Scientific Research Publishing

Beijing Law Review, 2025, 16(2), 1286-1308
https://www.scirp.org/journal/blr
ISSN Online: 2159-4635
ISSN Print: 2159-4627

Identification and Assessment of Regulatory Challenges in VLFS Projects with Ammonia Production

Romario Carvalho Nunes, Thomas de Almeida Schrote, Natham Gabriel Franco, Ketyllyn Oliveira, Hirdan Katarina de Medeiros Costa, Marilin Mariano dos Santos, Edmilson Moutinho dos Santos

Institute of Energy and Environment, University of São Paulo, São Paulo, Brazil
Email: romario.carvalho@usp.br, thomas.schroter@usp.br, natham_gabriel.geo@usp.br, ketyllynoliveira@usp.br, hirdan@usp.br, marilin.mariano@gmail.com, edsantos@iee.usp.br

How to cite this paper: Nunes, R. C., Schrote, T. d. A., Franco, N. G., Oliveira, K., Costa, H. K. d. M., Santos, M. M. d., & Santos, E. M. d. (2025). Identification and Assessment of Regulatory Challenges in VLFS Projects with Ammonia Production. *Beijing Law Review, 16,* 1286-1308.
https://doi.org/10.4236/blr.2025.162065

Received: May 10, 2025
Accepted: June 27, 2025
Published: June 30, 2025

Abstract

This study addresses the regulatory challenges associated with the use of Very Large Floating Structures (VLFS) to produce blue ammonia in the offshore context. VLFS are emerging as innovative technological solutions for the creation of sustainable production hubs, especially in remote regions and in the Brazilian pre-salt, promoting the integrated exploration of maritime resources and the reduction of carbon emissions. The analysis identifies legal gaps and necessary adaptations in national and international regulations. Currently, Brazilian legislation considers VLFS as vessels, with regulations limited to safety and naval registration, ignoring their technological and operational particularities. At the international level, the United Nations Convention on the Law of the Sea (UNCLOS) and standards such as MARPOL and SOLAS offer complementary regulatory bases, but they are insufficient for the specificities of VLFS. A case study highlights the production of blue ammonia, which uses natural gas with CO_2 capture and storage, as a strategic opportunity for Brazil. The research proposes good regulatory practices, including the creation of specific legal frameworks, adoption of international safety standards, rigorous environmental licensing criteria, and economic incentives for low-carbon technologies. It is concluded that the implementation of VLFS in Brazil depends on legislative advances, multi-sector integration, and institutional strengthening, allowing the alignment of technological innovation with the Sustainable Development Goals (SDGs). These frameworks represent an essential component in the sustainable energy transition and the efficient exploitation of maritime resources.

Keywords

Very Large Floating Structures, Regulation, Blue Ammonia, ODS, Oil and Gas

1. Introduction

This article addresses the issue of Long-Permanence Offshore Systems based on Very Large Floating Structures (VLFS) in projects with ammonia production. Firstly, it is highlighted that VLFS are essentially large artificial islands that float on the sea surface and can be classified as semi-submersible or fully floating.

VLFS have drawn the attention of professionals such as architects, urban planners, engineers, and environmentalists for offering innovative and environmentally friendly solutions for the creation of maritime infrastructure. The potential applications of VLFS are varied, including floating piers, hotels, fuel storage facilities, stadiums, bridges, airports, and even floating cities (Suzuki, 2005; Wang & Tay, 2011).

In this sense, the use of VLFS structures to compose HUBS and/or offshore production clusters, as well as the decentralization of the energy sector, aim to create sustainable energy matrices, which significantly increase Brazil's sustainable energy generation capacity and support Brazil's commitments under the Paris Agreement (Lamas-Pardo et al., 2015).

The main objective of these hubs is to create structures and processes that minimize the carbon footprint, promoting more ecological and efficient practices in long-term maritime environments. Therefore, it is up to the VLFS to materialize these hubs, offering support for the implementation of sustainable technologies and the creation of a versatile infrastructure in remote areas of the oceans, serving various activities, such as renewable energy production, industrial processing, offshore logistics, and even habitable areas (Scaranello, 2021).

Large floating structures represent a remarkable innovation in the field of offshore constructions, being an essential component of "Greener Offshore HUBs (GOH)". Such structures represent an innovative approach in the design of offshore activity hubs, aiming at an integrated and sustainable exploitation of maritime resources (Arlota, 2013).

In Brazil, considering that natural gas extraction in 2019 reached approximately 139 million m^3/day and the outlook is for an increase to 253 million m^3/day by 2029, the implementation of VLFS in the Pre-salt regions stands out as a viable option for the commercialization of natural gas reserves at the extraction site, since the transportation of the explored gas is challenging and expensive due to the distance from the coast (EPE, 2020).

Thus, it is possible to consider the production of hydrogen (H2) through the reforming of natural gas with capture and storage of CO_2 as a way of adding value to natural gas instead of its production. It is worth noting that the transformation of hydrogen into other fuels can be an interesting option in places where there are few low-carbon alternatives, but which are not economically viable at current prices. It is worth noting that the transformation of hydrogen generated at sea into ammonia also at sea takes advantage of the existing maritime transport infrastructure and the existing demand (Cavalcante, 2022).

In this sense, the use of VLFS in projects with ammonia production would represent solution for leveraging and utilizing from the abundant potential supply of energy in the Brazilian pre-salt layer, in the form of combustible gases, which, to date, have proven difficult to transport to the Brazilian coast or for export, with consequent application throughout the South Atlantic, with other low-carbon solutions.

Currently being processed in the Chamber of Deputies, Bill 4338/23 establishes the Emergency Program to Produce Ammonia and Urea, aiming to reduce the cost of natural gas used in the production of the former, in addition to ensuring the availability of these products for agriculture and livestock in Brazil (Brazil, 2023). Managed by the Ministries of Mines and Energy and Agriculture, it will be financed with federal resources, revenues from the sale of oil, which corresponds to the Union's share in the production sharing system (Brazil, 2023).

The use of ammonia as a fuel can be evaluated from technological, scientific, and economic perspectives; however, this work is specifically restricted to a regulatory-legal approach to the subject. The influence of emission standards in the maritime sector and the obstacles to transporting ammonia on board ships will also be highlighted, as they are related topics.

The topic is of profound relevance considering that ammonia is an inorganic chemical substance formed by nitrogen and hydrogen, which has 17.6% hydrogen by weight, in addition to being one of the most produced inorganic chemical compounds, contributing approximately 1.5% of global human CO_2 emissions in 2016 (MacFarlane et al., 2020).

Data indicate that ammonia production has grown along with population growth since the 1900s, so that in 2019, approximately 240 million tons of ammonia were produced, with production expected to reach approximately 300 million tons in 2030 (MacFarlane et al., 2020).

Therefore, this report aims to outline the identification and assessment of regulatory challenges in VLFS Projects with ammonia production, with an understanding of the risks involved in this activity, through the construction of an approach with proactive methodological premises for an adequate assessment of the topic.

2. Regulatory Aspects in the Current Context of VLFS

In Brazil, there are no specific legal provisions for VLFS, as there are for oil platforms and vessels. However, several concepts and applications can be replicated for VLFS. The evolution and expansion of these complex structures have raised technical and legal issues that require careful analysis.

Within the scope of this study, there is a broad discussion, both at the national and international level, about the classification of platforms as vessels, ships, or artificial islands. The discussion revolves around the navigability of the platforms and their fixed or mobile structure, which in turn entails several legal consequences, mainly regulatory.

