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Regulatory and legal frameworks recommendations for short sea shipping maritime autonomous surface ships

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ABSTRACT

This study aims to provide recommendations for addressing the gaps in the existing regulatory and legal frameworks, including the international and national regulations, rules, and standards for developing Maritime Autonomous Surface Ships (MASSs) for the Short Sea Shipping (SSS). The methodological approach consists of the following steps: analysing the characteristics of case-specific MASS and its operating areas for SSS; thoroughly reviewing the existing regulatory and legal frameworks to identify gaps; classifying the gaps based on severity levels (high, moderate, or low); assessing the outlook and usage of potential Key Enabling Technologies (KETs), and offering recommendations through four alternative approaches - interpretation, amendment, new development, or maintaining existing ones. This study deals with MASSs of various Autonomy Levels (ALs), retaining human involvement via consideration of Remote Control Centre (RCC). The obtained results for the use case demonstrate that 62%, 12%, 6% and 5% of the identified gaps pertain to SOLAS, COLREG, STCW and ICLL conventions, respectively. Moreover, 10%, 55%, and 26% of the gaps are categorised as high, moderate, and low severity, with 9% of the gaps addressable through proper justification without requiring amendments. Many of the moderately severe gaps can be mitigated by considering the use of KETs; highly severe gaps necessitate exemptions or bilateral/multilateral agreements, whereas low severity gaps require clarification or definitions amendments. This study provides insights to policymakers for systematically amending the frameworks and preparing the MASS code required for the design, testing and operation of the MASSs for SSS.

Abbreviation: ANS, Autonomous Navigation System; ADN, European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways; ABS, American Bureau of Shipping; AOC, Automatic Onboard Controller; AL, Autonomy Level; AI, Artificial Intelligence; ALARP, As Low As Reasonably Possible; BV, Bureau Veritas; COLREG, IMO's International Convention on the International Regulations for Preventing Collisions at Sea; CCTV, Closed Circuit TV; Con/CyS, Connectivity and Cyber-Security System; CSR, Continuous Synopsis Record; CCS, China Classification Society; DA, Degree of Automation; DMA, Danish Maritime Authority; DNV, Det Norske Veritas; DOC, Document of Compliance DOC; EC, European Commission; ECDIS, Electronic Chart Display and Information System; EPIRB, Emergency Position Indicating Radio Beacons; GSM, Global System for Mobile Communications; GMDSS, Global Maritime Distress and Safety System; ILO, International Labour Organisation; IMO, International Maritime Organisation; IMS, Intelligent Machinery System; ICLL, International Convention on Load Lines; ISO, International Organisation for Standardisation; IEC, International Electrotechnical Commission; KET, Key Enabling Technology; LSS, Local Sensor Systems; LiDAR, Light Detection and Ranging; LR, Llyod Register; ML, Machine Learning; MARPOL, IMO's International Convention for the Prevention of Pollution from Ships; MASS, Maritime Autonomous Surface Ship; MEPC, IMO Marine Environment Protection Committee; MLC, ILO's Maritime Labour Convention; MSC, IMO Maritime Safety Committee; MRC, Minimum Risk Conditions; MBR, Maritime Broadband Radio; MRCC, Maritime Rescue and Coordination Centres; NGAS, Next-Generation Autonomous Ships; NMA, Norway Maritime Authority; NK, Nippon Kaiji Kyokai; OC,, Onboard Control; OT, Operational Technology; PSC, Port State Control; PTZ, Pan/Tilt/Zoom; RTI, Requests To Intervene; R&A, Remote & Autonomous; RCC, Remote Control Centre; RSE, Regulatory Scoping Exercise; RS, Russian Maritime Register of Shipping; SA, Situational Awareness; SOLAS, IMO's International Convention for the Safety of Life at Sea; SMC, Safety Management Certificate; SSS, Short Sea Shipping; STCW, IMO's International Convention on Standards of Training, Certification and Watchkeeping for Seafarers; SAR, International Convention on Maritime Search and Rescue; SSAS, Ship Security Alert System; TMC, International on Tonnage Measurements of Ships; T_{DT}, Response deadline; T_{MR}, Maximum response time; UMS, Unattended Machinery Spaces; VDR, Voyage Data Recorder; VSAT, Very Small Aperture Terminal.

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1. Introduction

Remote and autonomous technology within the maritime industry holds immense promise, with the potential to enhance safety, reduce environmental impact, and optimise operational efficiency [1–3]. Simultaneously, it is anticipated that MASSs for SSS will play a pivotal role in addressing the ongoing shortage of seafarers while also ushering in new employment opportunities within the maritime sector [4]. While autonomy has already made significant strides in shore and aviation industries [5], the maritime sector faces unique challenges that must be addressed to fully unlock the benefits of technological advancements. The current regulatory and legal frameworks governing conventional ships have been developed with a human-centric approach, assuming the presence of a crew for navigation, monitoring, maintenance, and emergency handling [6]. However, MASSs are set to relocate the crew from onboard vessels to shore, creating a paradigm shift that demands new rules and regulations [7]. The absence of well-defined legislation tailored to autonomous SSS at international and national levels poses a significant obstacle to its growth. Furthermore, potential conflicts with existing regulations requiring human intervention must be resolved.

Short Sea Shipping (SSS) is the transportation of goods/passengers by sea over short distances, typically along coastlines or between nearby ports. Focusing on SSS as a prime domain for MASS is strategic due to its geographic proximity and repetitive operational patterns. Short distances and routine operations in SSS make it an optimal setting for autonomous technology integration, enhancing operational effectiveness and cost-efficiency [8]. Additionally, deploying MASSs in SSS (SSS-MASSs) aligns with environmental goals set by IMO [9] by promoting sustainability in coastal regions. As SSS often involves transportation between nearby ports and coastlines, there is a shared interest among these regions in establishing consistent and standardised regulations for the deployment and operation of MASSs. The focused nature of SSS allows stakeholders to address regulatory and legal challenges more efficiently and fostering collaboration. This collaborative approach contributes to the amendments of regulatory and legal frameworks that can be standardised across specific maritime areas, ensuring the safe and effective adoption of autonomous technologies in SSS.

Several significant industrial initiatives have recently concluded, focusing on the development of commercial SSS-MASSs. Notable examples include the projects Yara Birkeland [10] and ASKO [11]. Additionally, research-based efforts, both completed and ongoing, are dedicated to the development and testing of Key Enabling Technologies (KETs) essential for the remote and autonomous (R&A) operation of MASSs in general. These initiatives encompass projects such as MUNIN [12], AAWA [13], SISU, SVAN [14], the Revolt concept [15], the Design for Value [16], SFI AUTOSHIP [17], AEGIS [18], and AUTOSHIP [19]. KETs for SSS-MASSs include Autonomous Navigation System (ANS), Situational Awareness (SA), Remote Control Centre (RCC), Connectivity and Cyber-Security system (Con/CyS), and Intelligent Machinery System [19]. These technologies ensure precise navigation, real-time insights, remote operations, secure connectivity, and optimised machinery, respectively ushering in a new era of maritime autonomy and efficiency. However, to pave the way for the era of commercial MASSs for SSS, it is imperative to address the potential gaps and barriers spanning social, economic, and regulatory perspectives that currently impede progress. Alterative provisions promoting the KETs for remote and autonomous (R&A) operations of SSS-MASSs also need to be considered. These challenges have been a focal point of discussion in various research projects and pertinent literature. Remarkable efforts in this regard include the MUNIN project's analysis of international and UK national regulations within the context of SSS [20], Lemon's investigation into the adoption of unmanned ships within the framework of Australian legislative regulations [21], and the Danish Maritime Authority's examination of regulatory gaps in Danish regulations regarding the operability of autonomous ships [22]. On the international stage, Comité Maritime International [23] and Fastvold [24] examined the complications of the international legal framework, and the International Maritime Organisation (IMO) organised a Regulatory Scoping Exercise (RSE) aimed at assessing existing regulatory instruments [25], although critics pointed out its limitations in addressing the most intricate regulatory challenges, as pointed out by Ringbom [26]. An overview of crucial international regulations and their associated challenges and gaps was provided by Komianos [27], while Ringbom et al. [28] conducted a comprehensive analysis of the existing regulatory framework for the application and testing of autonomous ships in the Baltic Sea MASS trial areas. Furthermore, the implications of the United Nations Convention on the Law of the Sea (UNCLOS) within the context of MASS was explored by Van Hooydonk [29] and Chang et al. [30]. While these studies have shed light on the challenges inherent in the regulatory and legal frameworks pertinent to autonomous shipping, there remains a conspicuous absence of studies classifying the gaps into different severity levels to understand their impact and proposing comprehensive recommendations to mitigate these identified gaps at international, national, and regional levels, which are covered in this study.

Additionally, the interdisciplinary nature of approach is fundamental to addressing the multifaceted challenges within the maritime industry, particularly in the realm of Remote and Autonomous (R&A) operation of SSS-MASSs. By bridging the gap between engineering and law, this study delves into the intricate interactions between these disciplines to navigate the evolving landscape of maritime regulations and technological advancements. Engineering innovations in R&A technology, i.e. Key Enabling Technologies (KETs) must align seamlessly with regulatory and legal frameworks to ensure compliance, safety, and effectiveness. For instance, the development and implementation of MASSs for SSS necessitate a thorough understanding of both engineering requirements and regulatory mandates. This collaborative dialogue between engineers and legal experts is crucial for crafting regulations that facilitate the safe and efficient deployment of KETs while addressing potential regulatory and legal hurdles. In the maritime sector, the interaction between regulations and technologies is observed in areas such as decarbonisation and ballast water treatment. For instance, decarbonisation regulations [9] aimed at reducing greenhouse gas emissions from maritime activities drive innovation in technologies such as alternative fuels, hybrid propulsion systems, and energy-efficient vessel designs. Similarly, regulations concerning ballast water treatment to prevent the spread of invasive species influence the development of ballast water management systems and technologies for onboard treatment and disinfection. These examples highlight the symbiotic relationship between regulatory frameworks and technological advancements in the maritime industry, emphasising the importance of aligning regulations with innovative solutions to address environmental and operational challenges effectively.

This study aims to comprehensively analyse the gaps in instruments within regulatory and legal frameworks for MASSs intended for SSS (SSS-MASSs) and offer well-informed recommendations for effectively addressing the preceding challenges. The novelty of this study lies in: (a) identifying the gaps and classifying those into low, moderate and high severity considering their impact and timelines for addressing those; (b) providing detailed recommendations with justification for several autonomy levels (ALs) for SSS-MASSs, instead of offering general solutions for all ALs reported in the pertinent literature; (c) presenting a roadmap comprising several phases for the SSS-MASSs development, aligning the implementation of these recommendations with this roadmap phases.

The remainder of this study is structured as follows. Section 2 describes the methodological approach for the regulatory and legal frameworks analysis and gaps amendments. Definitions used to explain the formation of these frameworks are mentioned in Section 3. Section 4 provides the characteristics of the considered SSS-MASS use case and discusses its operating area, the system upgrade with the required KETs as well as the ALs. The analysis results including the gaps identified in regulatory frameworks and the associated amendments or improvements are described in Section 5. The legislative framework is analysed in Section 6, where the relevant recommendations are drawn. Section 7 explains the proposed way forward for the policy recommendations that aligns with the SSS-MASSs adoption. Lastly, Section 8 reports the key findings of this study and summarises the main recommendations for the instruments within the regulatory and legislative frameworks.

