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# Smart regulations in maritime governance: Efficacy, gaps, and stakeholder perspectives

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ABSTRACT

The paper explores maritime environmental regulations, analyzing industry perspectives and their operational execution. It critically assesses the International Maritime Organization (IMO) regulations' effectiveness in mitigating climate challenges within the shipping domain. The central argument is that the evolving and intricate nature of maritime regulations often impedes policy goal realization, enforcement, impact evaluation, and equity perception. Utilizing both quantitative and qualitative methodologies, this research gathers, analyses, and interprets data via surveys and interviews. This exploration seeks to evaluate the regulations' impact on reducing shipping's negative impact, especially concerning emissions, waste management, and noise pollution, under the umbrella of smart regulations. The results indicate that the current regulatory approach is neither comprehensive nor immediate, necessitating a more agile, digitally enabled framework to adapt to fast-changing industry conditions.

## 1. Introduction

Shipping regulations, in their holistic nature, cover a broad range of activities in the maritime sector. The primary objectives of these regulations are to ensure safety at sea, prevent human injury or loss of life, and prevent damage to the environment, particularly the marine environment, as well as property (Joseph and Dalaklis, 2021). In the modern era, marked by heightened global concerns over climate change and judicious resource utilization, the focus of shipping regulations has shifted towards facets crucial to the industry's sustainability (Gössling et al., 2021).

Within the shipping industry, climate change results from human interactions with the environment, especially the oceans. These interactions further interwoven with global economies and geopolitics, introduce complexities (Bu et al., 2022) leading to both beneficial and detrimental consequences for the marine ecosystem, the broader environment, economies, and societies (Burge et al., 2014). Hence, the International Maritime Organization's (IMO) has projected diverse regulations initiatives to combat and minimize the effect of shipping activities that include the ambitious regulations for emissions (Prause and Olaniyi, 2020), strategies for waste management, marine ecosystem conservation (Hämäläinen et al., 2022), and noise reduction in ports and surrounding areas (Olaniyi et al., 2022).

While environmental concerns are paramount, the sustainability discourse in the maritime realm fully encompasses economic and social aspects this is why shipping regulations continuously evolve in response to emerging challenges, technological advancements, and shifting global priorities. As new sustainability challenges arise, these regulations adapt to address them, supporting the industry's long-term viability and responsibility. According to Gunningham and Sinclair (2017), integrating sustainable practices in shipping is essential for mitigating climate change, conserving the environment and biodiversity, preserving resources, adhering to regulations, enhancing reputation, and achieving long-term economic benefits. Such a transformative approach is vital for a sustainable and resilient global industry driven by technological progress, environmental needs, and evolving regulations. In this context, the IMO plays a crucial role in reducing the industry's environmental impact by standardizing practices, promoting compliance, and facilitating innovation and as suggested by Bu et al. (2022), smart regulation offers a flexible and proficient approach to address these prevalent challenges in the shipping industry.

In the quest to regulate and refine industry practices, the emergence of smart regulations and sustainable strategies has been observed (Bloor et al., 2006) and they encompass avant-garde policies that harness

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technology and data to amplify operational efficacy and diminish environmental repercussions (Priadi, 2022). Within the maritime context, smart regulation aims to achieve policy goals efficiently and effectively, acknowledging the heterogeneity of the regulated entities (Quick and Bryson, 2016). It endeavors to strike an equilibrium between economic expansion and sustainability, promoting greener technologies and methodologies (Liu et al., 2020). Illustratively, smart regulation advocates for environmentally congenial fuels and autonomous navigation technology to mitigate human-induced mistakes (Ma and Li, 2021).

Amidst the maritime industry's accelerated transformation driven by technological innovation, environmental imperatives, and global trade dynamics, comprehending the adoption of smart regulations is imperative for the industry's sustainability and competitiveness. This is why current research utilizes both survey methods and expert interviews to probe into the IMO's regulatory methodologies to address maritime climatic challenges, explore smart regulation and its ramifications, and discern its influence on the maritime industry's imminent trajectory from the vantage point of diverse stakeholders.

The article pools two studies interconnected through their focus on maritime regulatory frameworks and their impact on the industry's evolution. The first study dissects challenges and opportunities in maritime regulatory execution, offering stakeholder insights on gaps, efficacy, and prospective interventions. It further attempts to correlate maritime industry transformation with the IMO's regulatory schema by scrutinizing three salient environmental regulations; targeting emissions, waste management, and noise in relation to the adaptive strategies of maritime stakeholders. The subsequent study concentrates on evaluating the descriptors (principles) associated with smart regulations to gauge its adoption within the maritime landscape as it morphs. These principles in regulatory design ensure that regulations are not merely beneficial, but also pragmatic, adaptable, and mindful of the broader environment in which they are implemented. Thus by analyzing adaptive strategies employed by maritime stakeholders, this study sheds light on how regulatory measures influence industry practices and behavior. By examining the extent to which these principles are embraced within maritime regulations, the authors further provides insights into the effectiveness and relevance of regulatory frameworks in guiding industry practices and fostering sustainable development.

In its entirety, this research augments the drive for effective shipping regulations, sustainable growth, and the endorsement of environmentally amicable and cost-effective maritime practices. The emphasis on stakeholder involvement ensures a reflection of diverse interests and priorities, culminating in policy recommendations.

Based on these considerations, the paper proceeds to Section 2 by reviewing vertical integration in the shipping industry, with emphasis on the role that shipping regulations have. Section 3 delineates the methodology; Section 4 presents the research findings and identifies patterns between regulations and the industry. The paper concludes with discussions and conclusions in Section 5.