Well, the VLFS, like oil platforms, could be classified as vessels. According to Law No. 9,537/97, the concept of vessel emerged, which in turn brought floating platforms as "Vessel—any construction, including floating platforms and, when towed, fixed ones, subject to registration with the maritime authority and capable of moving on water, by its own means or not, transporting people or cargo" (Brazil, 1997b).

The VLFS, therefore, must follow the rules applicable to Brazilian and foreign floating mobile platforms, through the Maritime Authority Standards NORMAM-01 and NORMAM-04. These standards include floating platforms in the concept of vessel, exactly in line with the provisions of law 9,537/1997, and are subject to registration at the Port Authority (CP), Delegations (DL) or Agencies (AG), whose data will be obtained through the Vessel Registration Title (TIE) issued (Brazil, 1997b).

Furthermore, according to Law 2,180/1954, the respective vessel will also need to be registered with the Maritime Court, which will maintain the general registry of naval property. This registry contains information such as the nationality, validity, safety, and publicity of the vessel's ownership, resulting in the issuance of the Maritime Property Registration Provision (PRPM) (Brazil, 1997a).

It is important to remember that it is necessary to observe the origin of the country from which the platform or vessel comes, whether Brazilian or foreign. This characteristic will imply the differentiation of the regulation to be applied, whether in the registration or operation thereof (Scaranello, 2021).

Platforms from non-Brazilian countries are subject to specific regulations, since their ownership must be registered in the country where they are headquartered. Through NORMAM-04, the Navy requires that foreign vessels also register temporarily with the Brazilian Maritime Authority (Brazil, 1997b).

Both NORMAM-01 and NORMAM-04 require that floating platforms, whether Brazilian or foreign, be subject to technical evaluation by the Navy to ensure compliance with current standards on maritime safety, protection of human life at sea, and prevention of contamination of water resources. As a result of this process, the Declaration of Conformity for Platform Operation will be issued by the Brazilian naval expert (Brazil, 1997b).

Another relevant regulatory step for VLFS is the decommissioning of the floating structure. The Navy will grant permission to remain in Brazilian jurisdictional waters for a period of ninety days, which may be extended upon evaluation. The management and registration of vessels in Brazil are carried out through the Vessel Registration Title (TIE) and the Maritime Property Registration Provision (PRPM), and not through a provisional registration.

In summary, it is observed that, despite there being a certain legal uncertainty both at national and international levels regarding the nature of the floating structures, there is no debate in the Brazilian Navy regarding the categorization of these platforms as vessels for regulatory purposes, in accordance with the legislation in force on safety in waterway traffic (Law No. 9,537/97).

3. Uses and Adaptations of Current Legislation for VLFS Projects

In this sense, due to the absence of national legislation regarding VLFS, the work evaluated the existing international legal institutes, legal sources, and aspects of international law of the sea, national sovereignty, and the application of the 1982 United Nations Convention on the Law of the Sea that can be used to support future legislation on VLFS here in Brazil.

The main question addressed during the research was: "What are the main laws and regulations (nationally and internationally) that regulate the installation of VLFS in deep and ultra-deep seas, as well as the integration with industrial production in the deep-sea maritime environment?"

In addition to the legislative research, it was based on the search for articles with the Keywords present in this work on the ScienceDirect journal platform. The research analysis method is analytical and comparative, which is a recommended approach to try to identify and address issues associated with large-scale construction and engineering (Robson, 2002).

At the international level, the United Nations Convention on the Law of the Sea (UNCLOS) regulates the use of the oceans and the installation of floating structures, such as Very Large Floating Structures, in exclusive economic zones and international waters. In addition, the International Convention for the Prevention of Pollution from Ships (MARPOL) and the London Convention regulate environmental protection, while the International Convention for the Safety of Life at Sea (SOLAS) guarantees safety and risk prevention in these structures. Finally, the Offshore Structures Standards Code defines the main technical guidelines for the construction, installation, and operation of floating platforms.

At the national level, legislation regarding VLFS is more limited, since, according to Law No. 9,537/1997, these structures are considered vessels for purposes of registration, safety, and regulation. Thus, the Maritime Authority's standards (NORMAM-01 and NORMAM-04) define the parameters for the registration, operation, and safety of these structures in jurisdictional waters. In addition, the Maritime Court has the duty to inspect the registration and ownership of vessels, according to Law No. 2,180/1954. Regarding environmental protection, Law No. 9,966/2000 provides for the prevention, control, and inspection of pollution by the discharge of oils and harmful substances into waters under national jurisdiction.

In conclusion, we can state that, although applicable national and international standards exist, there are notable gaps in the specific regulation of VLFS. Furthermore, there is a need to develop both national and international legislation, which is outdated in relation to the technological advances guaranteed by floating structures, and to ensure compliance between the two. Thus, the current regulation of

VLFS is based on the adaptation of navigation and waterway traffic legislation by considering these structures like vessels, in a way that ignores their particularities and technical, construction, and operational innovations.

4. Mapping and Assessment of Regulatory Challenges Identified in Selected Papers on VLFS Projects with Ammonia Production

VLFS begin with the development of planning and request for the necessary licenses, including licenses for seismic activities, exploration of the geological structure suitable for CO_2 storage and drilling, as well as for the construction of the necessary infrastructure, for the operation phase, and for future decommissioning when the CO_2 geological store is completed.

In this sense, it is imperative to identify and analyze the regulatory challenges associated with the use of Very Large Floating Structures (VLFS) in the production of blue ammonia, with a focus on the sustainable energy transition. The production of blue ammonia involves the use of natural gas with CO_2 capture and storage, reducing emissions compared to fossil fuels.

Through the selected articles, correlations were constructed around the constitutions, legislation, and Sustainable Development Goals (SDGs) present in the texts, classifying them by the subjects addressed, the economic activity to which they belong, the years in which they were implemented, and the countries that follow them. The texts address various facets of the Law of the Sea, especially in the context of the 1982 United Nations Convention on the Law of the Sea (UNCLOS), and how these principles are implemented or reflected in national legislation, with a particular focus on Brazil.

4.1. Methodology

To map and assess regulatory challenges, the concepts of Systematic Literature Review (SLR) and PRISMA were used to formulate two research questions and select the Web of Science as a database with the aim of ensuring a comprehensive and impartial analysis of the scientific literature, considering a global scope. The questions were developed using the PICO methodology, which is essential for the bibliographic search for evidence, to maximize the efficiency of the search in the database, focus on the scope, and avoid consulting unnecessary information. After constructing the questions, the bibliographic search for evidence begins, which will enable the recovery of evidence in the database based on the selection of search terms, use of Boolean operators, and combination of strategy elements.

SLR is a scientific research method that follows specific protocols and seeks to understand and give logic to a large volume of information in the scientific literature, to avoid duplication of studies and identify gaps in knowledge. In the case of this article, a meta-analysis was performed, that is, a quantitative review that statistically combines results from several studies on the same hypothesis. This meta-analysis was defined by PRISMA (Preferred Reporting Items for Systematic

Reviews and Meta-Analyses), which represents a set of guidelines for the preparation and reporting of systematic reviews and meta-analyses to ensure transparency, reproducibility, and methodological quality in these studies. Thus, the SLR is composed of the following systematic steps: Delimitation of the issue to be addressed in the review; selection of bibliographic databases for consultation and collection of material; development of strategies for advanced search; selection of texts and systematization of information found, and preparation of the review

The search for the selected parameters, which were applied to the database, resulted in 4410 documents found.