2. Methodological approach

The methodological approach adopted in this study closely follows the steps outlined in the previous authors' publication, which focused on the inland waterways (IWW) use case [31]. In this study, a theoretical use case is considered, representing a SSS-MASS intending to navigate along the Norwegian coast. This use case aligns with the SSS demonstrator ship utilised in the AUTOSHIP project [19], notably in 2023. Extensive research has been conducted to develop the KETs for the SSS-MASS use case [32], along with other relevant aspects to facilitate its Research and Analysis (R&A) operation during the demonstration. These findings are employed to provide recommendations that address identified gaps, rendering them more realistic.

The study narrows down the regulatory and legal bodies concerning the operational area of the SSS-MASS use case. This includes coverage of pertinent international governing bodies, major European regulations, and guidelines provided by the Norwegian Maritime Authority (NMA) for MASS operation. Pilotage act 1987 is also covered along with UNCLOS that forms the legal framework. It should be noted that the international governing bodies identified for the SSS-MASS use case (e.g., SOLAS, COLREG, etc.) remain the same for Deep Sea Shipping (DSS), along with the identified gaps. However, recommendations may require modification in certain cases, considering the communication pattern with the Remote Control Centre (RCC) for DSS. The recommendations that are made for the international governing bodies considering R&A operation of MASS in mind, also applicable to SSS-MASS in general regardless of its sailing route. Special routes that demand additional national and local regulations should be addressed separately. The study, however, does not provide recommendations for provisions explicit to special types of ships, such as tankers or passengers.

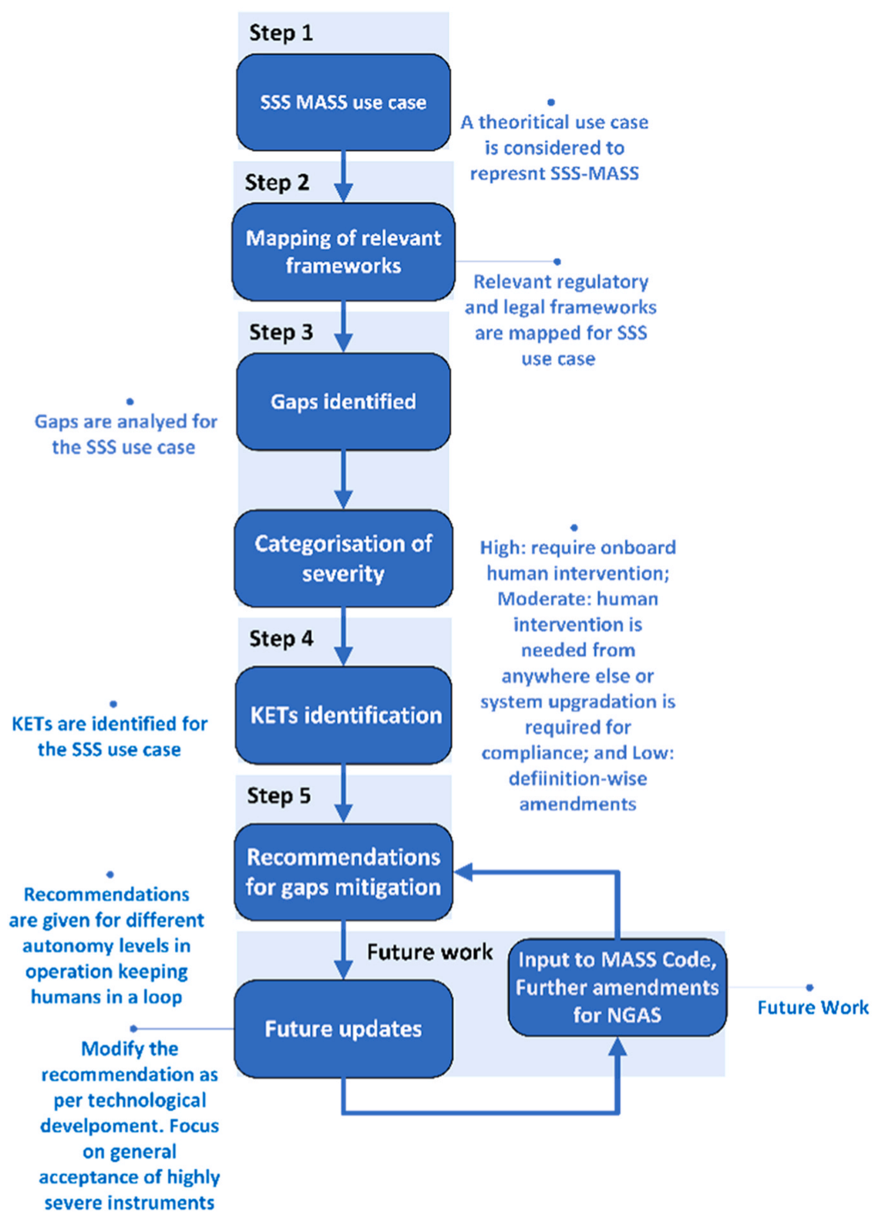

Fig. 1. Methodological flowchart.

The methodological flowchart adopted in this study is visually depicted in Fig. 1.

Step 1 focuses on an SSS-MASS use case and analysing its characteristics and operational areas to map relevant international, national, and regional regulatory bodies that form the regulatory and legal frameworks for the design, testing, and operation of SSS-MASSs.

Step 2 involves examining relevant regulatory and legal documentation, as well as recent studies [23,24], along with reports from pertinent autonomous shipping projects [12-14] and so on. The details are given in Table 1. Afterword, the mapping of the corresponding international, national, and regional regulatory and legal bodies including rules, regulations, standards, and policies is performed. These include SOLAS Convention, Load Line Convention, Tonnage Convention, STCW Convention, COLREG Convention, SAR Convention, MARPOL Convention, MLC Convention, European Directives, national and local regulations, IMO Interim Guidelines for MASS trials, IMO Guidelines on maritime cyber risk management, and Classification Societies' guidelines for Autonomous Shipping. The legal framework mainly includes UNCLOS, that considers flag state jurisdiction, port and coastal state jurisdiction, along with other provisions, including mandatory manning requirements and masters' obligations in distress situations. Fig. 2 illustrates an overview of the regulatory and legal frameworks considered for the SSS-MASS use case.

Step 3 identifies gaps within the context of SSS-MASSs, considering aspects such as, functional system specifications, navigation and collision avoidance protocols, crew competencies and training, communication systems, RCC system design, interface and operational specifications, port navigation procedures, and maintenance protocols. The analysis conducted in this study categorises the provisions identified in the instruments into three different severity levels. The severity levels define the impact of the provisions for SSS-MASSs growth as well as timeline to get internationally acceptable alternatives for those. The high, moderate and low severity levels for the provisions are defined as follows:

- Highly severe: Provisions that explicitly demand shipboard human/manual intervention for compliance. These provisions pose challenges for alternative solutions to meet their requirements, thus requiring careful consideration for international acceptance.
- Moderately Severe: Provisions involving human involvement in active or passive capacities without mandating shipboard presence or system enhancements through Key Enabling Technologies (KETs) for compliance. These provisions are classified as moderately severe, as trusted advanced technology could potentially offer alternative means to fulfil these provisions.
- Least Severe: Provisions mandating only minor wording adjustments or the inclusion of new/amended definitions. These provisions are characterised as the least severity, as these issues are relatively less critical, hence international acceptance can be provided.

Step 4 discusses the KETs [32] required to facilitate the Remote and Autonomous (R&A) operation of the case MASS.

In the last step, recommendations are provided for the analysed regulatory and legal frameworks to addressing the gaps for assuring the SSS MASSs. The RSE [25] presents four alternative approaches to address the instruments, which are also adopted here: (a) developing interpretations or equivalences based on the analysed provisions, (b) amending existing provisions, (c) developing new provisions, or (d) retaining the existing provisions. The four autonomy levels defined by IMO [25] are considered.

This study carried out an extensive literature review to map the relevant regulatory and legal bodies in the context of SSS-MASS (in Step 2 of Fig. 1), followed up with the gaps identification within existing frameworks (in Step 3 of Fig. 1), and then propose recommendations to address the associated gaps. (in Step 4 of Fig. 1). Table 1 illustrates the relevant sources that were reviewed, along with the classification of the input provided for this study. Emphasis was placed on sources related to SSS to pinpoint areas for improvement, propose recommendations or both for the relevant frameworks. In this study, identifying potential gaps in the operation of MASSs in SSS involved a meticulous examination of regulations set by diverse governing authorities. The examination typically entails considering several criteria, such as: (a) assessing the extent to which existing regulations cover SSS-MASSs operation; (b) evaluating the clarity and specificity of regulatory provisions to ensure that they provide clear guidance on compliance requirements for SSS-MASSs operators; (c) examining the consistency and compatibility of regulations across different governing authorities to avoid conflicts and ensure smooth operation of SSS-MASSs; (d) considering the adaptability and flexibility of regulations to accommodate technological advancements; and (e) assessing the adequacy of safety and security standards prescribed by regulations to mitigate risks associated with SSS-MASSs operations. While some pertinent literature listed in Table 1 identified gaps in the instruments within existing frameworks (Regulatory and Legal), none of these ensure coverage of all pertinent criteria when identifying the gaps, rendering them not entirely self-sufficient. Additionally, they did not classify the gaps based on the severity levels that define their potential in hindering the growth of SSS-MASSs. This study addresses this research gap. Additionally, the initial recommendations underwent a thorough review and refinement by experts with proper justification that they adequately address the gaps. The main objectives of the review and refinement process include: (a) ensuring recommendations are accurate and comprehensive; (b) assessing the relevance and practical applicability of recommendations; (c) evaluating the feasibility

Table 1
Reviewed sources and classification of the input for this study.