## 2. Background

### 2.1. Consequences of human interaction with the sea - a recap

The significance of shipping in the realm of international trade and commerce necessitates sustainable regulatory approaches. Human activities in the seas and oceans result in a plethora of direct and indirect ramifications. Prominent among these consequences are maritime pollution, habitat destruction, the introduction of invasive species, and a marked loss of biodiversity. Maritime activities directly imperil aquatic life, with collisions involving ships' propellers (Laist et al., 2021) being a notable example. Long haul and short-haul shipping activities are also contributing factors to significant toxin contamination in marine environments (Olaniyi et al., 2022). Furthermore, infrastructure developments, such as port construction, often lead to the obliteration of crucial coastal habitats, notably wetlands and mangroves. These habitats not only serve as breeding grounds for diverse marine species but also offer a bulwark against coastal degradation and tempestuous weather events (Madon et al., 2023).

Furthermore, shipping activities contribute to sea (and air) pollution not only through emissions from ships' exhaust but also through the release of untreated sewage, garbage, and through chemicals into the oceans (Prause et al., 2019). Ships use ballast water for stabilization, and this water, when transported globally, frequently contains invasive species detrimental to local ecosystems upon discharge (Wang et al., 2022). Globally, ships transport an estimated 3 to 5 billion tons of ballast water annually, and this water has been implicated in the transmission of infectious diseases. Under standard operating procedures, ballast water is securely stored to mitigate unintentional human exposure (Iteraeta, 2010; Makkonen and Inkinen, 2021). However, the exchange of ballast water across ports introduces harmful sediments into freshwater systems, subsequently contaminating and disrupting marine ecosystems. These pollutants linger in the vast expanse of the oceans, reshaping aquatic food webs (Wang et al., 2022). On the other hand, maritime emissions constitute a broad spectrum of pollutants, including sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter, carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), hydrocarbons (HC), and mercury (Hg). These emissions not only contribute to global climate change but also exacerbate environmental issues such as acid rain. Additionally, they pose significant challenges to respiratory health (Aresta et al., 2021).

On the other hand, maritime activities generate significant underwater noise that exerts adverse effects on marine species dependent on sounds for various vital functions such as communication, navigation, and feeding (Di Franco et al., 2020). Therefore, addressing noise pollution in coastal and port areas should be viewed not merely as an ecological endeavor but also as a socio-economic imperative. Noise pollution also has repercussions for coastal communities. To elaborate, the issue extends beyond underwater environments to affect the auditory landscapes of human settlements along coastlines. These impacts manifest in serious health implications, economic consequences, and regulatory considerations (Lähteenmäki-Uutela et al., 2019). Recognizing and addressing these multifaceted effects become increasingly critical when contextualized within the broader framework of sustainability objectives (Gössling et al., 2021).

### 2.2. Environmental regulations in shipping

The challenge of governing the maritime industry stems from its global nature. Vessels traverse international waters, navigating through regions with diverse regulations. This variance complicates the development of a unified regulatory framework. Coupled with the industry's dynamic nature, marked by evolving technologies and practices, maintaining current regulations becomes increasingly intricate.

However, IMO assiduously pursues mitigation strategies by leveraging appropriate regulatory instruments. Even though the goal of these initiatives is to help reduce emissions from shipping-related activities, each country has unique circumstances, especially when it comes to port infrastructure and ship energy systems (Xu et al., 2024). The organization promotes both technological and operational solutions in an integrative and adaptive manner (Liu et al., 2020). Among the pivotal regulations implemented by the IMO is the Safety of Life at Sea (SOLAS) Convention. SOLAS delineates minimum safety standards for vessels, covering construction, equipment, and operations. It seeks to enhance the safety of ships, crew, and passengers, thereby mitigating potential environmental hazards or damage to marine ecosystems (Joseph and Dalaklis, 2021).

Equally significant is the International Convention for the Prevention of Pollution from Ships (MARPOL), which addresses a spectrum of marine pollution, ranging from oil and chemicals to sewage, garbage, and atmospheric emissions. MARPOL establishes definitive limits on

emissions and discharges and mandates specific requirements for onboard waste management systems, thereby advocating sustainable environmental practices within the maritime domain (Gössling et al., 2021). Highlighting the expanding trajectory of the maritime sector, including the burgeoning cruise industry, the IMO emphasizes the significance of emissions emanating from both passenger and cargo vessels. The industry's proliferation, intrinsically linked to urban growth and concomitant environmental repercussions, necessitates stringent regulations, with the MARPOL Convention at the forefront. It prescribes standards for various emissions, striving to decelerate the sector's contribution to climate volatility (Olaniyi, 2017; Serra and Fancello, 2020).

The endorsement of the Energy Efficiency Design Index (EEDI) by the IMO signifies a monumental stride. Intending to augment the energy efficiency of vessels, the EEDI plays a vital role in curbing greenhouse gas emissions—a pertinent consideration, especially since the maritime sector initially remained outside the ambit of the Paris Agreement (IPCC, 2007) (Psaraftis, 2019). A further extension of this rule is the Energy Efficiency Existing Ship Index (EEXI) that measures the energy efficiency of existing ships. It assesses and compares the energy performance of vessels already in operation and calculated based on the amount of energy required to transport goods or passengers over a specific distance, taking into account factors such as the ship's size, speed, and propulsion system (Czermański et al., 2022). In synergy with the EEDI is the Ship Energy Efficiency Management Plan (SEEMP), which facilitates ship-owners and operators in boosting the energy efficiency of existing vessels through strategic measures (Psaraftis, 2019).