Research Questions

Research question 1 is "What are the available rules for implementing the new technology of offshore green hubs?" (Table 1) The related population or problem is "implementation of offshore green hubs," aiming at intervention for "regulation and technical standards," without the use of "comparison." The expected outcome is "to identify and describe the existing rules for the implementation of offshore green hubs."

Table 1. Questions and answers associated with the survey.

Research question	RQ1: What rules are available to implement the new offshore green hub technology?	RQ2: What are the public policies related to the offshore green hub?
Problem	Implementation of offshore green hubs	Development of offshore green hubs
Intervention	Regulation and technical standards	Public incentive and regulatory policies
Comparison	No comparison	No comparison
Result	Identify and describe existing rules for the implementation of offshore green hubs.	Inform and support the formulation of public policies aimed at the sustainable development of offshore green hubs.

Source: Prepared by the authors.

This first question is essential to understand which public policies to promote offshore green hubs have been implemented around the world. It is useful to understand the regulations and technical standards that guide the implementation of these hubs, whether there are international standards or specific national rules that must be followed, and whether there are regulatory barriers that may hinder or delay implementation. Finally, the results of this article may also be useful for future studies that relate to the country's policy to promote offshore green hubs.

Research question 2 is "What are the public policies related to offshore green hubs?" (Table 1) The related population or problem is "development of offshore green hubs," aiming at intervention for "public policies of incentive and regulation," without the use of "comparison." The expected result is "to inform and support the sustainable formulation of offshore green hubs."

This question aims to assess how effective public policies are in supporting for offshore green hubs to provide adaptation to this new technology. Questions about government incentives for the implementation of these hubs, which countries or regions have already adopted specific public policies for offshore green hubs, and how offshore green hubs fit into national energy and climate plans open numerous possibilities for analysis. The relevance of these questions is reinforced by the possibility of providing better parameters for the formulation and development of other policies to promote offshore green hubs. Table 1 summarizes the questions and answers related to the surveys carried out.

Search Parameters

Research question 1 "What are the available rules for implementing the new offshore green hub technology?" had the following criteria for search parameters: i) Study selection period: 2022-2025; ii) Keywords: Floating structures; Decarbonization; Energy transition; VLFS; Offshore green hubs; iii) Boolean search: All combinations between the keywords with the connector "AND" (Table 2).

Research question 2 "What are the public policies related to the offshore green hub?" had the following criteria for search parameters: i) Study selection period: 2022-2025; ii) Keywords: Floating structures; Decarbonization; Energy transition; VLFS; Offshore green hubs; iii) Search with Boolean operators: All combinations between the keywords with the connector "AND" (Table 2).

Table 2. Summary of research parameters.

Research question	RQ1: What rules are available to implement the new offshore green hub technology?	RQ2: What are the public policies related to offshore green hubs?
Database	Web of Science	Web of Science
Keywords	Floating structures; Decarbonization; Energy transition; VLFS; Offshore green hubs	Floating structures; Decarbonization; Energy transition; VLFS; Offshore green hubs
Synonyms	Not used	Not used
Application of Boolean connectors	All combinations between keywords with the connector "AND"	All combinations between keywords with the connector "AND"
Period	2022-2025	2022-2025

Source: Prepared by the authors.

Results in the Web of Science Database

After applying the search parameters from Research Questions 1 and 2, the Web of Science on March 25, 2025, using all combinations between keywords with the connector "AND" and refined by the period "2022-2025" (Table 3), found the following results:

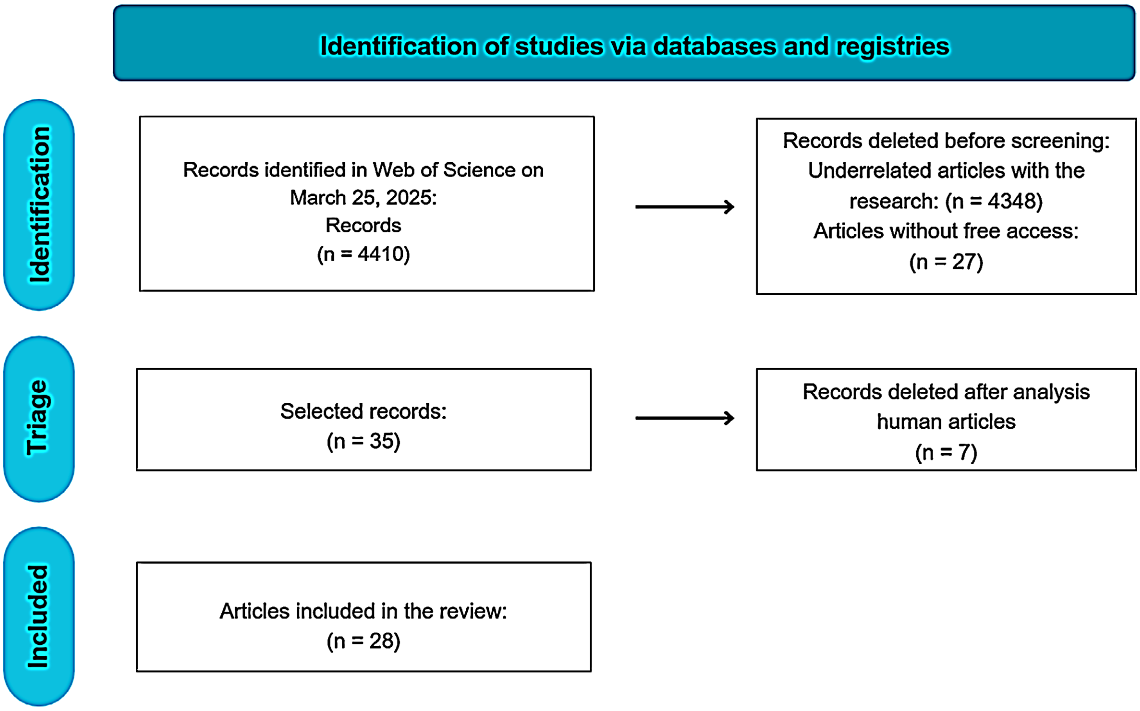
Table 3. Results found after applying the combinations in the research.

Keywords	Number of articles found	Number of articles open for free access
Floating structure + decarbonization+ energy transition	3	1
decarbonization + green offshore hubs + energy transition	5	4
floating structures + very large floating structures + energy transition	14	5
floating structures + very large floating structures + decarbonization	0	0
floating structures + very large floating structures + green hubs	0	0
floating structures + decarbonization + energy transition + very large floating structures + green hubs	0	0
very large floating structures + energy transition	14	5
very large floating structures + green hubs	0	0
very large floating structures + decarbonization	0	0
floating structures + decarbonization	7	4
floating structures + green hubs offshore	1	1
floating structures + energy transition	294	124
Decarbonization + energy transition	4.054	2533
decarbonization + green hubs offshore	8	6
Energy transition + green hubs offshore	10	9

Source: Prepared by the authors.

Thus, for the search parameters sought, a total of 4410 articles were found. However, it is possible to notice a low distribution in the number of articles in the different themes, since the search "Decarbonization + Energy transition" represents 92% of the articles found, while all the other combinations added together represent only 8%. In addition, we can see that the novelty of the themes "green hubs offshore" and "very large floating structures" results in a low number of articles found, while more consolidated themes, such as "decarbonization" and "energy transition," generate many more results.