Source type	Reference	Study Input Category				
		Regulatory		Legal		Others
		G	R	G	R	
Project Report	MUNIN [20]	✔	✔		✔	
	Danish Maritime Authority [22]	✔	✔	✔	✔	
	EMSA [33]		✔			
	Henrik et al. [34]	✔	✔	✔	✔	
Article/Book chapter	Comité Maritime International [23]	✔	✔	✔	✔	
	Fastvold [24]	✔	✔			
	Komianos [27]	✔				
	Ringbom et al. [26,28]	✔	✔			
	Van Hooydonk [29]			✔	✔	
	Chang et al. [30]			✔	✔	
International regulatory bodies	Different regulatory bodies [35–45]	✔				
IMO	Regulatory Scoping Exercise (RSE) [25]	✔				Ways of addressing the gaps
	Interim Guidelines for MASS trials [46]		✔			
	Guidelines on maritime cyber risk management [47]		✔			
EU regulation	EU directives [48–51]	✔				
Regional and local regulations	NMA guidelines for MASS [52]	✔				
Classification rules	Different class rules [53–63]	✔				
Other regulations	Pilotage act 1987 [64]			✔		
	UNCLOS [65]			✔		

G: Gaps; R: Recommendations

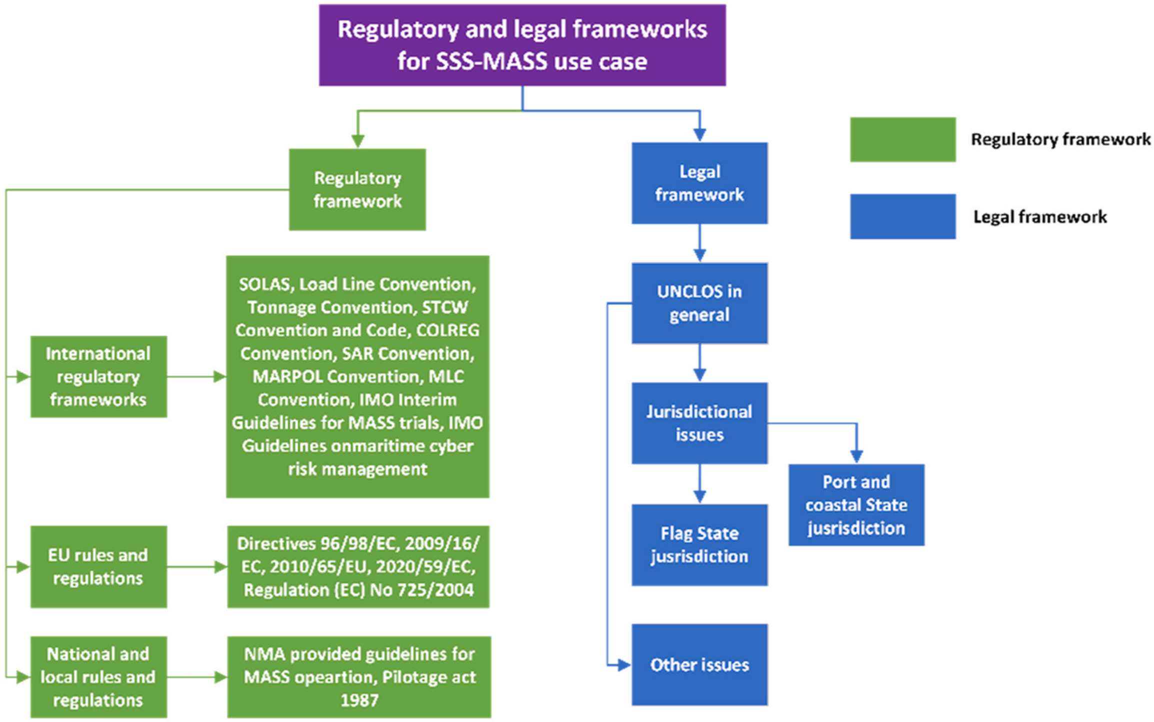

Fig. 2. Regulatory and legal frameworks for SSS-MASS use case.

and ease of implementation of recommendations; and (d) analysing the potential impact of recommendations on addressing identified gaps. This collaborative effort culminated in the final set of recommendations presented in this study, ensuring a well-informed approach to addressing gaps and enhancing regulatory and legal frameworks for SSS-MASSs.

It is important to acknowledge that during the phase of a fully autonomous mode, expert knowledge is necessary to adhere to the stipulations of the prevailing provisions. For the Next Generation Autonomous Ships (NGASs) possessing the highest AL, human intervention is not anticipated; these MASSs categories can function without necessitating the use of RCC. To satisfy the anticipated safety and security standards in this regard, additional enhancements, or fresh regulations (e.g, MASS codes which is envisioned to come into effect on 1 January 2028 according to IMO) are required. This stage falls beyond the scope of this study and is recommended for future investigation. Additionally, it's important to note that not all codes and standards are included in this study, and individual flag states might have their own legislations that aren't considered here.

3. Definitions

To understand the formation of regulatory and legal frameworks for SSS, this study employs the following definitions:

3.1. Regulatory framework

A regulatory framework is a structured system of laws, rules, and guidelines established by governing bodies to oversee and manage specific industries or activities. It provides the foundation for regulatory compliance and sets the standards to ensure safety, fairness, and efficiency within a particular sector. In the maritime context, the regulatory framework consists of several regulatory bodies (e.g., International Convention for the Safety of life at Sea convention (SOLAS), International Regulations for Preventing Collisions at Sea (COLREG)). These bodies, acting as pillars within the regulatory framework, are designed to maintain order, safety, and fairness in global maritime activities.

3.2. Regulatory bodies

Regulatory bodies are organisations or entities authorised by law to enforce and administer regulations within a specific industry or domain. These bodies are responsible for monitoring compliance, implementing rules, and safeguarding the interests of stakeholders to maintain the integrity and effectiveness of the regulatory framework. In the maritime sector, regulatory bodies such as SOLAS and COLREG are instrumental in shaping and upholding international maritime regulations. These bodies serve as the guardians of safety and fairness at sea, overseeing the adherence of maritime entities to the established rules and guidelines.

3.3. Instruments

In the context of regulations, instruments refer to specific documents or components within the regulatory bodies that articulate detailed rules, requirements, or standards. These instruments serve as tools for implementing and enforcing the broader regulations established by regulatory bodies, often specifying the practical aspects of compliance. In the maritime regulatory landscape, instruments take the form of SOLAS chapter 1 or COLREGs rule 1. These documents serve as the backbone of regulatory implementation, providing explicit guidance on ship design, testing procedures, and operational protocols for ensuring maritime safety and efficiency.

3.4. Provision

A provision is a specific rule, or stipulation within an instrument or set of regulations. It outlines detailed requirements, conditions, or obligations that entities or individuals must adhere to in order to comply with the regulatory framework. Provisions are essential components that offer precision and clarity in the application of regulatory standards. Within maritime instruments such as SOLAS chapter 1 and COLREGs rules, provisions play a crucial role. They delineate the exact specifications for ship design, testing, and operation, acting as the cornerstone for ensuring compliance with the regulatory standards set forth by the regulatory bodies.

The same definitions are also applicable for Legal framework. To understand the formation of regulatory and legal frameworks more preciously, Fig. 3 is prepared.

4. Case SSS-MASS characteristics

4.1. SSS-MASS use case

This study considers a cargo ship as the reference ship that transports fish feed in bulk from factory to fish farms along the Norwegian coast. During normal operation, the ship loads cargo at the fish feed factory's quay facilities and then sail to the fish farms, where the load is discharged whilst the ship holds its position via operating at the DP mode. The ship main particulars are provided in Table 2. The ship has a dedicated Feed Control and Monitoring (FCM) System. There are operator stations for the FCM System at the bridge and on the deck office. The FCM System has a wireless connection that is used to interface the factory automation system when moored at factory quay for loading. The potential operating area of the ship is within the Norwegian waters, which includes fjords, passages under bridges, strong currents, fog, rain, snow etc.

The considered use case is operated at fully autonomous mode at the open sea, i.e. the operating system of the ship makes decisions and determine actions by itself, without human intervention. When it sails close to the shore, port or heavy traffic zone, a remote operator takes control of the operation and the ship sails at remotely operated mode. The remote operation is conducted from a RCC located onshore for navigating the ship in remote mode, supervision of the ship in autonomous mode, the system health status checks and troubleshooting of possible malfunctions.

No crew, passengers or other persons are considered on board. Some technical personnel could be temporarily embarked on board for the purpose of maintenance or time-limited technical intervention but they have not been taking into account in the scope of this regulatory framework analysis.

To facilitate the remote and autonomous (R&A) operations of the SSS-MASS use case, the following key enabling technologies (KETs) are required: Autonomous Navigation System (ANS), Situational Awareness (SA), Remote Control Centre (RCC), Connectivity and Cyber-Security System (Con/CyS) and Intelligent Machinery System (IMS). Autonomous Navigation Systems (ANS) enable SSS-MASS to execute remote and autonomous (R&A) operations with unparalleled precision, seamlessly navigating through waterways. Augmented by Situational Awareness (SA), SSS-MASS gains real-time insights, enhancing its environmental perception for informed decision-making during autonomous tasks. The Remote Control Centre (RCC) serves as the central command, overseeing and managing MASS operations remotely, while Connectivity and Cyber-Security Systems (Con/CyS) establish a robust network infrastructure and safeguard against cyber threats, ensuring secure communication between the RCC and MASS. Integral to the operational efficiency are the Intelligent Machinery Systems (IMS), optimising onboard machinery through advanced automation and data-driven decision-making. Together, these interconnected components constitute a sophisticated technological ecosystem, propelling the maritime industry into a new era of autonomy and efficiency. The list of the SSS-MASS use case investigated systems is provided in D2.4 of AUTOSHIP project [66].

Table 2
Case SSS-MASS particulars.

Description	Value	Unit
Length overall	74.7	m
Length between p.p.	72.9	m
Breadth moulded	13.6	m
Draught max.	5.1	m
Gross tonnage	2145	t
Deadweight	1743	t

4.2. Autonomy levels

Most of the projects on MASSs [12,13] planned to operate at different autonomy levels (manual steering, remotely controlled and fully autonomous). The legal barriers are expected to vary and depend on the levels of autonomy at which the ship operates. In many cases, it is presumed that complex ship operations (such as port calls or sailing in densely trafficked areas) will be undertaken at a lower level of autonomy, compared to sailing in open waters.

Rødseth et al. [66] introduces the term 'Degree of Control' to define the onboard crew or operator's ability to reach the control position and to gain sufficient situational awareness to act safely and efficiently within a given time frame. This Degree of Control is denoted from C0 to C3. If there is a need to distinguish between control from an on-board

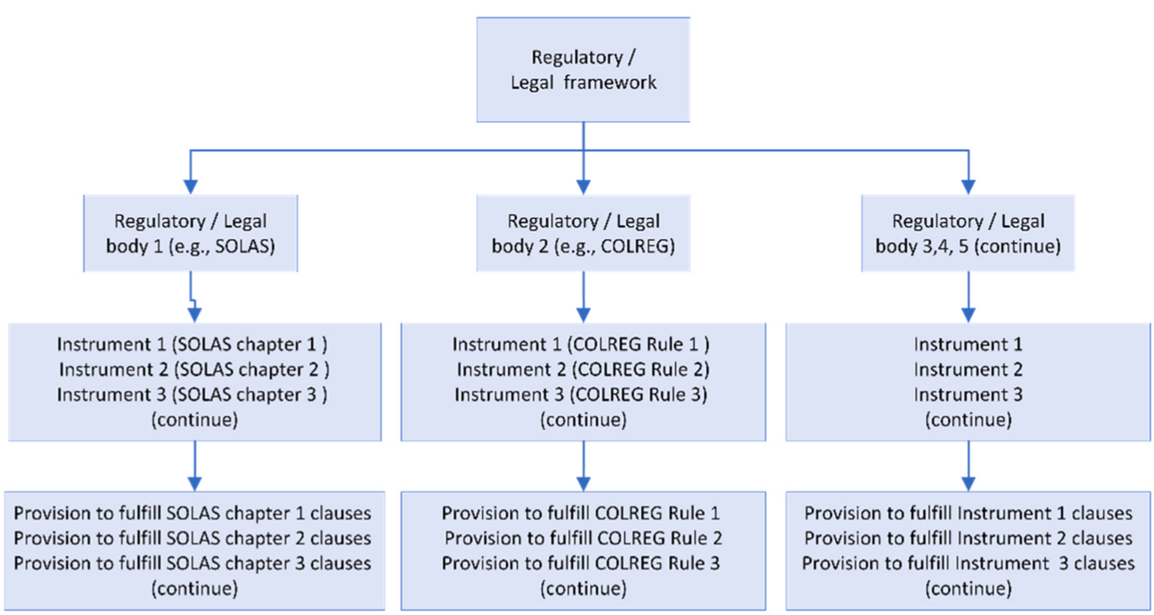

Fig. 3. Formation of regulatory and legal frameworks.

control station by crew, or personnel at an RCC, the prefixes O (Onboard) and R (Remote) are used, e.g., OC3 or RC2. Conversely, to decide the automation's ability to operate without direct control or supervision from operators, 'Degree of Automation' is defied and denoted from DA0 to DA3. According to Rødseth et al. [66], the investigated use case considers constrained automation (DA2) with supervisory control and discontinuous operator control (C2).