In addition, in a bid to counteract aquatic degradation from onboard waste, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) supervises the disposal of ballast water and sediments in ports globally (IMO, 2011, 2016a,b). This convention seeks to curtail the transfer of invasive species, hence safeguarding marine biodiversity, prescribes stipulations regarding the distance from the port where ballast water exchange should occur and imposes stringent thresholds on the presence and concentration of detrimental organisms during ballast water exchanges, with specific toxicity limits for certain pathogens (Campara et al., 2019).

However, a pressing concern with maritime regulations remains their enforcement on international waters. For instance, although the need for stringent shipping emission standards in the Mediterranean Sea was palpable, initial regulations did not extend comprehensively to this region due to various factors, notably the complexity arising from multiple maritime borders (Kliot, 2018). Yet, the recent inclusion of the Mediterranean Sea by the IMO, facilitated through amendments to MARPOL Annex VI, establishes a robust Mediterranean Emission Control Area (ECA) (UNEP, 2022). Effective from May 1, 2024, these regulations mandate that vessels in the Mediterranean use fuel with restricted Sulphur levels or adopt alternative compliance mechanisms. While the immediate implications might be financial, the long-term environmental and health dividends are undeniable (Testa, 2020). Furthermore, the IMO's Polar Code promulgates guidelines for ships maneuvering through the treacherous polar terrains, emphasizing ship design, equipment standards, crew training, and environmental conservation (Chircop, 2020).

### 2.3. Enhancing shipping regulations through smart approaches

As maritime activities can adversely impact both human health and the ecological environment, evaluating marine pollution has become a critical necessity for formulating effective management strategies. In recent years, the assessment of marine pollution has evolved from relying solely on isolated monitoring and sampling techniques to adopting a more comprehensive approach. One such approach involves assessing the effectiveness of mitigation activities implemented by policymakers (Chen et al., 2023).

The surging use of smart regulation heralds its potential to revolutionize the maritime affairs. Gasiola et al. (2019) investigate the nexus between regulations and sustainability within the maritime industry, proposing mechanisms by which regulations might incentivize sustainable practices. In other words, the conceptualization and evaluation of impactful regulatory disbursement is an integral component of regulatory science (Kapidani et al., 2020). Given the maritime industry's dynamic evolution, diverse regulatory definitions have been established, resulting in an amalgam of characterizations that can be employed to gauge the level of smart regulation assimilation within the sector. Various paradigms of these smart regulatory approaches are delineated as follows:

#### 2.3.1. Effectiveness and efficiency

Such regulations are crafted to achieve desired results without imposing undue burdens (Cordova-Novion and Jacobzone, 2011; Gunningham and Sinclair, 2017).

#### 2.3.2. Flexibility in regulatory implementation and transitions

Smart regulations eschew rigidity, allowing regulated entities to determine optimal methods of fulfilling requirements. They incorporate a variety of tools to realize policy aims, particularly in ensuring adherence to established norms (Alemanno and Sibony, 2015; Engle, 2016).

#### 2.3.3. Adaptation

Regulations should undergo periodic revisions to ensure contemporaneity, reflecting the malleability of regulatory frameworks in response to evolving conditions, needs, or feedback (Wiener, 2011; Lodge and Wegrich, 2016).

#### 2.3.4. Stakeholder alignment

Engaging stakeholders is imperative for gaining insights and averting unintended ramifications. Through their involvement, stakeholders can amplify safety measures, diminish emissions, and bolster sustainability, thereby augmenting industry growth and competitiveness (Balleisen and Eisner, 2008; Liu et al., 2020).

#### 2.3.5. Enhanced transparency

Articulating rules and their purposes lucidly is paramount, as this not nly elucidates directives but also cultivates trust among industry participants (Coglianese et al., 2008; Meijer, 2017).

#### 2.3.6. Adoption of best practices

Recognizing, comprehending, and integrating industry's most efficacious methods, tailored to specific needs, can amplify performance and yield superior outcomes (Hahn and Tetlock, 2008; Radaelli and De Francesco, 2017).

Examining the aforementioned paradigms, it becomes evident that smart regulations are instrumental in furnishing businesses with unequivocal directives regarding compliance, effectively eliminating ambiguities and propelling adherence to ecological norms (Liu et al., 2020). Furthermore, smart regulations function as levelling instruments, prescribing consistent standards for entities irrespective of their size or domain. This facilitates fair competition and curtails undue dominance by larger establishments over their smaller counterparts. In summation, the synergy between legislative frameworks and business operations is vital for realizing sustainability goals in shipping. Through collaborative endeavors, regulatory bodies and enterprises can champion sustainable modalities, ensuring sectorial affluence while safeguarding environmental interests (Akpinar and Ozer-Caylan, 2022). Embracing smart regulations can lead to improved safety standards, diminished emissions, and enhanced sustainability, thus spurring industry expansion and competitiveness. As elaborated in their publications IMO (2016a,b, 2023), the organization has been proactive in endorsing the uptake of smart regulations, as evidenced by the institution of a global data repository for greenhouse gas emissions, positioned to guide future regulatory innovations.