Due to the large number of articles found, it is necessary to select the articles that will be analyzed in detail. The first filter was made by excluding the keyword sets "Decarbonization + Energy transition," with 4054 articles, and "Floating Structures + Energy", with 294 articles, as they are considered very broad and generalist topics, which do not contain the specificity sought in the theme of blue ammonia production in the very large floating structures. In addition, a second filter is applied in relation to the accessibility of the articles, in which only the articles open for free access are selected, which led the research to exclude another 27 articles. Thus, the selection goes from 4,410 to 35 articles, which correspond to the remainder of all possible combinations of the chosen keywords with the Boolean connector "AND" of free access. Finally, the remaining articles were analyzed individually, and another 8 articles were excluded due to a lack of connection with the proposed theme, reaching the final number of 27 articles to be examined, as can be seen in Figure 1.



Source: Prepared by the authors.

Figure 1. Methodological path—RSL methodology outline.

Results

For a better understanding of the data collected, the relationship of the keywords that appear in the articles is verified, considering the 28 articles, as shown in Table 4.

Thus, we can observe a much greater ease in finding literature on the themes of Decarbonization and Energy Transition, since these are broader themes, in a way that they address a wide variety of areas, and are in focus due to climate change. On the other hand, the themes Floating Structures, VLFS, and Offshore Green Hubs are shown to be topics on the rise, but with few specific, concrete studies, they are mentioned more in a general way.

After selecting the articles, the methodology adopted was a detailed reading of them, focusing on the two research questions: "What are the rules available to implement the new technology of offshore green hubs?" and "What are the public policies related to offshore green hubs?" In this way, it was possible to establish the main legislation and public policies related to offshore hubs.

Table 4. Summary of the number of articles found.

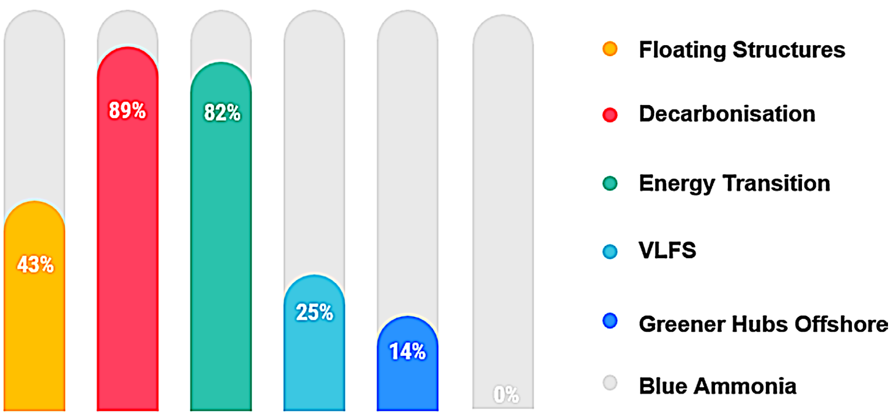
Keyword	Number of articles
Floating structures	12
Decarbonization	25
Energy transition	23
VLFS	7
Offshore Green Hubs	4

Source: Prepared by the authors.

4.2. Results and Discussions

When observing the selected articles, we can identify some limitations of the research, mainly due to the novelty of the themes "blue ammonia" and "offshore green hubs" in the literature, which present a bibliographic gap. To exemplify this statement, in this selection of articles, none were related to blue ammonia. Regarding the research questions, it is possible to observe a greater connection with offshore green hubs, due to the research methodology with the keywords that facilitate these results. However, we can still observe that the articles found mention offshore hubs indirectly, giving greater focus to the themes of decarbonization and energy transition in a broader aspect, without the specific details of these technologies.

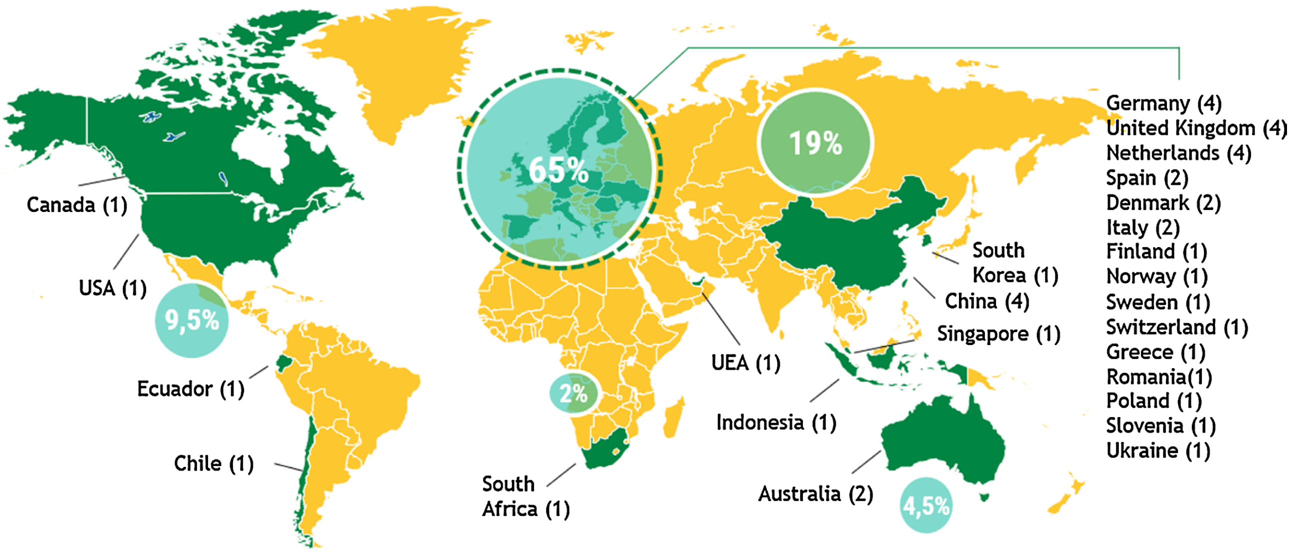
Figure 2 clearly demonstrates this bibliographic gap, where the keywords "Decarbonization" and "Energy Transition" appear in more than 80% of the selected articles, while "Offshore Green Hubs" appears in only 14% and "Blue Ammonia" is not even mentioned in the articles.



Source: Prepared by the authors.

Figure 2. Number of articles identified by keywords.

The research also revealed that, although the academic background of the authors of the articles is diverse, there is a greater concentration in European universities, with around 65% of the authors belonging to a university located in Europe, with emphasis on Germany, the United Kingdom, and the Netherlands, all with 4 authors. China is next, being the non-European country with the largest participation in these selected articles, as shown in Figure 3, which shows the number and origin of the authors of the selected articles.



Source: Prepared by the authors.

Figure 3. Number and origin of authors of selected articles.