To understand the degrees of automation and control considered in the considered SSS use case against the IMO defined autonomy levels, the mapping shown in Table 3 was performed. The columns represent the human control degrees whereas the rows represent the automation degrees. The unlabelled cells represent combinations that cannot be sustained. The mapping demonstrates that the investigated use case has an IMO defined autonomy level RU, which corresponds to the constrained automation level (DA2) with supervisory control and discontinuous operator control (C2).

In a legal context, compliance with the provisions a possible at lower autonomy levels without any amendments, just by considering the equivalences, whereas amendments or even new regulations might become necessary at higher autonomy levels. Therefore, this study considers the IMO defined autonomy levels (see Appendix A) used in the Regulatory Scoping Exercise (RSE) [25], which are: M: Manual navigation with automated process and decision support; R: Remotely controlled ship with crew on board; RU: Remotely controlled ship without crew on board, and A: Fully autonomous ship.

5. Regulatory framework amendment

5.1. Mapping of International regulatory bodies

The mapping of the International regulatory bodies applicable to the SSS-MASS use case and covered by the investigation is listed in Table 4.

5.2. Identified gaps and proposals for instruments within international regulatory bodies

This section analyses and identifies the gaps in compliance with international instruments for the investigated SSS-MASS use case. Recommendations/amendments or new developments are proposed to address its operation. The regulatory bodies mapped in Table 3 are considered, as they are sufficient to cover the major SSS-MASSs operations. The proposals are considered adaptable wherever possible based on different levels of autonomy and the provisions are addressed by either: developing interpretations/equivalences, amending existing provisions, developing a new provision or not proposing changes nothing as it does not hinder SSS-MASSs operation. Additionally, the provisions are classified to identify the ones that require worldwide acceptance and assure the sailing of SSS-MASSs on international waters. The identified gaps, classified by their severity levels (ranging from less severe to high severity), are listed in Appendix B.1. For a more comprehensive version of the gaps, along with well-justified proposals, supplementary material is included with this study.

Table 4
Mapping of international regulatory bodies for SSS-MASS use case.

Regulatory bodies	Purpose
SOLAS Convention [35]	International Convention for the Safety of Life at Sea, 1974, deals with requirements about safety of life at sea. The current SOLAS Convention includes Articles setting out general obligations, amendment procedure and so on, followed by an Annex divided into 14 chapters.
Load Line Convention [36-38]	IMO International Convention on Load Lines (CLL), 1966, deals with requirements about Load Lines and its associated Intact Stability Code (Protocol of 1988, Part A), and the IMO Instruments Implementation Code (III Code).
Tonnage Convention [39]	IMO International Convention on Tonnage Measurement of Ships (TMC), 1969, deals with requirements about tonnage measurement.
STCW Convention and Code [40,41]	IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, and Seafarers' Training, Certification and Watchkeeping Code, deal with training, certification and watchkeeping requirements.
COLREG Convention [42]	IMO Convention on the International Regulations for Preventing Collisions at Sea, 1972, deals with requirements for preventing collisions at sea.
SAR Convention [43]	International Convention on Maritime Search and Rescue 1979, deals with maritime search and rescue requirements.
MARPOL Convention [44]	IMO International Convention for the Prevention of Pollution from Ships, 1973, deals with requirements for the prevention of pollution of the marine environment by ships from operational or accidental causes.
MLC Convention [45]	ILO Maritime Labour Convention, 2006, embodies all up-to-date standards of existing international maritime labour conventions and recommendations.
IMO Interim Guidelines for MASS trials [46]	IMO Interim Guidelines for MASS trials MSC.1/Circ.1604, 14 June 2019, assist relevant authorities and relevant stakeholders with ensuring that the trials of MASS related systems and infrastructure are conducted safely, securely and with due regard for protection of the environment.
IMO Guidelines on maritime cyber risk management [47]	IMO Guidelines on maritime cyber risk management MSC-FAL.1/Circ.3, 5 July 2017, provide high-level recommendations on maritime cyber risk management to safeguard shipping from current and emerging cyber threats and vulnerabilities.

5.2.1. SOLAS convention

This convention (International Convention for the Safety of Life at Sea, 1974 [35]) deals with requirements for the safety of life at sea and specifies the minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag states are responsible for ensuring that ships under their flag comply with its requirements, and the certificates prescribed in the Convention. The

Table 3
Mapping of IMO proposed and SSS use case autonomy levels.

	C0	C1	C2	C3
DA0				M
DA1			R	R
DA2		RU	RU	RU
DA3	A	RU	RU	RU

current SOLAS Convention includes Articles setting out general obligations, and amendment procedures, followed by an Annex divided into 14 chapters.

The study identifies several key gaps in the context of SSS-MASSs operations, along with corresponding proposals for addressing them. These gaps include: (a) the need for comprehensive definitions and terminology specific to SSS-MASSs operations, (b) amending the regulations for habitable conditions and those pertinent to emergency systems and crew-related procedures, (c) the provision for Continuous Synopsis Record (CSR) and casualty investigations for both the RCC and onboard ship, and (d) the regulations concerning certificates, manuals, and security definitions. To address these gaps, the provided recommendations include: (a) adapting the list of definitions mentioned in [29] along with clarifying the definitions of "master," "crew," and "responsible person," particularly considering their absence onboard, (b) designating the remote operator at the Remote-Control Centre (RCC) as the authority, introducing the terms 'Digital Captain' and 'Digital Chief,' (c) granting exemptions from habitable conditions requirements at autonomy levels RU and A, where crew presence is not anticipated, (d) exempting the unmanned MASSs from certain emergency requirements while focusing on essential subsystems, (e) establishing distinct control stations and introducing a central manual override station, (f) facilitating the CSR process at the RCC, while ensuring the RCC operator's involvement in marine casualty investigations, (g) providing electronic copies of certificates onboard ship, (h) clarifying the roles of RCC Security Officers, and (i) outlining the critical functionalities of the ship system. These types of provisions, as they require definition or clarification-wise amendments, are considered of low severity in terms of achieving worldwide acceptance. Thus, these provisions can be prioritised (compared to others) when preparing the roadmap for SSS-MASSs adoption.

The other type of identified provisions, considered to be of medium severity level where the KETs are sufficient to justify the alternatives with equivalent or even enhanced safety levels. The recommendations put forward to address these types of gaps include: (a) adding the three fundamental components (ship control system, connectivity, and remote control centre) along with their functions in the ship system, (b) adopting a risk-based approach for redundancy in ship-shore communication, and (c) clarifying roles at different autonomy levels. The recommendations of this category cover various aspects, including alarms, redundant gauge glass, communication protocols, damage control plans, distress alerts, and expanding the master's duties. Furthermore, recommendations are provided to clarify terms pertinent to electronic bridge operations, private network coverage, bandwidth needs, distress signalling, and the overriding authority for remote operators.

The provisions that necessitate explicit human intervention are classified as high severity. The provided recommendations include: (a) autonomous operation of doors and equipment, (b) redundancy in sensors, automatic control, and central manual override stations, (c) inspections and tests of machinery space at port, (d) alternative safety measures, (e) a goal-based approach for defining the system architecture. Additionally, exemptions should be granted for (a) accommodation and (b) crew-related requirements, specifying a maximum duration for unmanned operation.

It must be noted that the following SOLAS chapters are not applicable to the SSS use case, and therefore, not reviewed herein: (a) Chapter VIII dealing with the requirements for nuclear ships, (b) Chapter X dealing with the requirements for high-speed crafts, (c) Chapter XII dealing with the requirements for additional safety measures for bulk carriers, and (d) Chapter XIV dealing with the requirements for ships operating in polar waters.

Additionally, no amendments and other relevant findings are identified for Chapter XIII, which deals with requirements for compliance verification.

5.2.2. Load line convention

The IMO International Convention on Load Lines (ICLL) [36] deals with requirements for Load Lines and its associated Intact Stability Code (Protocol of 1988, Part A) [37], as well as the IMO Instruments Implementation Code (III Code) [38].

The convention requires identifying an equivalent person responsible for the master's duties and responsibilities, as well as includes provisions for crew safety, such as guardrails and elevated walkways, which might seem unnecessary for SSS-MASSs without seafarers. The provided recommendation considers keeping these provisions for overall human safety. Inspectors, pilots, PSC inspectors, or repair personnel might still need vessel access for inspections, navigation, security, or maintenance, especially during port mooring. These recommendations are classified as low severity, necessitating only clarifications.

To address the gaps at a medium severity level, the provided recommendations deal with two crucial aspects pertaining to provisions and assumptions. Firstly, provisions requiring manual intervention or crew presence (such as operating valves, windows, or side scuttles) should be updated to match autonomous functionality. The provided recommendations include (a) automated closing mechanisms, (b) sensors to check bulkhead and ventilation closure status, and (c) methods to seal external openings, considering different situations, including port service delegation. Secondly, the ICLL requires that certain pre-departure functions are performed by the master and crew. The provided recommendation includes an interpretation designating the RCC operator as responsible for these tasks.

5.2.3. Tonnage convention

The IMO International Convention on Tonnage Measurement of Ships (TMC), [39] deals with requirements for tonnage measurement. The provided recommendations to address the gaps of low-severity include (a) amending the definitions of crew, master and a passenger (Annex I, Reg. 2(6)), and (b) designating an RCC operator as the master for MASSs at RU and A autonomy levels A. A comprehensive description for a passenger is provided to differentiate from the master, remote operator, crew, RCC personnel, and others engaged in ship-related activities. Additionally, the definition of 'master' is provided similar to SOLAS Chapter II-1, No XIV.

5.2.4. STCW convention and code

The IMO International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers [40] and the Seafarers' Training, Certification, and Watchkeeping Code [41] deal with training, certification, and watchkeeping requirements to ensure that seafarers can fulfil their duties and responsibilities on board ships. The recommendation to address the gaps of low-severity level includes the definition of seafarers, distinguishing between those with operational responsibilities and others with different duties. It recommends designating an RCC operator as a master, potentially from a seafarer background for steering/monitoring SSS-MASSs at autonomy levels RU and A. This interpretation aligns the master's rights and obligations with the remote operator's role, covering navigational responsibilities and representing the ship/shipowner to authorities. Additionally, the recommendation stresses that local personnel will handle maintenance and repair work onboard when the ship is moored. The RCC will collaborate with local human resources at various destinations to establish a work permit system, ensuring the effective operation of unmanned ships while maintaining safety and compliance with regulations.