Yet, as the maritime domain undergoes metamorphosis, the interplay between smart regulation and maritime regulations becomes increasingly salient, especially concerning sustainability aspirations. Fulfilling these aspirations necessitates astute crafting of smart regulations, delicately balancing its pros and cons (Priadi, 2022) and streamlining compliance procedures through automation, offering fiscal and temporal advantages to shipping corporations, augmenting compliance levels, and minimizing manual errors (Bu et al., 2022).

The adoption of the SMART paradigm across various sectors exemplifies its relevance to the maritime domain. For instance, Meeus et al. (2010), in their exploration of "smart regulation for smart grids," employed smart regulations to diminish compliance expenditures, unravel regulatory intricacies, and foster innovation. Gunningham and Sinclair (2017) champion a composite regulatory strategy, promoting cooperation among diverse regulatory entities rather than an over-reliance on a solitary policy instrument. Such an approach facilitates the integration of a plethora of tools, customized to address a myriad of environmental challenges, thereby necessitating a creative, flexible, and pluralistic stance on environmental regulation (Kajander and Solarte-Vasquez, 2022). They also can bolster safety and ecological outcomes and results-oriented strategies over prescriptive mandates (Niksirat et al., 2019).

## 3. Methodology

The present research examines the strategies employed by IMO regulations to address climate challenges within the maritime sector. It probes into the notion of smart regulation and its potential integration into forthcoming maritime regulatory endeavors, gleaning insights from diverse stakeholders within the shipping industry. A multimodal methodology has been adopted, entailing a composite strategy that melds deep document analysis with both quantitative (surveys and statistical analysis) and qualitative (interviews) techniques. The conceptual framework was constructed from documentary sources, which include official publications from the IMO, pertinent international entities, academic research articles, and sector-specific reports.

### 3.1. Identification of variables

Variables are categorized based on their context or domain in the analysis shown in Table 1. Variables identified in relation to shipping-induced climatic challenges encompass emissions (e.g., greenhouse gas emissions, Sulphur oxides, Nitrogen oxides and particulate matter), waste management (specifically ballast water), and noise pollution. Smart regulations represent a vital facet of contemporary governance, aiming to foster an environment conducive to innovation, economic expansion, and societal well-being (Cordova-Novion and Jacobzone, 2011). Variables associated with smart regulations pertain to characteristics of smart regulation, namely: effectiveness & efficiency, flexible regulatory uptakes and transitions, adaptation, stakeholders' alignment, enhanced industry transparency, and the adoption of best practices. Fundamentally, these principles in regulatory design ensure that regulations are not merely beneficial, but also pragmatic, adaptable, and mindful of the broader environment in which they are implemented. In adherence to best practices, the authors conducted a pilot survey to evaluate the content validity, clarity, and appropriateness of both the survey and interview instruments. Subject matter and methodology experts scrutinized these materials, as emphasized by Van Teijlingen and Hundley (2001).

**Table 1**
Categorization of variables according to their domain.

| Context in analysis | Variables |
|---|---|
| Shipping-induced climatic challenges | Emissions, waste management, noise pollution |
| Smart regulations | Effectiveness & efficiency, flexible regulatory uptakes and transitions, adaptation, stakeholders' alignment, enhanced industry transparency, and the adoption of best practices |

### 3.2. Survey

A specialist survey was collected online from 500 pre-screened stakeholders operating in the shipping industry. Initial contact was done via email. This mostly involved actors actively involved in the day-to-day operations of Sea transportations such as the ports, ship operations, shipbuilding, research, manufacturing etc. The data was collected from January 2022 to August 2023. Additionally, surveys were administered in-person during meetings, workshops, and conferences. The questionnaire was divided into two studies. The first study gathered respondents' demographic information and gauged their familiarity with various IMO environmental regulations. This study delved into their perspectives on IMO regulations by exploring satisfaction levels, identifying regulatory gaps, and assessing expectations for future performance. The second study centered on evaluating maritime regulations to ascertain the extent of smart regulation adoption in the maritime sector. This "self-report" questionnaire featured Likert-type questions based on the six pre-identified characteristics of smart regulations (i.e., *effectiveness & efficiency, flexible regulatory uptakes and transitions, adaptation, stakeholders' alignment, enhanced industry transparency, and adoption of best practices*). A 5-point summative rating scale, ranging from −2 to +2, was utilized to determine the degree to which stakeholders either strongly agreed or disagreed with issues related to smart regulations, as illustrated in Table 2.

The sample presents a wide spectrum of stakeholders enabling verifiable analyses of the regulations on the maritime industry. This selection method ensured representativeness, which minimizes bias and enhances the likelihood that survey results are generalizable to the broader maritime population. Opinions were collected from 104 participants, which included maritime practitioners (N = 67) and researchers (N = 37) from 11 countries: Denmark (N = 11), Estonia (N = 14), Finland (N = 26), Germany (N = 17), Norway (N = 6), Poland (N = 11), Sweden (N = 9), and the United Kingdom (N = 7). Additional participants hailed from Latvia (N = 1), Lithuania (N = 1), and Nigeria (N = 1). All participants are recognized experts in areas such as shipbuilding, ship operations, ports, and related fields.