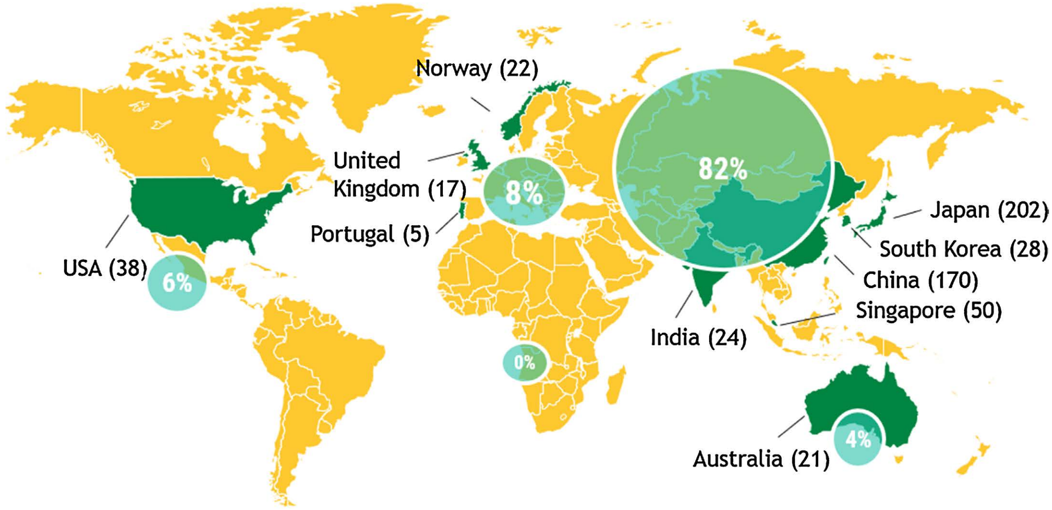
The data above allow us to confirm a trend that has already been observed by the international community, where Europe and especially China have been investing in research and development, including in the academic field, regarding Decarbonization and Energy Transition, contrary to, for example, the United States.

The research also revealed a curious fact: although the academic origin of the authors of the articles is largely linked to European universities, when it comes strictly to VLFS, there is a significant number of articles located in the Far East, concentrating more than 80% of the scientific articles—with emphasis on China, with more than 150 articles, as shown in Figure 4.

It is important to mention that most of these articles are related to the areas of Naval Engineering and Physics/Fluid Mechanics, and are not necessarily linked to VLFS as an instrument for Energy Transition and Decarbonization. In any case, it is observed that, when it comes to scientific articles focused on engineering, the situation is reversed, with Asia being the major global protagonist.

Regarding the themes of the selected articles, it was prepared with the help of the "Word Cloud" tool, an image that highlights the words that appear most in the titles of the selected articles, as shown in Figure 5.

There is a strong synergy between the themes, with the words "Energy," "Transition," "Decarbonization," "Offshore," "Floating," and "Green" being the most mentioned words in the selected articles.



Source: Prepared by the authors.

Figure 4. Number of scientific articles related to the VLFS theme.

Source: Prepared by the authors.

Figure 5. Word cloud with the most cited words in the titles of the selected articles.

The following are discussions related to the questions addressed in the mapping of the selected articles.

Question 1

From the literature review, Research Question 1: "Rules available to implement offshore green hubs", we can conclude that the implementation of offshore green hubs still faces regulatory gaps, but several legal frameworks, strategies and policy guidelines already offer partial support and point the way for the development of this sustainable infrastructure, mainly in the European Union and partner countries, while the rest of the world is lagging in this regard. We can mention the EU Strategy for Offshore Renewable Energy (2020), which promotes regional cooperation, efficient use of maritime space, and development of electrical infrastructure. However, most countries' planning is still focused on decarbonization targets and investment in renewable energy, which shows the distance between a specific framework for offshore green hubs and legal and regulatory harmonization between countries.

Question 2

From the literature review, Research Question 2: "Public policies related to offshore green hubs", the implementation of offshore green hubs is strongly linked to the development and coordination of national and international public policies, which are still in their early stages. Some public policies found were carbon pricing, to make green hydrogen competitive against fossil fuels, subsidies, and green financing, which are recommended as direct incentives for offshore projects, and public-private partnerships and climate financing mechanisms, which demonstrate viable models of government support. Thus, public policies for offshore green hubs are under development and are supported by clear and ambitious climate goals and specific economic incentives; however, they come up against integrated spatial and energy planning and solid international coordination.

The analysis highlights the enormous potential of offshore green hubs as strategic components in the global energy transition, especially for their role in the decarbonization of emissions-intensive sectors and the production of alternative fuels, such as blue ammonia. However, the research also shows that, despite the growing interest in the topic, there is still a significant gap in terms of specific regulation and targeted public policies, which compromises the viability of these infrastructures and makes it difficult to attract investment and align the different actors involved.

Furthermore, the results indicate that countries are still focusing their efforts on initial decarbonization targets, without the capacity to formulate regulatory frameworks that consider the specificities of offshore green hubs. The lack of clear technical standards, adequate spatial planning, and robust international coordination emerges as one of the main challenges to be faced. Overcoming these obstacles requires not only technological advances, but also a national and international political effort to ensure legal certainty, economic incentives, and territorial integration.

Therefore, this study highlights the urgent need for initiatives that promote regulatory and political maturity on the subject, fostering scientific production and multisectoral dialogue. Only then will it be possible to transform the technological potential of offshore green hubs into a sustainable and scalable reality in the global energy scenario.

4.3. Initial Conclusion

All texts emphasize the importance of the 1982 United Nations Convention on the Law of the Sea as an international regulatory framework that defines the rights and responsibilities of States in the use of the oceans, the management of marine resources, and the protection of the marine environment. There is a comparative analysis between the international guidelines established by UNCLOS and how these guidelines are reflected (or not) in Brazilian national legislation. Law No.

9433/97, for example, is mentioned in relation to the management of water resources in Brazil, but with a limitation of not explicitly including the seas (Diehl, 2006).

Furthermore, all texts discuss the need for sustainable use of marine resources, environmental protection, and prevention of marine pollution, with mentions of specific cases and examples of Brazilian policies and projects such as the Recognition of the Continental Margin (REMAC) and the Brazilian Continental Shelf Survey Plan (LEPLAC).

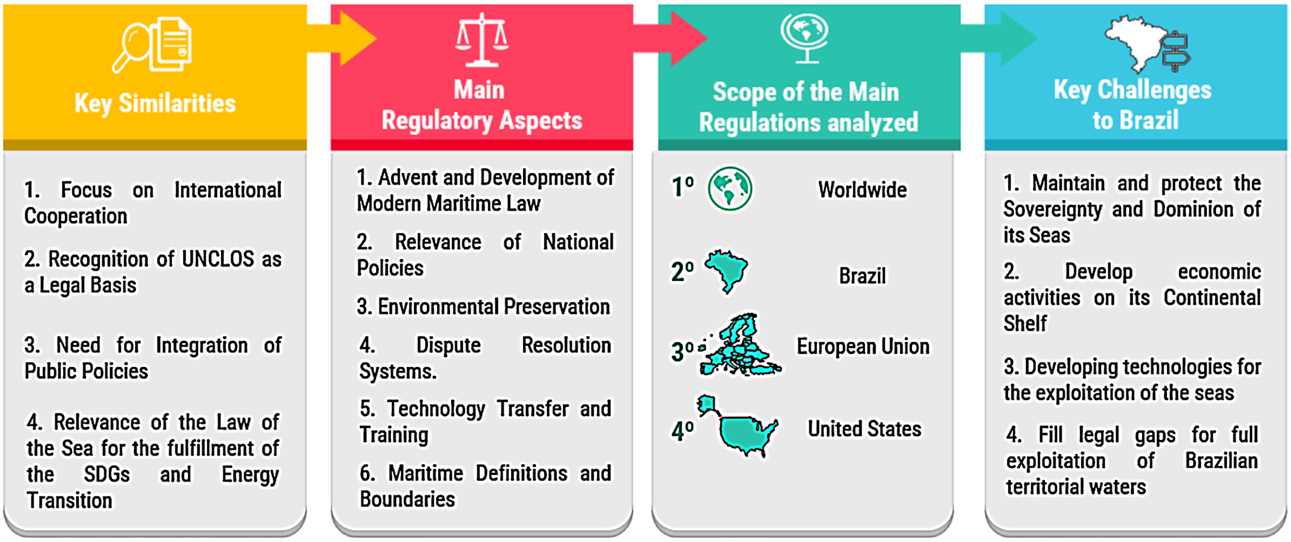
Some differences were noted in the thematic approaches and historical perspectives. Some texts focus more on the legal framework and principles of UNCLOS, such as the definitions of territorial sea, exclusive economic zone, and rites of passage. Other texts are more specific about technological advances and their legal implications, such as the use of buoys and gliders for marine data collection and the associated regulatory challenges. There are also texts that analyze practical cases, such as the MOX plant and the issue of maritime pollution, providing examples of how UNCLOS has been applied in real situations (Araújo Júnior, 2017).