The identified gap of medium-severity level includes: (a) the inadequacy of the existing regulatory framework in addressing the training and qualification of remote operators (RCC personnel) for SSS-MASSs, given the absence of onboard seafarers, (b) watchkeeping requirement mention in Chapter VIII, Regulation 2(2)(1), and (c) the introduction of remote operators. The provided recommendations consider (a) amending the STCW convention to incorporate training frameworks and minimum supervised simulator hours for RCC operators, as outlined in the AUTOSHIP project's D7.2 guidelines [67], (b) changes in Chapter VIII, Regulation 2(2)(1) to allow watchkeeping navigational officers to periodically supervise RCC operators and have temporary off-ship duties, (c) a new qualification framework for RCC personnel based on STCW requirements and operational technology, emphasizing navigational expertise and technical knowledge for remote operators, (d) integrating the D7.2 training frameworks and STCW convention amendments to cover training, certification, medical standards, control procedures, competence, rest hours, and drug/alcohol prevention. The same drug and alcohol provisions applicable to ships should also apply to RCC, (e) integrating the system-operated tasks onboard and proposing to consider Key Enabling Technologies (KETs) for remote steering/monitoring. They suggest defining four types of tasks for RCC personnel—monitoring, supervision, intervention, and direct control—depending on the operation's complexity and scope, supported by an onboard Intelligent Machinery System (IMS) / Digital Chief and Autonomous Navigation System (ANS) / Digital Captain.

5.2.5. COLREG convention

The IMO Convention on the International Regulations for Preventing Collisions at Sea [42] deals with requirements for preventing collisions at sea. The study addresses various regulatory considerations for crewless ships, particularly focusing on (a) the navigational aspects and (b) collision avoidance. The provided recommendations include: (a) incorporating special regulations for navigational signs to distinguish between manned and unmanned ships, highlighting the importance of maintaining navigational lights and shapes for conveying information, (b) discussing the ability of crewless ships to indicate distress signals remotely and emphasizing that existing provisions won't hinder their operability, (c) suggesting clear procedures and testing requirements for demonstrating the capabilities of remote operators and automated ship control systems, including collision avoidance algorithms and key enabling technologies, (d) providing interpretations for the roles of "Master or crew" in algorithm-based control and for meeting lookout standards, ensuring safe speeds, evaluating collision risks, and taking necessary actions in SSS-MASSs, and (e) establishing performance criteria for situations to address communication disruptions between remote operators and ships.

5.2.6. SAR convention

The International Convention on Maritime Search and Rescue [43] deals with maritime search and rescue requirements. For this convention, the study emphasises the need to clarify the application of rescue and distress concepts to unmanned SSS-MASSs. Recommendations include: (a) exemptions from the duty to render assistance for such ships, particularly at autonomy levels RU and A, (b) SSS-MASSs could conduct sweep searches and relay distress alerts but refrain from directly recovering individuals in distress unless their equipment allows for it, (c) activation of the Global Search and Rescue (SAR) system should be similarly limited for unmanned SSS-MASSs as unmanned SSS-MASSs without seafarers, workers, or passengers on board might require recovery rather than rescue, (d) clarifications regarding the use of distress notification equipment and procedures for alerting distress status, (e) explaining SSS-MASSs' ability to use the Global Maritime Distress and Safety System (GMDSS) for alerting distress status to Maritime Rescue Co-ordination Centres (MRCCs), (f) advices considering salvage procedures and (g) the mandatory use of Emergency Position Indicating Radio Beacons (EPIRBs) for SSS-MASSs to ensure environmental and maritime safety.

5.2.7. MARPOL convention

The IMO International Convention for the Prevention of Pollution from Ships [44] deals with requirements for the prevention of pollution of the marine environment by ships from operational or accidental causes. This convention falls within the scope of the IMO Marine Environment Protection Committee (MEPC) and not within the scope of the IMO Maritime Safety Committee (MSC). The recommendations in study suggest: (a) interpretations into maritime regulations regarding reporting obligations and emergency preparedness for SSS-MASSs, and (b) keep the emergency plans both at the RCC and onboard SSS-MASSs, in accordance with relevant MARPOL chapters and OPRC Convention articles. For reporting obligations outlined in MARPOL Protocol 1, it suggests assigning this responsibility to the remote operator at the RCC for SSS-MASSs. This suggestion is based on the technical feasibility of collecting pollution-related information. Regarding emergency preparedness, keeping the emergency plans both at the RCC and onboard SSS-MASSs ensure effective pollution prevention and response measures while accommodating the unique operational aspects of crewless ships.

5.2.8. MLC convention

The ILO Maritime Labour Convention [45] embodies all up-to-date standards of existing international maritime labour conventions and recommendations. This convention falls within the scope of the International Labour Organisation and not within the scope of the IMO Maritime Safety Committee (MSC). For this convention, the recommendation proposes an amendment to the Safe Manning Document regulations for remote control centre (RCC) operators by adding a provision that outlines workload limits for RCC operators and emphasises the necessity for medical examinations, especially in cases requiring special criteria. It specifically mentions managing workload based on exposure to electronic screens. The purpose of this amendment is to ensure that RCC operators maintain appropriate work and rest hours, considering the unique demands of their role, while also addressing potential health concerns. While unmanned SSS-MASSs may already align with safety requirements outlined in UNCLOS Article 94(4)(b) and SOLAS chapter V, regulation 14(1), this adjustment aims to further enhance the regulations to suit higher autonomy levels.

5.2.9. IMO interim guidelines for MASS trails

The IMO Interim Guidelines for MASS trials (MSC.1/Circ.1604) [46] has been developed to assist relevant authorities (coastal states, flag states; and states) and stakeholders (shipowners, authorised representatives, operators and other involved parties in the conduct of MASS trials) with ensuring that the trials of SSS-MASSs related systems and infrastructure are conducted safely, securely and with due regard for the protection of the environment. This circular was approved by the Maritime Safety Committee, at its 101st session [68]. The recommendation suggests no changes to the existing Interim Guidelines. It justifies this by emphasising the need for trials of SSS-MASSs related systems and infrastructure to maintain safety, security, and environmental protection standards equivalent to those outlined in relevant regulations. The circular outlines ten main objectives for planning and conducting these trials, covering aspects such as risk management, compliance, personnel qualifications, human factors, infrastructure, communication, reporting, scope, and cyber risk management. The Committee aims to continually review and adjust the guidelines based on experience and changing circumstances.

5.2.10. IMO Guidance on maritime cyber risk management

The IMO Guidelines on maritime cyber risk management (MSC-FAL.1/Circ.3) [47] provide high-level recommendations on maritime cyber risk management to safeguard shipping from current and emerging cyber threats and vulnerabilities. The Maritime Safety Committee [69] also adopted the Resolution MSC.428(98) dealing with Maritime Cyber Risk Management in Safety Management Systems. This resolution urges administrations to incorporate cyber risks into existing safety management systems (as defined in the ISM Code) by the first annual verification of a company's Document of Compliance after January 1, 2021, with applicability to the SSS-MASS use case. While recommending no amendments, it proposes including the issuance of a cyber security compliance certificate for cloud infrastructure used in SSS-MASSs. The justification lies in considering additional rules, standards, and guidelines, such as Bureau Veritas Rule Note, ISO/IEC 27001 standard, Guidelines on Cyber Security for Ships, and NIST Framework. Moreover, the need for discussing cyber security certification of cloud infrastructure is emphasised to engage international workgroups.

5.3. Mapping of European regulatory bodies

The mapping of the European Union regulatory bodies applicable to the considered SSS-MASS use case is listed in Table 5.

5.4. Identified gaps and proposals for instruments within European Union regulatory bodies

This section addresses the gaps in compliance with European Union regulations for the considered SSS-MASS use case. Recommendations/ amendments or new developments are proposed to address the identified gaps for its operability in European waterways. The regulatory bodies mapped in Table 4 are sufficient to cover the European governing bodies for the SSS autonomous operation. The proposals are considered dynamic, as mentioned in the preceding sections, and addressed according to one of the four ways employed in RSE [25]. This paper summarises the identified gaps in the instruments within EU regulatory bodies and provides proposals for their modifications. The identified gaps, categorised by their severity levels (ranging from less severe to high severity), can be found in Appendix B.2. An extended version of the gaps as well as proposals with proper justification is provided as supplementary materials to this study.

5.4.1. Directive 96/98/EC

The Council Directive 96/98/EC on marine equipment [70] deals with the uniform application of the relevant international instruments relating to marine equipment to be placed on board EU ships and to ensure the free movement of such equipment within the Union. The current regulation stipulates that marine equipment on EU ships must adhere to international design, construction, and performance standards. However, these standards are not yet established for SSS-MASSs. To bridge this gap, a suggestion is made to create a bilateral agreement among EU member states that outlines the marine equipment requirements for SSS-MASSs. This agreement would ensure a shared understanding of design, construction, and performance criteria. This proactive approach is seen as more efficient than waiting for the development of international standards, as it would expedite the process. This proposal aligns with Article 30, allowing non-compliant equipment if it meets the directive's intent as determined by the flag state, and Article 31, permitting exemptions for equipment undergoing testing or evaluation.

Table 5
Mapping of European Union regulatory bodies for SSS-MASS use case.

Regulatory bodies	Purpose
Directive 96/98/EC [70]	Council Directive 96/98/EC of 20 December 1996 on marine equipment, deals with the uniform application of the relevant international instruments relating to marine equipment to be placed on board EU ships and to ensure the free movement of such equipment within the Union.
Directive 2009/16/EC [48]	Directive 2009/16/EC of the European Parliament and the Council of 23 April 2009 on Port State Control, deals with common criteria for control of ships by the port State and harmonising procedures on inspection and detention.
Directive 2010/65/EU [49]	Directive 2010/65/EU of the European Parliament and of the Council of 20 October 2010 on reporting formalities for ships arriving in and/or departing from ports of the Member States and repealing directive 2002/6/EC, deals with the simplification and harmonisation of administrative procedures applied to maritime transport by making the electronic transmission of information standard and by rationalising reporting formalities.
Directive 2002/59/EC [50]	Directive 2002/59/EC of the European Parliament and of the Council of 27 June 2002 establishing a Community vessel traffic monitoring and information system, deals with enhancing the safety and efficiency of maritime traffic, improving the response of authorities to incidents, accidents or potentially dangerous situations at sea, including search and rescue operations, and contributing to better prevention and detection of pollution by ships.
Regulation (EC) No 725/2004 [51]	Regulation (EC) No 725/2004 of the European Parliament and of the Council of 31 March 2004 on enhancing ship and port facility security, latest consolidated version: 20/04/2009, deals with enhancing the security of ships used in international trade and domestic shipping and associated port facilities in the face of threats of intentional unlawful acts.

5.4.2. Directive 2009/16/EC

The Directive 2009/16/EC of the European Parliament and the Council on Port State Control [48] deals with common criteria for control of ships by the port State and harmonising procedures on inspection and detention. The directive has gaps related to (a) the use of the terms 'master' and 'crew' without clear definitions when they are not physically present on board, and (b) lack of generic parameters for determining the ship risk profile in SSS-MASSs operations. Recommendations include (a) clarifying the terms 'master' and 'crew' by interpreting a RCC operator as fulfilling a master's responsibilities for conventional ships as well as introducing definitions for 'autonomous ships,' 'remote control centre,' and 'remote operator.', and (b) amendments in Annexes I and II to specify the generic parameters for determining the ship risk profile in SSS-MASSs operations. These amendments suggest categorising SSS-MASSs as higher risk initially due to their operational reliability and considering its type and age for risk assessment.