The analysis of the survey comprises two studies. Statistical methods suing a reputable statistical software package to interpret the perceived effectiveness of these regulations and to identify patterns and trends. Linear regression analysis, specifically dealing with the standardization of variables was employed to examine the relationship between IMO regulations and their perceived effectiveness within the industry, as evaluated by industry stakeholders. Standardization in the context of this work means converting variables to a common scale where each variable has a mean of zero and a standard deviation of one (Allen,

**Table 2**
To what extent do you agree or disagree with the following on shipping regulations.

| | Factor dimensions | Survey questions |
|---|---|---|
| 1 | Effectiveness & efficiency | Regulations are realistic |
| 2 | Flexibility in regulatory uptakes and transitions | The regulatory instruments accelerated compliance in the BSR |
| 3 | Adaptation | Regulatory responsiveness so far in the BSR has been satisfactory |
| 4 | Stakeholders' alignment | Regulatory compliance has a been a win-win between policy makers and the stakeholders |
| 5 | Enhanced Industry transparency | Regulations have high-level predictability and dependability |
| 6 | Adaption of best practices | Regulations has improved public perception of the industry |

N of data = 104.

1997). This analytical method provides a straightforward interpretation and comparison of coefficients and a foundation for subsequent qualitative analysis. The mean score of answers obtained regarding stakeholders' collective agreement on each description of smart regulations indicates the extent to which each factor correlates with the overall underlying perspectives.

### 3.3. Interviews

To counteract potentially low survey response rates, interview data were incorporated based on Aguilar Solano's (2020) approach to qualitative data triangulation. Moreover, rating scales are recognized to have various shortcomings. One criticism is that their measures are sometimes perceived as "too easy" to construct to yield meaningful results, as articulated by Taherdoost (2019). Consequently, both the pilot survey and expert interviews were designed to allow open discussions on each topic to address this concern. This approach aligns with what Fowler Jr. (1995) described as "the field pre-test with observation." Wording was refined as needed after recording and analyzing item-specific feedback. Content analysis techniques were employed to identify and categorize descriptive elements within the interview data.

Sampling for expert interviews was randomized. Request letters for interviews were dispatched to various maritime officials across Europe. Twenty-seven in-depth formal and semi-formal expert interviews were conducted across six countries: Finland, Germany, Poland, Estonia, Denmark, and Sweden. These sessions aimed to enrich survey data with qualitative insights postulated in Liamputtong (2020). The interviewees represented a diverse array of maritime experts, with a majority positioned at management levels. Open-ended questions, mirroring those in the survey, were employed to capture qualitative data. When needed, follow-up phone calls and emails were deployed for further clarification and validation. In situations where face-to-face interviews were impractical, phone or video calls served as alternatives. Each interview session ranged from 20 to 45 min in duration. The ensuing findings will spotlight areas where regulations have demonstrated effectiveness and will also highlight potential areas of enhancement, thereby fostering evidence-based policymaking in the maritime sector. Details of the interview questions are presented in Table 3.

To analyze the interview results, the authors designed a comprehensive framework drawing upon the methodologies posited by Ritchie et al. (2013); Bryman (2016) & Gomes et al. (2023) in Table 4.

**Table 3**
Expert interview questions.

| | Interview questions |
|---|---|
| 1 | Please say what you do and your country of residence |
| 2 | Which shipping regulations you are familiar with |
| 3 | Please can you describe how satisfied you are with the preparation level of IMO regulations? |
| 4 | Are there gaps you noticed in the shipping regulations? Please let us talk about them. |
| 5 | What are your thoughts about the current intervention measures in the industry? |
| 6 | In view of the sustainability goals (i.e. economic, social and ecology), do you think maritime regulations will generate benefit for BSR in the long term? |
| 7 | What future discussions do you think are best for the future success of shipping regulations? |

**Table 4**
Maritime Regulatory Effectiveness Analysis Framework (MREAF).

| | Framework | Objective | Metrics/actions |
|---|---|---|---|
| 1 | Demographic Contextualization | Understand the diversity and representation of the sample | *Roles/Professions distribution<br>*Country of residence distribution |
| 2 | Regulation Familiarity Assessment | Determine which regulations are most/least recognized | *Frequency of each regulation mentioned<br>*Thematic groupings of similar regulations |
| 3 | Satisfaction Level Profiling | Gauge satisfaction with IMO regulation preparation | *Distribution of satisfaction levels (e.g., Very Satisfied to Very Unsatisfied). |
| 4 | Gap Identification and Classification | Identify and understand perceived gaps in regulations | *Types of gaps (e.g., infrastructural, clarity, enforcement)<br>*Frequency of each gap type mentioned |
| 5 | Intervention Evaluation | Assess views on current intervention measures | * Positive, negative, neutral view distribution<br>*Specific intervention measures under critique or praise |
| 6 | Sustainability Outlook Mapping | Gauge the perceived long-term benefits of maritime regulations | *Outlook per sustainability goal (economic, social, ecology)<br>* Positive, negative, neutral outlook distribution |
| 7 | Future Discussion Agenda Setting | Identify areas of significant interest or concern for future regulations | * Themes/topics frequency distribution<br>* Ranked list of themes/topics for future discussions |
| 8 | Quality Control and Reliability Measures | Ensure consistency and trustworthiness in analysis | * Periodic revisits to coding system<br>* Inter-coder reliability checks<br>* Peer-review of categorizations |

## 4. Results

### 4.1. Survey results

#### 4.1.1. Study 1: challenges and prospects in maritime regulation implementation: stakeholder perspectives on gaps, effectiveness, and future interventions

Majorities of respondents (98 %) are acquainted with the emissions and efficiency regulations. 85 % of them recognize waste management and maritime litter regulations, while 54 % report familiarity with noise management regulations. Other regulations cited by respondents include those concerning *non-indigenous species in ballast waters, the ongoing discussion on biofouling regulation, pilotage, MASS regulations, seafarer safety, and general safety regulations*. The pronounced familiarity with emissions and efficiency regulations suggests that these have garnered widespread recognition within the maritime industry. It intimates that stakeholders are well-versed in environmental regulations, a vital prerequisite for both compliance and effective enforcement. Conversely, the diminished familiarity with noise management regulations may pinpoint an avenue for bolstering awareness and education among stakeholders.

