountability, and garner support for the effective use of technology and international law.

Encourage research and innovation about the Invest in research and development to drive innovation in technology solutions and advance the understanding of international legal frameworks related to marine policy. Foster interdisciplinary collaborations between scientists, technologists, legal experts, and policy-makers to explore new approaches, technologies, and legal mechanisms for addressing emerging challenges in marine governance (Bilawal Khaskheli et al., 2023), by implementing these suggestions, policymakers and stakeholders can enhance the implementation of technology and international law in marine policy. This research contributed to more effective and sustainable management of marine resources, protection of marine ecosystems, and the promotion of equitable and responsible practices on a global scale. Foster public awareness about the importance of technology and international law in marine policy and engage stakeholders in decision-making processes. Promote education and outreach initiatives to increase understanding of the value of marine ecosystems and the role of technology and international law in their protection (Khaskheli et al., 2023). Foster partnerships with civil society organizations, local communities, and indigenous groups to incorporate diverse perspectives and ensure inclusive and participatory marine policy development and implementation.

5.2 The future direction of limitation policy

The future direction of limitation policy concerning technology usage and international law in marine policy will focus on adapting to technological advancements and developments while maintaining compliance with international laws and agreements. Policymakers will have to deal with the challenges presented by these cutting-edge maritime technologies in order to lessen the potential environmental harm that deep-sea mining and autonomous ships could cause. In order to manage marine resources sustainably, combat illicit fishing, and minimize pollution, it will be necessary to strengthen regulatory frameworks and promote collaboration between states. Responsible practices and marine environment conservation for future generations rely heavily on encouraging data and technology exchange, capacity building, and inclusive decision-making. The international community will have the resources it needs to protect our oceans if it embraces innovation and transparency.

It will become increasingly important for countries to encourage the sharing of data and technologies in order to monitor and manage maritime ecosystems efficiently. Better understanding and concerted action to address global marine concerns can result from the promotion of open data regulations and the transfer of technology. New methods of exploration, extraction, and transportation may become available in the marine industry if technological development continues at its current rate. Future limiting regulations must assess and address the potential environmental consequences and hazards of cutting-edge technologies like deep sea mining, autonomous vessels, and cutting-edge fishing gear. Compliance with international laws and agreements pertaining to marine activities will be emphasized, as will the need to ensure that technical improvements are in line with sustainability goals and environmental preservation. In order to efficiently manage marine resources, combat illicit fishing, avoid marine pollution, and protect biodiversity, nations may need to strengthen their regulatory frameworks and collaborate on transboundary concerns.

Author contributions

MK: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. SW: Conceptualization, Supervision, Writing – original draft. XZ: Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. IS: Funding acquisition, Resources, Writing – review & editing. CS: Investigation, Formal Analysis, Writing – review & editing. SR: Methodology, Data curation, Writing – review & editing. ZI: Investigation, Writing – review & editing. DB: Methodology, Formal Analysis, Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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