5.4.3. Directive 2010/65/EU

The Directive 2010/65/EU of the European Parliament and of the Council on reporting formalities for ships arriving in and/or departing from ports of the Member States and repealing directive 2002/6/EC [49] deals with the simplification and harmonisation of administrative procedures applied to maritime transport by making the electronic transmission of information standard and by rationalising reporting formalities. There is a gap in the current directive concerning the definitions of "master" and "person duly authorised," particularly when they are not physically on board the ship. This issue is exemplified in Article 4 regarding notifications before port arrival. A proposal is put forth to specify the meanings of these terms in situations where they are not present on board, aligning with Directive 2009/16/EC. Additionally, there's a broader recommendation to clarify the legal role of the master to address the ambiguity surrounding their responsibilities and authority.

5.4.4. Directive 2002/59/EC

The Directive 2002/59/EC of the European Parliament and of the Council 02 establishing a community vessel traffic monitoring and information system [50] deals with enhancing the safety and efficiency of maritime traffic, improving the response of authorities to incidents, accidents or potentially dangerous situations at sea, including search and rescue operations, and contributing to more effective prevention and detection of pollution by ships. The directive has gaps relating to the term "master" used throughout and proposes its clarification, especially in Article 4, Article 17, Article 18, Article 18a, and Article 19, considering the master's absence on board. It recommends referencing Directive 2009/16/EC. Additionally, Article 16, which addresses information transmission about hazardous ships, lacks clarity about whether it includes SSS-MASSs operations. The proposal suggests interpreting "ships" in Article 16 to encompass the operability of SSS-MASS, justifying this by highlighting that SSS-MASSs operations align with the article's operational context and should not be deemed ships posing hazards.

5.4.5. Regulation (EC) No 725/2004

The Regulation (EC) No 725/2004 of the European Parliament and the Council on enhancing ship and port facility security [51], (latest consolidated version: 20/04/2009) deals with enhancing the security of ships used in international trade and domestic shipping and associated port facilities in the face of threats of intentional unlawful acts. The issues identified in this regulation are similar to those in the ISPS Code.

5.5. National regulations

The scope of this section is limited to the analysis of the Norwegian Maritime Authority (NMA) guidelines for the design, building, testing and operating the investigated SSS MASS use case and the pilotage act 1987 to address the pilotage issues.

5.5.1. NMA guidelines for MASS operation

Norwegian Maritime Authority (NMA) promoted autonomous shipping to a large extent and developed their own guidelines on handling SSS-MASSs [52]), based on the IMO MSC.1/Circ.1455 [71] process.

Following guidance are referred to in the Section 3 of this NMA document:

i. Ship Safety and Security Act
ii. Reg. n°.1072 on construction of ships
iii. Reg. n°.666 on the manning of Norwegian ships (manning Reg. 09)
iv. Reg. n°.537 on watchkeeping on passenger and cargo

In addition, the Norwegian Coastal administrations are conducting the Act relating to the Pilot Services.

5.5.2. Pilotage act 1987

Pilotage is subject to various national regulations in each coastal and port State, where an authorised or licensed pilot needs to manoeuvre the ships through dangerous or congested waters, such as harbours or river mouths. Pilots are higher-skilled professionals in navigation, as they are required to know immense details of waterways as well as display expertise in navigating ships of all types and sizes.

Pilotage Act 1987 [64] governs the operation of maritime pilotage in the United Kingdom, but it lacks provisions for the integration of SSS-MASSs. Pilotage is often mandatory for ships in various ports, posing challenges for autonomous vessel trials. The identified gaps, categorised by their severity levels (ranging from less severe to high severity), can be found in Appendix B.3. An extended version of the gaps as well as proposals with proper justification is provided as supplementary materials to this study. The provided proposal suggests that the Act should be temporarily exempted by local governments to allow trials of SSS-MASSs. For long-term integration, recommendations include incorporating provisions such as (a) fixed pilot boarding arrangements, (b) control transfer to the pilot, (c) redundant and secure communication connections, and (d) training for pilots on unmanned ships. The justification is that these provisions would accommodate lower autonomy level ships and trials for higher autonomy levels, ultimately moving toward shore-based pilotage with remote operators or specialised personnel taking control. Alternatively, specially trained remote operators at a RCC could act as pilots, necessitating explicit regulation.

5.6. Classification societies guidelines for MASS operation

This study analysed the guidance provided by the following classification societies: Bureau Veritas (BV) [53], [54], DNV [55], [56], LR [57], ABS [58], [59], NK [60], Russian Maritime Register of Shipping (RS) [61], China Classification Society (CCS) [62] and UK Maritime [63]. The IMO MSC.1/Circ. 1455 [71] steps were also employed to check the harmonisation of the classification societies guidelines.

The assessment revealed inconsistencies in the alignment of class societies' guidance for SSS-MASSs with the IMO MSC.1/Circ. 1455. However, Lloyd's Register (LR) and the American Bureau of Shipping (ABS) guidance for MASS are more closely aligned with the Maritime UK code for MASS and goal-based approaches. Notably, discrepancies arise due to different expert groups' involvement in each class society's guidance development. This isn't the case for guidance related to novel technology introduction, which displays similarities among investigated class societies (BV, DNV, ABS) and strong resemblance to IMO MSC.1/Circ. 1455.

Furthermore, the evaluation indicates that class guidance is more extensive within the scope of preliminary design and analysis, outlining high-level requirements for KETs of SSS-MASSs. However, there's limited reference to detailed KET design and analysis, with such information mainly present in the guidance and recommended practices for novel technology assurance. Particularly, aspects concerning Artificial Intelligence (AI) and Machine Learning (ML) are inadequately covered. Future development of SSS-MASSs' guidance should focus on addressing these aspects more thoroughly in the detailed design and analysis of KETs.

Another aspect that is worth mentioning is related to testing of SSS-MASSs functions. Currently, autonomous function testing aspects are dispersed across multiple documents, lacking a clear process for developing and testing KETs, such as collision avoidance system safety performance. This deficiency should be rectified through inclusion in class societies' recommended practices, codes, and guidance.

6. Legal framework analysis and proposed amendments

The legal framework includes the jurisdictional rules, which lay down the states' rights and obligations to take measures with respect to ships. These are laid down in the UN Convention on the Law Of the Sea (UNCLOS) [65]. This convention has been ratifies by 168 parties, which includes 167 states and the European Union. This section discusses UNCLOS in general and different jurisdictional issues to identify the hurdles in SSS-MASSs' operability and associated recommendations to address those at national or international levels.

6.1. UNCLOS

UNCLOS defines the rights and obligations of states over the seas. It enjoys widespread acceptance worldwide and its provisions regarding navigational rights and duties are widely accepted. The convention lay down the rules for the establishment and delimitation of maritime zones and includes rules for each zone with respect to states' rights and obligations. The key issues addressed by this body of law include: to what extent ships can navigate in different sea areas; what obligations do states have over ships flying their flags; and what rights do other states have to interfere in the navigation of ships in different sea areas.

A first and fundamental question in the context of SSS-MASSs to be resolved in UNCLOS is whether ships without a crew on board are 'ships' or 'vessels' within the meaning of the convention at all. The two terms are used interchangeably in UNCLOS, but neither is defined. Article 91 (Nationality of Ships) provides that each state shall fix the conditions for the grant of its nationality to ships, which implies that the national law of the flag state will be critical for the definitions used. This study identified that the existing international conventions that define the term 'ship' do not include references to crewing, whereas at a national level, the definition of a ship is usually disconnected from whether or not the ship is manned. However, introducing the term "autonomous ship" as a special case of a ship into UNCLOS is necessary in particular due to its wide scope of application. Once it is defined, SSS-MASSs could be regarded as vessels/ships by the virtue of their size, features and functions, and like other conventional ships, the jurisdictional rules are also applicable to SSS-MASSs. This paper summarises the identified gaps in the instruments within ULCLOS and provides proposals for their modifications. The identified gaps, categorised by their severity levels (ranging from less severe to high severity), can be found in Appendix B.3. An extended version of the gaps as well as proposals with proper justification is provided as supplementary materials to this study.

6.2. Jurisdictional issues

Flag state and Port and Coastal state jurisdictional issues are identified in this section. Moreover, the challenges for SSS-MASSs' wide acceptability are discussed.

6.2.1. Flag state jurisdiction

Flag state's jurisdiction applies irrespective of the ship's location. UNCLOS establishes that all states have a right to the sail ships flying their flag and to fix the conditions for granting nationality to ships (Article 90 and 91(1)). It also includes the detailed duties for flag states. Generally, UNCLOS avoids 'freezing' the requirements of flag states at a given point in time or technical level by not providing any precise obligations, and keeping it to an abstract level, while still preserving the international character of rules in question.

However, in the context of SSS-MASSs, requirements for the manning (Article 94(2)(b)) need to be handled. Additionally, lack of harmonised rules (Article 94(5)) could provide a general barrier for the wide acceptance of SSS-MASSs. To address this issue, a bilateral agreement between two contracting parties or agreements between states in a broader geographical area (e.g., basic sea, North Sea, Mediterranean Sea) could be considered. This would establish commonly agreed rules for SSS-MASSs' functionality and mitigate the regulatory gap. Alternatively, regulations could be enforced to ensure the general acceptability of SSS-MASSs amongst different nations. However, it would take a long time to establish such international rules.

6.2.2. Port and coastal state jurisdiction

Port and coastal states' jurisdiction defines other states' parallel jurisdiction over the same ship depending on the maritime zone concerned. The coastal state's authority over a foreign ship increases with the proximity of the ship to its shores. In the context of port and coastal state jurisdiction, the lack of universally agreed rules and regulations for SSS-MASSs can impede their access to ports, thereby restricting their freedom of movement. The proposal suggests (a) incorporating the acceptance criteria in general terms for the unmanned SSS-MASSs into UNCLOS to grant admission into harbours, and (b) defining the roles of Port and Coastal States in recovering unmanned SSS-MASSs under complete loss of control is advised. These measures would create a framework to ensure coastal waterway safety and the recognition of distress situations. However, for the right of 'innocent passage' through territorial seas, no action is required as long as SSS-MASSs comply with the concept of ship and remains outside the activities stipulated in Article 19(2). Regarding the obligation set in Article 94(4)(b) for ships to have a master and crew, the recommendation is to interpret a remote operator at a RCC as the master for autonomy levels R and RU, and to exempt autonomy level A from manning requirements in UNCLOS. The justification revolves around the practical roles of remote operators and the concept of safe manning levels, aiming to ensure compatibility with UNCLOS obligations while accommodating various autonomy levels of SSS-MASSs.