Of the stakeholders, 86.5 % express satisfaction with the regulatory preparation level. Nonetheless, the predominant challenges noted in the implementation of maritime regulations are *underdeveloped infrastructure* (87 %) and *deficient regulation services, monitoring, and sanctions* (77.9 %). The predominant satisfaction with regulatory preparation insinuates stakeholders' trust in the IMO regulatory body's capacity to devise efficacious stipulations.

However, some stakeholders discerned other lacunas, such as *vague regulations, tardy regulatory publications, and ambiguous regulatory timelines*. Feedback from respondents spotlighted challenges in the practical application of regulations, *noting absent or protracted rules and instances where regulations engendered new quandaries* (e.g., *scrubbers; LNG)*. Issues like *inconsistent and nebulous regulations, impracticable limits that vary across regions, and challenges for ship-owners* surfaced. Moreover, concerns about *shipping companies' reluctance to incur additional expenses for implementing new seafarer regulations* were particularly pronounced.

Collectively, these issues accentuate that, although regulatory frameworks might be meticulously crafted, hurdles persist in their pragmatic implementation. These feedbacks underscore the need for clear, feasible, and timely regulations that stakeholders can readily comprehend and adopt.

On the topic of *regulatory adequacy*, 35 % of respondents concurred that existing regulations are sufficient, while 64 % dissented. Approximately 99 % of participants identified *enhanced incentives, financial backing, regulatory enforcement, and penalties for non-compliance as pivotal for the future triumph of clean shipping regulations*. *Information collaboration* was deemed paramount by 97 % of respondents, with *regulatory enforcement and penalties for non-compliance* following at 76 % and 78.6 %, respectively. Clearly, stakeholders discern a need for amplified communication and stricter regulations to efficaciously counter environmental tribulations. Some propose that *future regulatory endeavors should proffer clear initial steps, alternative options, co-regulation, and more defined timelines for enforcement*.

Regarding the sustainable agenda and its benefits, a resounding 91 % of stakeholders concurred that *prevailing shipping regulations will engender ecological, social, and economic benefits*. Such a response underscores a collective confidence in the long-term positive ramifications of these regulations. The result indicates the recognition of UN SDGs of maritime stakeholders that will probably be reflected to daily operations and standard procedures.

#### 4.1.2. Study 2: the assessment of maritime regulations using identified characterization of smart regulation

This study evaluates regulations through identified attributes of smart regulation: *effectiveness & efficiency, flexible regulatory uptakes and transitions, adaptation, stakeholder alignment, industry transparency, and adoption of best practices*.

A significant portion of stakeholders concurred that shipping regulations are both effective and efficient (91.3 %). Also that *regulatory instruments accelerated compliance (75.9 %); regulatory responsiveness so far in the BSR has been satisfactory* (74 %); *regulatory compliance has a been a win-win between policy makers and the stakeholders* (75.9 %); *regulations have high-level predictability and dependability* (82.7 %) and that *regulations has improved public perception of the industry (82.5 %)*. *Conversely, a minor segment voiced disagreement regarding the mutual benefits of regulatory compliance for policymakers and stakeholders* (10.6 %), *as well as doubts about the high predictability and reliability of regulations* (11.5 %). The predominant sentiment among respondents leans towards a favorable view of regulations in terms of their practicality, their facilitative role in compliance, regulatory responsiveness, and predictability. These findings imply that shipping regulations are perceived as potent instruments for realizing both industry and environmental objectives. Nonetheless, the existence of a dissenting minority (ranging from 10.6 % to 11.5 %) emphasizes the importance of continuous engagement and enhancement in regulatory measures.

The stipulated confidence interval, spanning from 1.26 to 1.45 for study 2, delineates the range within which the true population mean is projected to reside at a designated confidence level. This interval functions as a margin of error for the estimation endeavor. Within this specific framework, the interval substantiates the claim that the genuine average sentiment concerning smart regulations in Europe likely resides within this demarcated range. The mean response value at 1.36 indicates that, on average, respondents hold a generally positive attitude towards smart regulations. In contrast, the median response, recorded at 1.0, is lower than the mean (1.36), suggesting a potential rightward skew in the data distribution. This skewness raises the possibility of outliers or a subset of respondents with notably more positive views. Despite a standard deviation of 0.48, the overall results show a moderate level of response variability that suggests some respondents have some extreme opinions. The observed rightward skew in the distribution of data may reflect the complexity, diversity, and contentious nature of regulatory issues within the maritime sector. At this point, it is also imperative to acknowledge, however, that the data may not strictly adhere to a normal distribution. This is substantiated by the skewness value of 0.61, indicating a somewhat positively skewed response distribution. Consequently, while the majority of respondents may hold positive views, there exists a right-skewed tail in the distribution, where a minority may harbor highly positive opinions.

The presence of a negative kurtosis value (−1.66) signifies a platykurtic distribution of responses. In practical terms, this implies thinner tails and a flatter distribution compared to a normal distribution. Thus, a smaller fraction of stakeholders express extreme responses, with opinions tending to cluster around the mean. The calculated entropy value of 0.94 quantifies the level of randomness or uncertainty within the dataset. In this context, it suggests a moderate degree of response diversity, signifying that respondents hold varying opinions on the topic under consideration.