Still in the wake of historical contextualization, it was found that, with the increase in demand for natural resources due to consumption patterns, population growth, and scarcity of raw materials on the continent, there was a need to make maritime law more complex. The laws that regulated activities in the ocean were limited to navigation until then, and the main interest was in the maritime environment. However, with technological advances and greater demand for the riches of the ocean floor, conflicts arose between several countries due to the exploitation of resources that this legislation was not capable of covering. Thus, it was essential to develop maritime law to encompass countries in different conditions of exploitation, aiming to establish equal conditions of exploitation or the delegation of rights acquired by geographic position or other reasons (Lima, 2006).

Based on these findings, a summary of the main similarities found in the articles was created, as well as the main regulatory aspects addressed. In addition, the scope of the main legal provisions studied and the main challenges Brazil faced in adapting to the global reality of ocean exploration were verified. These analyses were consolidated in **Figure 6**.

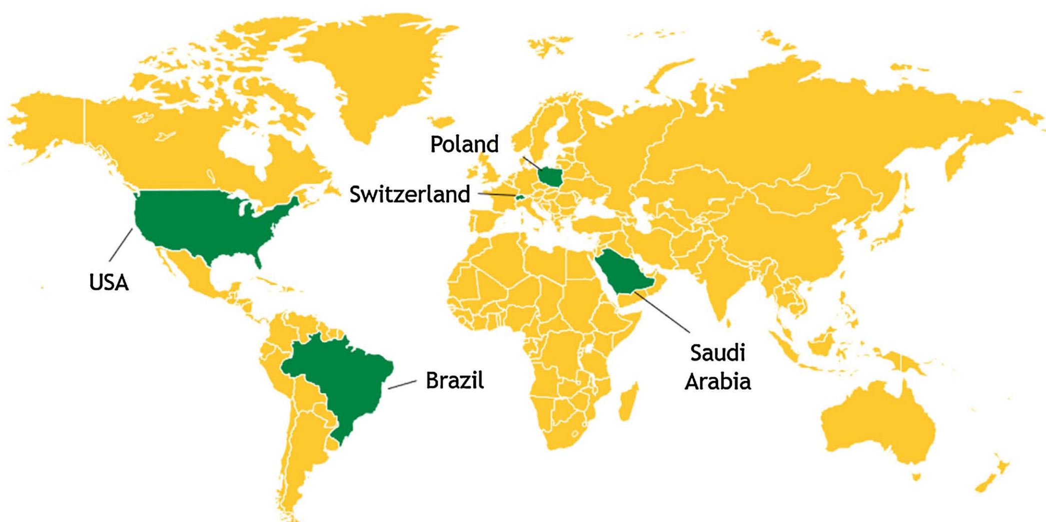
Finally, a recurring theme across all articles is international cooperation, which prioritizes common interests over national interests. This is reflected in the signing of the United Nations Convention on the Law of the Sea, in which all signatory countries agree on the regulation of maritime activities, significantly affirming the interdependence of the use of the sea and the responsibility for the protection of its resources. In doing so, they ensure respect for the fundamental principles: jurisdiction of possession, sovereignty, and use of maritime waters in relation to preservation, protection, and monitoring.

In any case, when researching specifically on ammonia regulation and VLFS, the literature is still limited. Only 7 articles related to ammonia regulation and VLFS were found. **Figure 7** shows that the articles were written by authors from universities in only 5 countries, with Brazil, Poland, Saudi Arabia, Switzerland, and the United States, in that order, being the countries of origin of the universities that published these articles.



Source: Prepared by the authors.

Figure 6. Consolidation of the main analyses arising from the selected and studied articles.

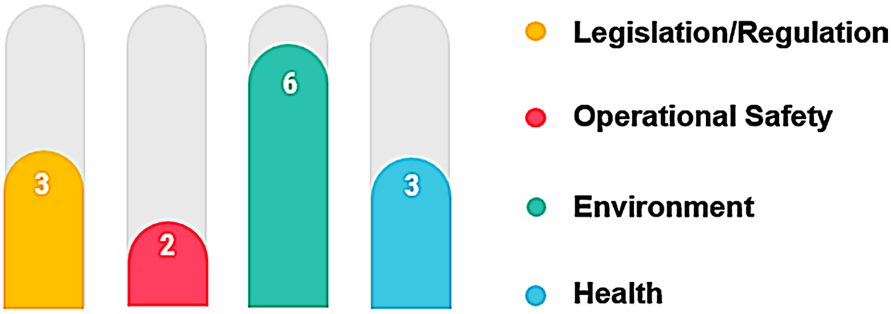


Source: Prepared by the authors.

Figure 7. Consolidation of the main analyses arising from the selected and studied articles.

In addition to this literary restriction, low adherence and development of relevant themes for activities related to ammonia in VLFS were identified, such as specific regulations and legislation for such activities in this environment, operational safety, environment, and health, as can be seen in Figure 8.

The literature review played an extremely important role in surveying maritime legislation, especially those related to the offshore region, where the focus of the research is located: Large Floating Structures (VLFS). In this sense, the selection of topics was concerned with addressing Modern Maritime Law in a diversified and comprehensive manner in all its aspects, considering everything from the beginning of its development to its main current challenges and conflicts. This ensures a suitable repertoire for the study of VLFS, a field that has been little explored but has enormous potential for integrated and sustainable exploration.



Source: Prepared by the authors.

Figure 8. Articles that have the development of themes relevant to activities with ammonia in VLFS.

Blue ammonia is aligned with global goals, such as the Paris Agreement and the Kyoto Protocol, which require substantial reductions in greenhouse gas (GHG) emissions by 2050. In the maritime sector, the IMO (International Maritime Organization) has set targets to reduce CO_2 emissions by 70% and GHG emissions by 50% by 2050, encouraging the use of alternative fuels such as ammonia. However, international standards, such as those of DNV (Det Norske Veritas), specify criteria for the safety, design, and operation of onboard ammonia systems, requiring more robust regulations for emerging technologies such as fuel cells. MARPOL 73/78, with its updates, regulates emissions of NOx, SOx, and other pollutants in maritime transport. Ammonia, being carbon-free, meets the emission requirements, but requires strict controls to avoid spills due to its toxicity (Machaj et al., 2022).

The integration of CCS technologies to capture CO_2 generated during its production relies on blue ammonia. Models that combine CCS with conventional methods, such as the Haber-Bosch process, have been suggested to reduce emissions to levels competitive with green ammonia. Research indicates that combining electrolysis processes with solid oxide fuel cells (SOFCs) can increase energy efficiency in blue ammonia production, reducing operating costs and energy consumption per kilogram produced. In addition, LNG (liquefied natural gas) tanks and transportation systems can be adapted to ammonia with minimal modifications, which reduces costs and simplifies the transition to the new fuel.