6.3. Other provisions

Apart from jurisdictional concerns, certain UNCLOS provisions pose potential challenges for SSS-MASSs' operations. Specifically, (a) the obligation outlined in Article 94(4)(b) that mandates ships to have a qualified master and crew has been discussed earlier, and (b) Article 98 (1) of UNCLOS [65] which entails ship masters assisting those in distress, with reduced obligations in cases of serious ship danger. These regulations could have limitations regarding SSS-MASSs due to the absence of on-board masters. The recommendation suggests (a) an exemption needs to be introduced for unmanned SSS-MASSs, allowing their duty to render assistance to be limited, (b) SSS-MASSs could engage in sweep searches and relaying distress alerts, at autonomy levels RU and A, but not in direct person recovery from water, unless onboard equipment permits, (c) at level R, crew and Remote Control Centre (RCC) operators act as masters, while at level RU, remote operators' physical assistance may be limited and relayed through RCC to Maritime Rescue and Coordination Centres (MRCCs), (d) for fully MASSs, RCC operators intervene to relay distress signals to MRCCs, and (e) advanced remotely operated lifesaving devices might assist MASSs, though equipping them with such devices could impact cost efficiency.

7. A roadmap towards recommended policy implementaton

To establish a roadmap towards implementing the proposed recommendations that promotes commercial SSS-MASSs, it is essential to plan and initiate a set of activities. One of the initial steps involves identifying the major regulatory and legal challenges that pose barriers to the acceptance of SSS-MASSs. Additionally, having agreed-upon standards for the safe operation of SSS-MASSs is vital at both national and international levels. These standards should be flexible to support the development of various ships incorporating autonomous systems. Currently, the use of autonomous systems is limited to small-sized ships operating within a state's territorial area. However, it is anticipated that larger SSS-MASSs will be designed and constructed in the future.

The IMO is in the process of developing a non-mandatory Maritime Autonomous Surface Ships (MASS) code, slated to precede a mandatory MASS code, with the aim of facilitating the general operation of MASS. To formulate the MASS code, the IMO seeks input from the involved stakeholders to identify gaps in instruments within existing frameworks and propose both short- and long-term solutions to address these challenges. According to the IMO's timeline, the MASS code is anticipated to take effect on 1 January 2028. This code will address the gaps of the existing regulatory framework and establish internationally accepted guidelines for MASS. This study findings are informational input to IMO for the MASS code development.

To understand the necessary amendments across different regulatory bodies for the SSS-MASS use case, Fig. 4 (left) provides a visual representation. This figure is prepared considering the international governing bodies mentioned in Table 4 and other EU directives, outlined in Table 5, which covers most of the regulatory bodies for the SSS-MASSs operation in general sailing in EU waterways. Fig. 4 (left) shows that out of the identified provisions requiring justifications or amendments, 62% pertain to SOLAS, 12% to COLREG, 6% to STCW, and 5% to LLC. The remaining 15% are related to other regulatory bodies. It's important to note that while this study primarily focuses on the SSS-MASS use case, it encompasses a wide range of international regulatory bodies that are also relevant to deep sea shipping.

Additionally, this study incorporates the severity analysis as shown in Fig. 4 (right), which reveals 55% of the provisions are found moderately severe which requires technological support to convince the policy makers for their alternative provisions. With the advancement of the technologies and trials of MASS, more experience will be gathered and utilised to amend these provisions further if required. Conversely, 10% of the provisions are found to pose high severity as they require explicit human involvement. For these, temporary exemptions or bilateral agreements between contracting parties, and even broader state-level agreements, could offer interim solutions. However, getting an international acceptance to these provisions would likely require an extended timeline. This analysis also demonstrates that 26% of provision requires definition or clarification wise amendments, an area where IMO could take swift action. For instance, IMO recently published a list

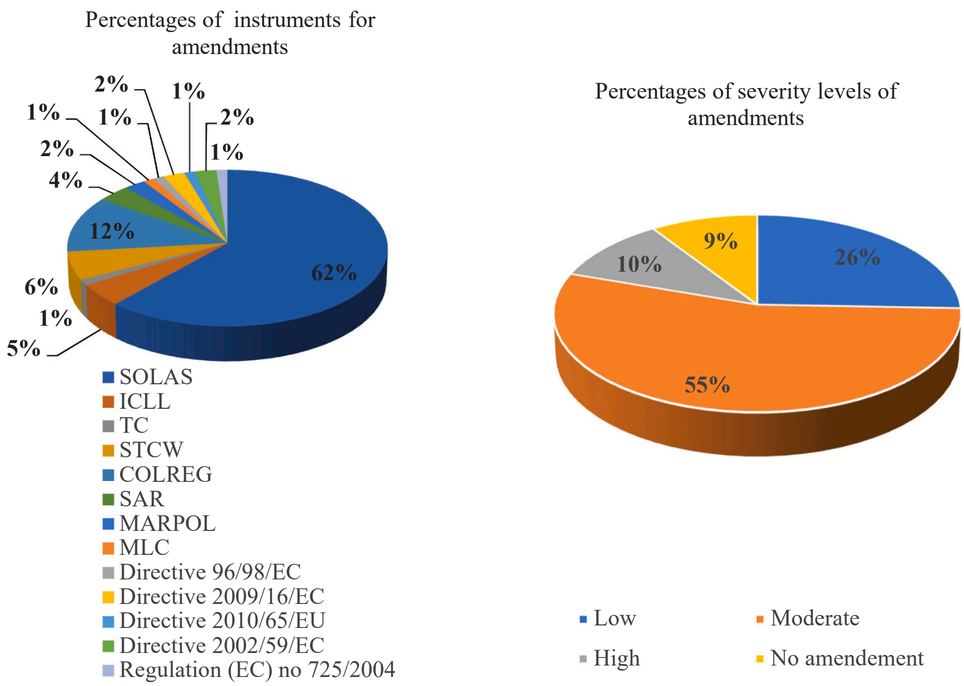

Fig. 4. An insight of provision amendments for regulatory bodies of the AUTOSHIP SSS use case; left: percentages of identified provisions for amendments; right: percentages of severity levels for amendments. Based on the analysis in D7.4 [62].

of useful definition [63] for MASS operation, which is one of the requirements identified in this study and considered to have less severity. Notably, 9% of the provisions do not impede SSS-MASSs operations, rendering no amendments necessary.

Moreover, Fig. 4 provides a comprehensive overview of the required amendments across various instruments within regulatory bodies. It presents the distribution of identified provisions necessitating justifications or amendments, categorised by regulatory body and severity level. This data guides the roadmap's development by highlighting critical areas for amendment focus. The breakdown of provisions per regulatory body—SOLAS, COLREG, STCW, and LLC—helps pinpoint where the most substantial changes are needed. Additionally, the demonstrated severity analysis in Fig. 4 (right) offers insights into the urgency and nature of required amendments, whereas the gradation of severity levels, encompassing less severe, moderately severe, and high severity, informs the prioritisation of amendments. This information shapes the timeline and approach for regulatory adjustments, considering factors like technological progress, policy advocacy, and global acceptance.

Nevertheless, the evolution and integration of SSS-MASSs can be effectively understood through a structured progression spanning four distinct phases as shown in Fig. 5. Each phase encompasses specific objectives and actions aimed at facilitating the safe and efficient adoption of SSS-MASSs technology, along with the implementation of the proposed recommendations. These phases are outlined below, highlighting the key milestones and considerations at each stage of development.

7.1. Phase 0

In this initial phase, the emphasis lies in creating goal-based standards that form the foundation for the journey toward SSS-MASSs. Carrying out a Regulatory Scoping Exercise helps in understanding the limitations and potential obstacles in SSS-MASSs implementation. Interim guidelines for MASS trials offer a practical structure for initial testing and experimentation. One of the key goals is to identify gaps in instruments within the current regulatory, legal, and liability frameworks. By addressing these gaps, the objective is to simplify the operational environment and establish conditions favourable for SSS-MASSs operation. However, during this phase, only conventional ships are anticipated to be operational.

7.2. Phase 1

In this phase, conventional ships are transformed into SSS-MASSs. Existing ships are retrofitted to showcase SSS-MASS abilities through trials and demonstrations. Meanwhile, rules and legal frameworks are adjusted to fit different levels of challenges in these changes. The outcome is the creation of a non-mandatory MASS code, providing guidance for responsible SSS-MASSs operation. As experiences grow, adjustments are proposed to prepare for the construction of new SSS-MASS, ensuring a smooth transition and informed decisions.

7.3. Phase 2

As progress continues, the attention turns to building new SSS-MASSs that have RCC and human involvement. In this phase, changes are made to create a necessary and compulsory MASS code, making the rules stricter. Insights from real-life situations and observations guide further enhancements, leading to better NGASs. The changing nature of this phase highlights the need to adjust regulations and technology to ensure a balanced and effective SSS-MASSs operation.

7.4. Phase 3

In this phase, the goal is to achieve the highest level of autonomy, where NGAS operate completely on their own without RCC or human involvement. This shift is made possible by fully implementing a new MASS code designed specifically for NGAS. This phase marks significant milestones, including technological progress and the complex coordination of regulations and operational standards. The aim is to guarantee the safe and dependable operation of ships that are fully autonomous and unmanned.

While Fig. 5 outlines specific time frames for each phase, predicting exact timelines for policy changes and the development of SSS-MASSs is

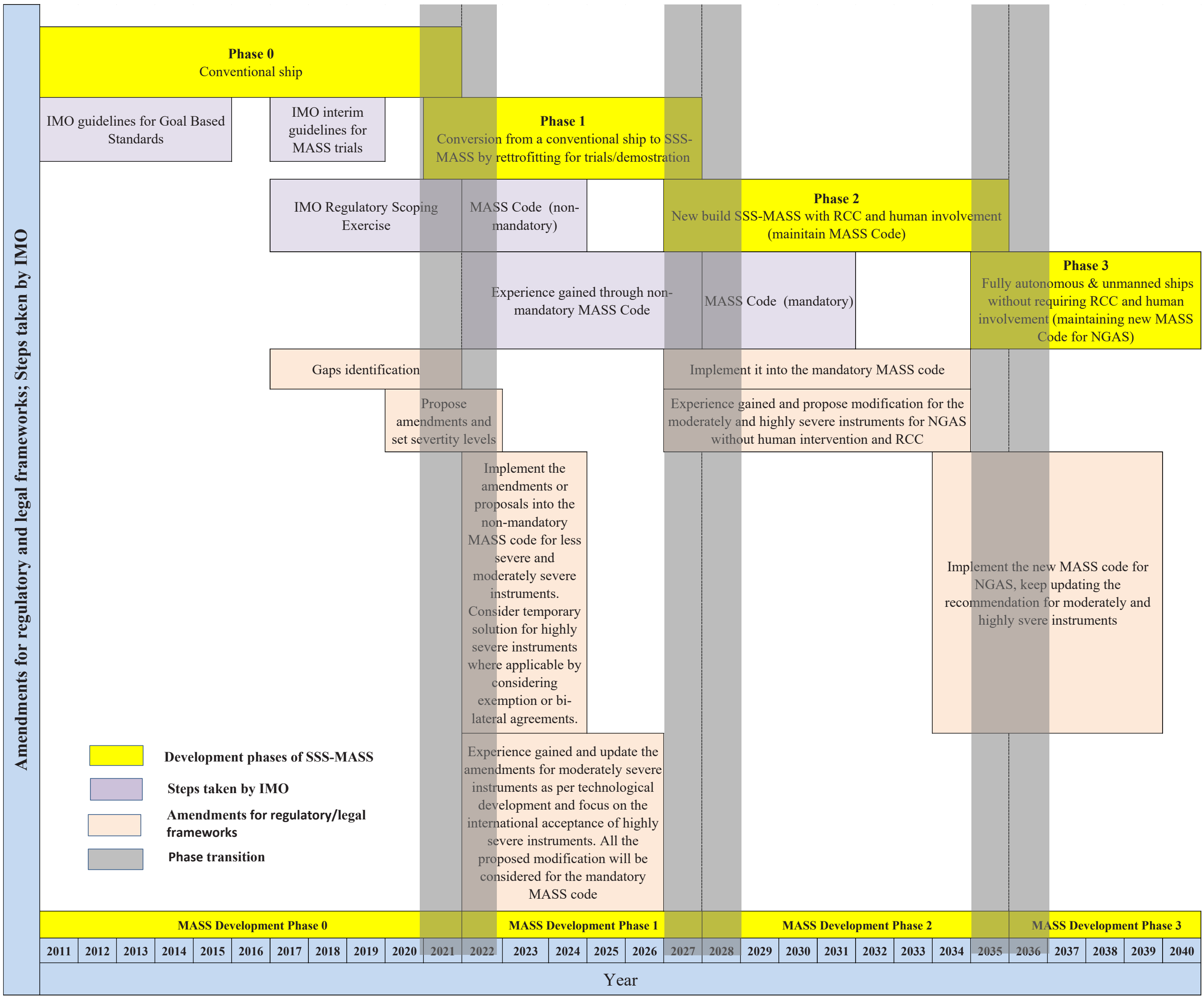

Fig. 5. A roadmap for the policy recommendations implementation along with the SSS-MASSs adoption.