Overall, *effectiveness & efficiency*, with the lowest *p*-value of 2.05 %, is the most statistically significant variable among all the variables examined. To determine which of the other five variables have a significant impact on *effectiveness & efficiency*, additional regression analysis, following Allen (1997), was conducted. Using the R-squared statistic, which represents the proportion of the variance in the dependent variable, explained by the independent variables in a regression model, the results show that all coefficients and related R-tests for *flexible regulatory uptakes and transitions* (0.05), *adaptation* (0.11), *stakeholder alignment* (0.15), *industry transparency* (0.18), *and adoption of best practices* (0.16) were statistically substantial with positive signs. Their β-coefficients percentages also indicate that they collectively account for approximately 72 % of *effectiveness & efficiency*. In other words, changes in *effectiveness & efficiency* occur for each one-unit change in the predictor variables, while holding all other predictors constant. Collectively, these findings imply that a substantial proportion of all variables are crucial predictors of *effectiveness & efficiency*.

### 4.2. Interview results

On average, most issues outlined in the questionnaire were reiterated 2–3 times during the interviews, Therefore the results of the interviews presented herein exclude topics already addressed in the survey. The subsequent analysis categorizes additional topics and concerns under each question, listed in order of their frequency of mention.

#### 4.2.1. Level of satisfaction with IMO regulations

Most respondents expressed mixed sentiments concerning the preparation level of International Maritime Organization (IMO) regulations. Prominent concerns pertained to the availability of compliant fuels and the financial implications of transitioning to low-Sulphur fuel or installing scrubbers. The topic of Ballast Water Management was cited nine times. Despite extensive preparation time, various stakeholders have reservations about the cost and feasibility of retrofitting existing vessels with ballast water-treatment systems. Additionally, the aim to reduce Greenhouse Gas (GHG) emissions by 2050 elicited a divergent range of responses. While some stakeholders view this as a commendable initiative, others critique the absence of specific mechanisms to meet these goals, expressing concerns that such regulations might impair competitiveness. Although not within the scope of this research, the industry's level of preparedness for digitalization and cybersecurity, guided by IMO's non-binding recommendations, remains a subject of debate. To summarize, stakeholder satisfaction varies significantly, dependent upon the specific IMO regulation in question. While the necessity for regulation is generally acknowledged, concerns about the practicalities, associated costs, and implementation deadlines prevail. Several stakeholders advocate for a more phased and collaborative approach to regulatory development and execution.

#### 4.2.2. Identified gaps in shipping regulations

Most respondents highlighted the lack of stringent, short-term

enforcement mechanisms in emissions control as a significant shortfall. One stakeholder specifically mentioned that *this absence undermines the effectiveness of IMO initiatives*. Another glaring gap pertains to cybersecurity; there exists no binding international legislation mandating specific cybersecurity measures. Other frequently cited deficiencies include the safe and environmentally sound recycling of ships, labor rights—particularly in the context of seafarers' mental well-being—and gaps in dealing with piracy. Additional issues raised encompass the enforcement and monitoring of Ballast Water Management, regulations for Liquefied Natural Gas (LNG), and the lack of a comprehensive framework governing autonomous ships, a sector poised for growth.

#### 4.2.3. Opinions on current regulatory interventions

The prevailing view indicates that existing regulatory measures lack immediate enforcement mechanisms, thereby calling their short-term efficacy into question. Labor rights, particularly in the backdrop of the COVID-19 pandemic, were also frequently mentioned. The consensus posits that although these interventions represent steps in the right direction, they are insufficiently comprehensive or urgent to fully address the industry's complex challenges.

#### 4.2.4. Regulatory impact on sustainability goals

Economic Sustainability: Despite the high initial compliance costs, the synergistic impact of these regulations has the potential to yield long-term benefits, provided there is rigorous implementation and global collaboration. Social Sustainability: Must focus on regulations like the Maritime Labor Convention aim to elevate the welfare of seafarers, potentially contributing to a more sustainable and appealing work environment in the long term. Ecological Sustainability: The effectiveness of environmental regulations is contingent upon global compliance and enforcement—a conclusion strongly reinforced by survey results.

#### 4.2.5. Future discussions for regulatory success

According to one interviewee … *addressing critical areas in future discussions could pave the way for more comprehensive, effective, and universally accepted shipping regulations…* Other suggested domains for these discussions include Digital Transformation, Climate Resilience, Stakeholder Involvement, Enforcement Mechanisms, Public-Private Partnerships, Ethical and Social Considerations, Transparency and Data Sharing, Regional Specificity, and Periodic Review and Adaptation.

## 5. Discussion - implications on sustainable maritime operations

The provided analysis offers a balanced overview of maritime stakeholder satisfaction regarding IMO regulations, highlighting both the commendable strides and the existing gaps in regulation preparation and implementation. The response captures the multidimensional complexities of how different regulations are perceived by industry players, taking into account economic feasibility, technological constraints, and environmental imperatives.

The results further prove that, the current regulatory approach lacks comprehensiveness and immediacy, calling for an agile framework that can adapt to rapidly changing industry conditions, possibly facilitated through digital transformation. A smart regulatory approach would prioritize and employ data analytics for real-time compliance monitoring, and engage stakeholders in agile, iterative processes for regulatory development and implementation. The high initial costs and global enforcement challenges imply that a multi-criteria decision analysis could be beneficial. This would integrate economic, social, and ecological considerations into a unified framework for smart regulation.