Defining specific standards for blue ammonia, including residual CO_2 emissions, is crucial for its widespread adoption. The creation of low-emission shipping corridors (green shipping corridors) is also proposed to speed up their implementation.

In conclusion, the transition to blue ammonia as a marine fuel requires a balance between strict regulations and technological solutions. Although it is a viable alternative to reduce emissions in the short term, its adoption depends on investments in CCS, process optimization, and international standardization to ensure safety and sustainability (Machaj et al., 2022).

Blue ammonia production uses carbon capture and storage (CCS) to reduce CO_2 emissions, but faces significant challenges related to methane leaks along the natural gas supply chain. High leakage rates could compromise the climate benefits of carbon capture, especially over shorter time horizons, due to the strong impact of methane on global warming (Mayer et al., 2023).

To address these challenges, some solutions have been proposed. Reducing methane leaks is essential, and this requires advanced monitoring and control technologies. In addition, improvements in CCS efficiency, such as capturing CO_2 from exhaust gases, can increase the sustainability of the process. Public policies also play a crucial role, incentivizing CCS infrastructure and penalizing high emissions to balance costs and increase the competitiveness of blue ammonia. Despite the limited use of renewable energy, it can be strategically integrated into the blue process to improve its efficiency and reduce emissions (Mayer et al., 2023).

Therefore, the regulation of blue ammonia depends on an integrated approach, which combines technological advances, rigorous inspection, and economic incentives, with the aim of mitigating emissions and making the process more sustainable and competitive in the short and long term (Mayer et al., 2023).

5. Proposal of Good Regulatory Practices Based on the Identification and Assessment of Regulatory Challenges in VLFS Projects with Ammonia Production

Structures (VLFS) projects with ammonia production present significant regulatory challenges due to the structural and technological innovations involved. These challenges range from the absence of specific regulatory frameworks to the need for environmental compliance and alignment with international standards. To address them, it is essential to create a specific legal framework that considers the particularities of these structures and differentiates them from conventional vessels or platforms. This regulation must be aligned with international conventions, such as the United Nations Convention on the Law of the Sea, and applicable national standards, including NORMAM-01 and NORMAM-04.

Furthermore, strict criteria for environmental licensing must be established. Clear guidelines for Environmental Impact Assessment (EIA) should include detailed analyses of impacts on marine ecosystems, mandatory mitigation and compensation plans, and continuous monitoring systems with periodic reports. Furthermore, it is essential to adopt international safety standards, such as the Offshore Structures Standards Code and the SOLAS Convention, ensuring the protection of human life and the environment. The use of carbon capture and storage (CCS) technologies should also be encouraged to reduce CO_2 emissions.

Research and innovation play a strategic role. It is necessary to foster public-private partnerships aimed at developing technologies to produce blue ammonia, in addition to implementing technical training programs to train qualified professionals in the operation and development of these structures. Decommissioning management must also be regulated, with safe procedures that guarantee the environmental recovery of impacted areas. Establishing specific funds for decommissioning can prevent the abandonment of floating structures.

Another important aspect is multi-stakeholder engagement. The participation of governments, civil society, and the private sector in the planning and execution of projects is crucial. Mechanisms for resolving regulatory and intergovernmental conflicts also need to be developed. In addition, economic incentive policies, such as subsidies and tax incentives for low-carbon technologies, should be implemented to strengthen the economic viability of projects. These efforts should be aligned with the Sustainable Development Goals (SDGs), with a focus on the sustainable use of marine resources and combating climate change. The adoption of these good regulatory practices aims to consolidate an effective and sustainable regulatory environment for VLFS projects with ammonia production.

These practices aim to ensure the technical, legal, and environmental viability of VLFS projects, promoting a balance between economic development and environmental preservation. The proposal recognizes the complexity of these projects, integrating environmental, technical, and social aspects into a comprehensive regulatory framework, which is essential to ensure sustainable and safe operations. The use of international standards, such as SOLAS and the United Nations Convention on the Law of the Sea, strengthens the legitimacy and compliance of VLFS with global practices. In addition, the emphasis on reducing emissions through technologies such as carbon capture and storage demonstrates a commitment to sustainability and the Sustainable Development Goals (SDGs).

Regarding stakeholder consultations, it must be mandatorily and bindingly integrated into the legal framework of the project, with a guarantee of transparency, representativeness, and respect for fundamental rights. This approach, in addition to complying with legal and international obligations, strengthens the legitimacy of the project and reduces socio-environmental and legal risks, as can be seen in Table 5.

The interaction of the proposed regulatory framework for the VLFS with offshore oil and gas laws, especially in the context of the Brazilian pre-salt, will require a careful, coordinated, and technically accurate legal integration, given the high degree of legal and institutional complexity involved.

Offshore operations — especially in the pre-salt — are governed by a set of rules and institutions:

1) Legal Framework for Petroleum

Law No. 9,478/97 (Petroleum Law) establishes the concession regime.

Law No. 12,351/2010 defines the production sharing regime for the pre-salt and strategic areas.

Decree No. 9,129/2017 regulates the onerous assignment.

ANP (National Agency of Petroleum, Natural Gas and Biofuels) regulates exploration, production, marketing, and transportation activities.

Table 5. Main steps and proposed actions.

Stage	Actions/Key Elements
Stakeholder Mapping	-Local and traditional communities: fishermen, quilombolas, indigenous people -Economic sectors: transport, logistics, fishing, tourism, agriculture, etc. -Public agencies: IBAMA, ICMBio, FUNAI, city halls, states -Organized civil society: NGOs, neighborhood associations, universities
Preliminary Phase (Planning and Licensing)	-Formal prior consultations on the basis of ILO Convention 169 -Inclusion of consultation as a mandatory step in environmental licensing -Creation of a Multi-stakeholder Advisory Committee with representatives from all parties
Environmental Impact Study Phase (EIA/RIMA)	-Legal holding of public hearings in accessible locations -Early and transparent dissemination of studies with accessible language -Inclusion of the population's manifestations in the environmental agency's technical opinion
Decision and Monitoring Phase	-Motivated response to consultation contributions -Legal mechanisms for social monitoring and reevaluation of the project -Continuous transparency through public portals and periodic reports

Source: Prepared by the authors.

2) Other Relevant Milestones

Law No. 10,233/2001 regulates logistics and transport infrastructure.

Navy and ANTAQ rules govern navigation and port security.

Therefore, the regulatory structure of the mega port should avoid conflicts of jurisdiction and normative overlap, through clear legal instruments and federative cooperation, include specific clauses on offshore oil and gas in its foundational legal framework and, finally, be adaptable to the evolution of the pre-salt legal regimes, respecting the technical, environmental and contractual requirements of the operators and PPSA.

In terms of environmental licensing and decommissioning protocols, Brazil already has a legal structure that is very similar to that of other countries. For example, for environmental licensing, the responsible in Brazil is IBAMA (federal level), with the support of state and municipal agencies and requires complete licensing with EIA/RIMA, monitoring of marine fauna (dolphins, turtles), participation of fishing communities in public hearings and conditions: anti-corrosion systems, leakage prevention and socio-environmental compensations. In the United Kingdom, for example, the responsible authority is the OPRED (Offshore Petroleum Regulator for Environment and Decommissioning), whose requirements are a prior strategic environmental assessment (SEA), marine risk management plans and public consultation with NGOs and Scottish fishermen.