challenging. This difficulty arises from factors like technological advancements, regulatory shifts, and the industry's speed in adopting new technologies. In this study, past accomplishments by the IMO and their ongoing efforts in MASS development are taken into account to provide a general estimate of the time frames for each phase.

The tasks linked to Phase 0 [2011–2021] have already been successfully completed by the IMO. The comprehensive guidelines for goal-based standards [72], regulatory scoping exercise [25], and interim guidelines for MASS trials [73] have been made publicly accessible. Apart from that, considerable research efforts have been pursued to identify the gaps in instruments within the existing regulatory, legal and liabilities frameworks [22–24], [26–28].

During Phase 1 [2021–2027], a crucial task involves converting existing ships into SSS-MASS for comprehensive demonstrations before designing new ones. The AUTOSHIP project [19] has notably showcased autonomous operations of SSS and IWW ships in 2023, contributing significantly to this endeavour. Simultaneously, the IMO has taken a significant step by preparing a non-mandatory MASS code, expected to be completed by the latter half of 2024. To support the development of this non-mandatory MASS code, this study methodically outlines necessary amendments and modifications for the instruments within regulatory and legal frameworks related to the SSS-MASS. These amendments are prioritised based on identified severity levels. To address the existing regulatory framework gaps for SSS-MASS, it is advisable to integrate recommended amendments from this study into the non-mandatory MASS code, considering the least severe and moderately severe provisions. Periodic updates for moderately severe provisions are essential based on industry experience to consider the advances of pertinent technologies and incorporate valuable lessons learned from the MASS operation. The highest severity provisions may require temporary measures, such as exemptions or bi-lateral agreements. To obtain international acceptance for the highest severity provisions, international collaboration between different stakeholders is required.

These non-mandatory MASS codes offer a phased implementation approach, starting with their inclusion in MASS trials to gather relevant experience. Drawing from this practical knowledge, there's a plan to develop a mandatory MASS code, set to be enforced from January 2028 [74]. This significant step is part of Phase 2 [2027–2035], when newly built MASS are expected to become operational. It's important to note that even in Phase 2, RCC and human interventions are expected.

Moving to the concluding Phase 3 [2035 onwards], a transformative change is anticipated as NGASs are expected to operate without the need for RCC or human intervention. In this advanced stage, a refined version of the MASS code becomes crucial to maintain the desired safety and security standards for NGASs. In anticipation of this new code, the lessons learned from implementing the MASS code for retrofitted and new build MASS, along with ongoing technological advancements enhancing KETs, are expected to be invaluable contributors.

8. Conclusions

Integrating SSS-MASSs into current maritime regulations requires addressing significant gaps in various areas. This study thoroughly examines the regulatory and legal shortcomings concerning a MASS use case for SSS and provides practical suggestions to fill these gaps. The proposed changes aim to streamline the regulatory process through modifications to existing regulations. Using four autonomy levels defined by IMO's RSE, the study systematically deals with regulations through interpretations, modifications, new regulations, or confirming no changes if MASS operations are unaffected.

The major conclusions drawn in this study are outlined below:

i. The regulatory and legal frameworks for the SSS-MASS use case are thoroughly analysed to identify the gaps and classified those into different severity levels (high, moderate and low) based on how modern technology impacts human intervention, regulatory compliance, and global acceptance.

ii. To ensure clarity in SSS-MASSs operations, it is crucial to establish clear definitions, particularly for low-severity provisions. This includes implementing measures such as habitability regulations for crewless ships, exemptions at RU and A autonomy levels, and re-evaluating emergency protocols, lighting, muster, and embarkation requirements. Furthermore, clarity in assessing damage control plans, remote machinery space supervision, and role definitions is vital, with the designation of RCC operators as "master," "crew," and "responsible person." Updates are deemed necessary for CSR, casualty investigations, certificates, and manuals. Simultaneously, at a low severity level, there is a focus on defining regulatory terms under UNCLOS, suggesting the addition of "autonomous ship" as a subcategory in the definitions of 'ships' and 'vessels.' This addresses the absence of crewing references and the right of 'innocent passage' for SSS-MASSs in territorial seas, ensuring a comprehensive and coherent framework for SSS-MASSs operations.

iii. The study recommends addressing moderately severe provisions in SSS-MASSs by emphasising secure and efficient remote monitoring and control. Collaboration between ship control systems, connectivity, and the RCC is highlighted for remote operations. The RCC oversees ship monitoring, ensuring dual communication means, aligned regulations, and addressing safety features. Clarifications in definitions, roles, and "electronic bridge" terminology are emphasised, alongside discussions on RCC connectivity, technical specifics, and distress alerts. Ship masters' responsibilities extend to RCC operators. The study covers crew duties, autonomous navigation, and crewless ship regulations, emphasising safety and qualifications. At a moderate severity level, UNCLOS recommendations focus on acceptance and operation concerns, suggesting temporary categorisation, specific rules, admission criteria, and defined roles for Port and Coastal States. Qualified masters and crews are highlighted, with remote operators suggested for specific autonomy levels and exemptions for fully autonomous SSS-MASSs, emphasising adaptable regulations based on operator competence and safety considerations.

iv. The proposals for highly severe provisions in SSS-MASSs prioritise safety, addressing challenges related to the mandatory presence of humans on board. Recommendations encompass onboard control, safety measures, rule compatibility, and Search and Rescue (SAR) involvement. For manual control and local device operations, suggestions include redundancy, automatic mechanisms, and central manual override stations. Safety requirements and equipment for unmanned ships are reassessed, proposing exemptions and alternatives, particularly for survival craft and rescue boats. Discussions on compatibility with existing regulations advocate transparent evaluation based on technical criteria like ship control systems and RCCs to ease the transition to unmanned operations. In SAR scenarios, unmanned ships focus on relaying distress alerts and sweep searches, necessitating adjustments to the Global SAR system for improved communication and coordination. At a higher severity level, the proposals address challenges in the Pilotage Act, recommending exemptions for SSS-MASS trials under specific conditions and advanced remote lifesaving devices, emphasising facilitation of trials while acknowledging unmanned SSS-MASSs' limitations.

v. Certain provisions do not necessitate amendments either because they do not directly hinder MASS operations or because they contain exemption criteria to encourage innovation or testing. Examples include Directive 2016/1629/EC and the Bureau Veritas Classification Rules, which contain provisions promoting the use of new technologies and offering derogations for specific vessels to foster innovation.

vi. Identified provisions needing amendment for the SSS-MASS use case include 62% under SOLAS, 12% under COLREG, 6% under STCW, and 5% under LLC. A severity analysis reveals 55% as moderately severe, needing technological support for alternative provisions via potential amendments from technological advancements and MASS trials. Conversely, 10% are highly severe, demanding human involvement. Temporary exemptions or bilateral agreements could serve, though international acceptance takes time. Moreover, 26% need definition or clarification-based amendments, an area for IMO to act promptly. Notably, 9% don't impede MASS operations, requiring no changes.

vii. A thorough assessment of the minimum redundancy required to ensure satisfactory safety levels is an essential component of comprehensive risk assessment and cost-benefit analysis. While redundancy is critical for safety, its implementation should be considered only if stringent safety requirements demand it. Thus, if it is determined that a minimum redundancy of zero suffices to maintain the minimum safe level, the implementation of redundancy, which incurs high costs, can be avoided.

viii. Prominent Classification Societies have issued Guidelines for Autonomous Shipping, such as Bureau Veritas Guidance Note NI 641 DT R01 [52] and DLV rule on autonomous and remotely operated ships [64]. These guidelines and rule notes can be effectively utilised for concept design, preliminary analysis, detailed design, and comprehensive analysis of MASS, although they may lack uniformity in defining rules.

ix. A roadmap towards implementing the proposed recommendations along with the SSS-MASSs development is presented considering the severity levels of the provisions. This roadmap proposes to implement the recommendations into the non-mandatory MASS code first for MASS trails. Later based on experience gain and along with the technological advancements, the provisions will be upgraded to include those into the Mandatory MASS code. The same cycle in regard to experience gain and upgradation of the provisions based on technological advancements will be repeated again to convert these Mandatory MASS code to MASS code for NGAS at later stage.

The recommendations outlined in this study offer valuable insights for policymakers, helping them understand the needed improvements in various regulatory bodies. These proposals could potentially be integrated into the development of the non-mandatory MASS code by the IMO as mentioned before. The roadmap for policy implementation can also assist in estimating the timeline for national and international acceptance of those alternatives. Moreover, the study focuses on important regulatory and legal bodies related to the SSS-MASS use case, with tailored proposals for upcoming SSS-MASS development.

CRediT authorship contribution statement

Dag Atle Nesheim: Resources. **Yaseen Adnan Ahmed:** Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization. **Ilia Maslov:** Resources. **Gerasimos Theotokatos:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Lars Andreas Lien Wennesberg:** Resources.

Data availability

No data was used for the research described in the article.

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Author statement

We, the authors of the revised manuscript titled " Regulatory and legal frameworks recommendations for short sea shipping maritime autonomous surface ships," hereby provide the following statement:

In the process of revising this manuscript, each author has made significant contributions, ensuring its improvement and refinement. Specifically, we have properly addressed the feedback provided by the reviewer.

Furthermore, we affirm the integrity of the data presented in the revised manuscript, asserting that it has been collected and analysed in accordance with rigorous scientific standards and ethical guidelines. The authors collectively declare no conflicts of interest associated with the publication of this revised manuscript.

Having undergone thorough review and approval by all named authors, we confidently submit this revised manuscript to Marine Policy, ensuring compliance with all relevant ethical standards and regulations. The content of this manuscript is the sole responsibility of the authors and does not necessarily reflect the views of any affiliated institutions or organisations.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106226.

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