Even though from the interviews, the most critical gaps in shipping regulations pertain to emissions control, labor rights, and cybersecurity, the absence of stringent, short-term enforcement mechanisms for reducing greenhouse gas emissions remains a pivotal issue, as it directly influences the sector's long-term sustainability and its alignment with global climate objectives. Additionally, gaps in labor rights, especially regarding seafarers' mental health and well-being, that surfaced conspicuously during the COVID-19 pandemic, reveal the urgency of updating and enforcing such regulations. As maritime operations increasingly incorporate digital technologies, the absence of comprehensive cybersecurity regulations poses significant risks to operational integrity and data security. These gaps warrant immediate attention to foster a safer, more sustainable, and more secure maritime industry.

Key areas like Digital Transformation and Climate Resilience underscore the need for regulatory sandboxes where new technological approaches can be tested in a controlled environment before full-scale implementation. This is where the concept of "smart shipping regulations" comes in handy because it promotes the use of intelligent technology and practices to enhance safety, security, efficiency, and environmental sustainability in the shipping industry. Using the characteristics of smart regulation, effectiveness & efficiency, flexible regulatory uptakes and transitions, adaptation, stakeholders' alignment, enhanced industry transparency, and the adoption of best practices must be enforced.

While geopolitical emergencies such as the Russia-Ukraine Conflict and the Red Sea Crisis present significant challenges for maritime regulations and smart regulation efforts, they also provide opportunities to strengthen regulatory frameworks, enhance collaboration, and promote innovative solutions to safeguard the safety, security, and sustainability of maritime activities in volatile regions. By addressing these challenges proactively and constructively, policymakers can contribute to a more resilient and adaptive maritime sector capable of navigating geopolitical uncertainties and promoting peace and prosperity at sea. For example even though tensions in Black Sea and the Red Sea can lead to increased security risks for maritime transportation, it gives opportunity to prioritize the development and enforcement of measures to enhance maritime security, including stricter surveillance, enhanced information sharing, and improved coordination among maritime stakeholders. There should be contingency plans, emergency response mechanisms, and crisis management protocols to mitigate the impact on maritime operations and ensure a coordinated and timely response to potential threats or disruptions.

The adoption of best practices for instance is not merely a straightforward replication endeavor. It necessitates an in-depth comprehension of the underlying tenets of these practices and the intricacies of the target environment. The objective is to harness established strategies while ascertaining their pertinence and adaptability to varying contexts. For instance, within the maritime domain, best practices may encompass safety guidelines, eco-friendly measures, supply chain protocols, or benchmarks for customer service. Tailoring these best practices can empower the industry to boost operational proficiency, refine stakeholder engagement, and carve out competitive edge in the marketplace.

This discussion could benefit from a more nuanced understanding of the temporal changes in stakeholder satisfaction. Regulations often see varying degrees of acceptance and critique over time, as the industry adapts and new technologies emerge explained in Pató et al. (2019). It would be beneficial to further delve into the role that collaboration between public and private sectors could play in enhancing the preparedness levels for IMO regulations. Cross-sector partnerships may facilitate more practical, cost-effective, and universally acceptable solutions, thereby potentially increasing stakeholder satisfaction. However, a limitation of the current discussion is the absence of the voices of smaller shipping companies and developing nations, whose perspectives can significantly differ from larger, more developed stakeholders.

In sum, maritime regulations have the potential to generate long-term benefits across economic, social, and ecological sustainability goals. Still, the ultimate efficacy hinges on the rigor of implementation and global adherence to these regulatory frameworks and from the standpoint of smart regulation, the authors suggest a conclusion through the lens of efficiency, adaptability, and stakeholder engagement.

## 6. Conclusion

The survey analysis revealed a pervasive familiarity with emissions and efficiency regulations within the maritime sector. Despite this familiarity, there exist notable gaps in understanding and significant challenges in implementation, including insufficient infrastructure and subpar monitoring mechanisms. The data further illuminate stakeholder concerns regarding ambiguous regulatory guidelines and the financial implications of implementation. In the domain of smart regulations, a majority of stakeholders perceive these rules as both effective and efficient. However, opportunities for refinement in the realms of flexibility, adaptation, and stakeholder alignment came up. Statistical analyses corroborate the robustness of these findings, with approximately 72 % of the variables examined emerging as significant predictors of regulatory effectiveness and efficiency.

Interviews distinctly underscore the exigency for an adaptive regulatory framework that is both cost-efficient and operationally feasible. The employment of performance-based standards, as opposed to prescriptive mandates, may serve to mitigate the current gaps in immediate enforcement mechanisms—most notably in the area of emissions control. The efficacy of smart regulations could be further augmented through the incorporation of real-time monitoring and data analytics to dynamically enforce compliance.

The study takes a pivotal role in elucidating the complex interplay between smart regulations and the evolving dynamics of the maritime industry. The insights garnered are invaluable for industry leaders, policymakers, and other stakeholders in formulating judicious strategies that catalyze the sustainable advancement of the maritime sector. Furthermore, by delineating the merits and limitations of smart regulations within the maritime industry, this study serves as an instructive guide for other sectors contemplating the adoption of analogous regulatory frameworks. Such cross-sectoral knowledge transfer ensures that best practices are disseminated and implemented on a broader scale.

## CRediT authorship contribution statement

**Eunice O. Olaniyi:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft. **Maria Claude Solarte-Vasquez:** Conceptualization, Validation, Writing – review & editing. **Tommi Inkinen:** Validation, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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