Regarding the implementation of this regulatory proposal in the country, it is necessary to remember that Brazil has considerable institutional and technical capacity to apply rules such as SOLAS (International Convention for the Safety of Life at Sea), especially in large-scale port projects, but still faces practical and structural challenges to ensure full compliance at all levels. In summary, we have the following Strengths and Weaknesses:

Strengths:

1) Existence of national standards compatible with SOLAS, such as:

2) NORMAMs (Maritime Authority Standards) that incorporate relevant parts of SOLAS;

3) Requirement of an Individual Emergency Plan (PEI) and Mutual Aid Plan (PAM) for terminals and ports;

4) Modern ports such as Açu, Suape, and Itapoá already operate partially in line with international standards;

5) Presence of naval and offshore engineering companies with experience in international certifications (DNV, ABS, etc.).

Challenges and Gaps:

1) Lack of national standardization between different port authorities (some ports use different standards for security, control of dangerous cargo, etc.).

2) Deficit of investments in emergency response infrastructure (rescue, fires, spills).

3) Need for continuous updating of crews, operators, and inspectors, especially on changes to SOLAS standards (such as chapters on cybersecurity and fire containment on container ships).

4) Poor integration with international maritime safety systems, such as LRIT (Long-Range Identification and Tracking) and GMDSS (Global Maritime Distress and Safety System), although this is improving.

In summary, Brazil has a solid institutional base and technical expertise to apply SOLAS, especially in large modern port projects. However, for the mega port to be fully compliant, it will be necessary to invest in maritime security infrastructure and continuous training, integrate emergency plans and systematic inspections, and strengthen coordination between the Navy, ANTAQ, and private operators.

6. Final Considerations

The implementation of Very Large Floating Structures (VLFS) to produce blue ammonia represents a strategic opportunity to drive the sustainable energy transition, especially in countries like Brazil, which has vast pre-salt resources. However, the lack of a specific and updated regulatory framework highlights the urgent need for legal adaptations that consider the technical, environmental, and operational particularities of these structures.

The proposal for good regulatory practices presented in this text reinforces the importance of robust environmental licensing, continuous monitoring, adoption of international safety standards, and encouragement of research and technological innovation. In addition, it highlights the need for integrated stakeholder management and public policies aligned with the Sustainable Development Goals (SDGs), with a view to ensuring a balance between economic development and environmental preservation.

With the consolidation of a clear and efficient regulatory framework, Brazil can position itself as a global leader in the sustainable exploration of maritime resources and contribute significantly to international efforts to combat climate change and develop a low-carbon economy.

Nevertheless, a critical analysis of the proposal reveals some points that could be improved in future studies. First, there is a lack of specific legal details. Although the need for a dedicated regulatory framework is mentioned, there is a lack of concrete guidelines on how to adapt it to the Brazilian reality, especially regarding integration with current maritime legislation and tax issues. Second, while the text addresses the importance of environmental monitoring, it does not present strategies for managing cumulative and synergistic impacts, which are common in large offshore projects and can generate significant socio-environmental conflicts.

Another point that deserves attention is community participation, which, despite being mentioned, lacks a detailed plan on how to effectively integrate local communities, often affected by offshore projects, into the decision-making process. In addition, the economic viability of VLFS projects has not been sufficiently discussed, especially considering the current scenario of fluctuating natural gas prices and low-carbon technologies. Finally, the proposal assumes that Brazilian regulatory institutions have the technical and administrative capacity to implement and monitor the suggested requirements. However, the history of regulatory slowness in complex sectors points to the need to strengthen these institutions.

While the proposal represents a robust and well-targeted effort to integrate technological innovation and sustainability into VLFS projects, its success will depend on greater coordination between technical, legal, and social aspects. To consolidate these structures as pillars of the energy transition in Brazil, it will be essential to overcome economic challenges, strengthen institutional governance, and ensure that local communities and the environment are prioritized in the regulatory process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Araújo Júnior, L. R. S. D., & Oliveira, L. P. S. (2017). The Role of the International Tribunal for the Law of the Sea in Environmental Protection: A Case Study of the Mox Plant. *Revista de Estudos e Pesquisas Avançadas do Terceiro Setor, 4,* 67-96. https://doi.org/10.31501/repats.v4i1.8094

Arlota, A. S. C., & Cardoso, C. M. V. (2013). The Legal Nature of Offshore Oil Platforms—

A Study of the Offshore Industry. *Brazilian Journal of Oil, Gas and Energy Law, 4,* 23-36.

Brazil (1997a). *Law No. 9,537 of December 11, 1997, Which Provides for the Safety of Waterway Traffic in Waters Under National Jurisdiction and Contains Other Measures.* Official Gazette of the Union. https://www.planalto.gov.br/ccivil_03/leis/l9537.htm

Brazil (1997b). *Law No. 9,537 of December 11, 1997, Which Provides for the Safety of Waterway Traffic in Waters under National Jurisdiction and Contains Other Measures.* Official Gazette of the Union. Executive Branch. https://www.portodemaceio.com.br/portal/en/environmental-legislation

Brazil (2023). *Casa Civil. Law Project 4338/2023.* https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=2386002

Cavalcante, L. R., & Negri, F. (2022). *Productivity in Brazil: Performance and Determinants—Vol 2.* IPEA.

Diehl, F. P., & Siqueira, C. B. (2006). The Legal Guardianship of Marine Waters in Brazil and the National Political Management of Water Resources: International Acts and Incident National Legislation. *Journal of Coastal Research, 39,* 994-999.

EPE (Energy Research Company) (2020). *National Energy Balance (BEN) 2020: Base Year 2019.* https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2020

Lamas-Pardo, M., Iglesias, G., & Carral, L. (2015). A Review of Very Large Floating Structures (VLFS) for Coastal and Offshore Uses. *Ocean Engineering, 109,* 677-690. https://doi.org/10.1016/j.oceaneng.2015.09.012

Lima, I. (2006). Argentina, Brazil, Uruguay and the Regulation of the Use of the South Atlantic. *Journal of Economics & International Relations, 5,* 41-55.

MacFarlane, D. R., Cherepanov, P. V., Choi, J., Suryanto, B. H. R., Hodgetts, R. Y., Bakker, J. M. et al. (2020). A Roadmap to the Ammonia Economy. *Joule, 4,* 1186-1205. https://doi.org/10.1016/j.joule.2020.04.004

Machaj, K., Kupecki, J., Malecha, Z., Morawski, A. W., Skrzypkiewicz, M., Stanclik, M. et al. (2022). Ammonia as a potential marine fuel: A review. *Energy Strategy Reviews, 44,* Article ID: 100926. https://doi.org/10.1016/j.esr.2022.100926

Mayer, P., Ramirez, A., Pezzella, G., Winter, B., Sarathy, S. M., Gascon, J. et al. (2023). Blue and Green Ammonia Production: A Techno-Economic and Life Cycle Assessment Perspective. *iScience, 26,* Article ID: 107389. https://doi.org/10.1016/j.isci.2023.107389

Robson, C. (2002). *Real World Research: A Resource for Social Scientists and Practitioners Researchers* (3rd ed.). Blackwell Publishing.

Scaranello, T. (2021). *Oil Rig and Its Legal Set to Ship.* Editora JusPodivm.

Suzuki, H. (2005). Overview of Megafloat: Concept, Design Criteria, Analysis, and Design. *Marine Structures, 18,* 111-132. https://doi.org/10.1016/j.marstruc.2005.07.006

Wang, C. M., & Tay, Z. Y. (2011). Very Large Floating Structures: Applications, Research and Development. *Procedia Engineering, 14,* 62-72. https://doi.org/10.1016/j.proeng.2011.07.007