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Fostering Sustainable LNG Bunkering Operations: Development of Regulatory Framework

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Abstract: Liquefied natural gas (LNG) is a liquid form of natural gas, predominantly composed of methane, that has emerged as a promising alternative to traditional hydrocarbon fuels in the maritime transportation sector due to its lower greenhouse gas (GHG) emissions. As the world shifts towards renewable energy sources, LNG is increasingly recognized as a bridge fuel that can help mitigate global warming. However, the production and use of LNG can result in methane emissions, which have a higher global warming potential than carbon dioxide. To address this issue, competent authorities aim to develop regulatory frameworks to reduce the potential environmental impact of LNG and promote its use as a cleaner fuel in the maritime sector. We used a systematic approach to selecting and synthesizing the sources relevant to the LNG bunkering process to provide an overview of the current state of regulations, standards, guidance, and trends in LNG bunkering to minimize the potential adverse environmental impacts.

Keywords: LNG; LNG bunkering; GHG emissions; alternative fuels; regulations

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1. Introduction

The vigorous development of globalization had an equally strong impact on the development of the maritime industry and transport by creating a single market. Maritime transport nowadays forms the backbone of international trade and the global economy, as more than 80% of the world's trade is transported by sea.

However, the increase in capacity, number of ships, infrastructure, and other factors often negatively impact the environment. Therefore, environmental protection today is a significant challenge for the sustainability of maritime industry. According to available data, maritime sector is directly responsible for 2–3% of global carbon dioxide (CO_2) emissions, which could grow to almost 17% by 2050 without the introduction of regulations by competent authorities [1]. In the same period, greenhouse gas (GHG) emissions of total shipping traffic experienced an increase of 9.6% from 2012–2018 and an increase of 0.13% in global anthropogenic emissions [2].

With all this in mind, there was a need for solid and well-organized actions to protect our shared future, coordinated from the highest levels of the maritime industry. For example, the European Union (EU) adopted a plan called 'Fit for 55′, which aims to reduce greenhouse gas emissions by 55% by 2030 and achieve complete climate neutrality by 2050. Also, the International Maritime Organization (IMO) adopted mandatory measures to reduce greenhouse gas emissions from maritime transport following the International Convention on the Prevention of Pollution from Ships (MARPOL).

According to the IMO, liquefied natural gas (LNG) is a liquid with a vapor pressure greater than 0.28 MPa at 37.8 °C [1]. It has emerged as the leading solution in the global transition from fossil to renewable energy sources as the purest fossil fuel. Since LNG contains only trace amounts of sulfur, on average less than 0.004%, the emission of harmful SOx compounds is reduced by 95–100%. Furthermore, depending on the engine technology used and the quality of the LNG, using LNG as a propellant reduces NOx compound emissions by 40–80%, carbon dioxide (CO_2) emissions by 25–30%, and particulate matter (PM) emissions by 90–100%.

On the other hand, as a fossil fuel, LNG has disadvantages in the form of methane emissions, which may be even more harmful to the environment than carbon dioxide. Methane has nearly 87 times the global warming potential of CO_2 in the first 20 years after emissions and 36 times in the first 100 years [2]. Moreover, according to available data, approximately 3.2–3.4% of produced natural gas leaks into the atmosphere before being burned, with the global average leakage rate estimated to be around 2.2% [3]. With this in mind, it is understandable that there is a certain amount of concern due to the increase in number of vessels using LNG as fuel, following the assumption that this trend could lead to a further rise in methane emissions.

The initial goal of the study is to identify and present the potential good and negative implications of using LNG as a fuel in maritime transport, with a focus on methane as its main component, as well as the potential hazardous emissions that may arise as a result of its use. The next aim is to use systematic strategies to select, synthesize and present an overview of the current state of regulations, standards, guidelines, and trends in the performance of LNG bunkering operations. Finally, the third objective is to express concern about whether existing regulations and standards are adequate, given the increased number of LNG-powered ships, and encourage continuous monitoring and evaluation of the effectiveness of existing regulations and the development of new ones to achieve environmental goals and procedure sustainability.

By integrating these objectives, this study aims to provide a comprehensive analysis of the use of LNG as a marine fuel, considering its potential strengths and weaknesses. In addition, this study reveals vital considerations for safe, efficient, and sustainable LNG bunkering operations by examining current regulations, standards, policies, and industry trends.

The regulatory framework has been divided into High-Level Instruments, Technical Standards, and Industry Guidance (Figure 1).

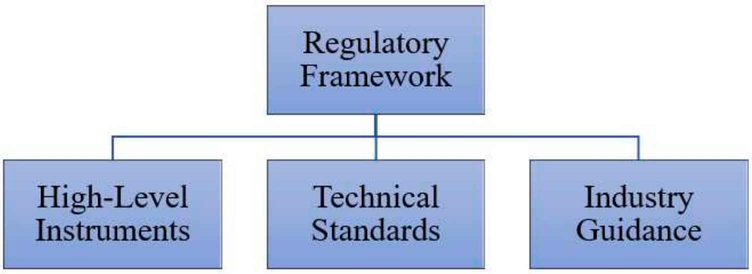

Figure 1. Regulatory Framework Division.

2. High-Level Instruments

2.1. Marpol

To begin with, the IMO developed MARPOL as the principal international Convention intended to avert pollution from ships caused by operational or unintentional causes. The Convention consists of a basic text (MARPOL Convention and Protocols) and six annexes dealing with various types of pollutants:

- Annex I—Prevention of pollution by oil;
- Annex II—Prevention of pollution by noxious liquid substances in bulk;
- Annex III—Prevention of pollution by harmful substances carried by sea in packaged form;
- Annex IV—Prevention of pollution by sewage from ships;
- Annex V—Prevention of pollution by garbage from ships;
- Annex VI—Prevention of air pollution from ships.

Over the years, growing international awareness of global air pollution issues has necessitated the implementation of mechanisms to reduce harmful emissions from ships. As a result, through a Protocol adopted in September 1997, Annex VI was added to MARPOL on 19 May 2005, to address the problem of ship air pollution. The adoption of Annex VI was a watershed moment in this confrontation, and it proved to be a good starting point that will be improved and updated following the advancement of new technologies and knowledge. In addition, the Marine Environment Protection Committee (MEPC) issued several resolutions and amendments, two of which have proven to be highly significant.

Firstly, amendments to Annex VI adopted by MEPC.176(58) in 2008 established stricter emission limits through regulations 13 and 14, which became legally effective on 1 July 2010. Regulation 13 governs nitrogen oxide (NOx) emissions and applies to any marine diesel engine with a power output of more than 130 kW installed on a ship, as well as any engine with a power output of more than 130 kW that undergoes a major conversion on or after 1 January 2000 [3].

Regulation 14 is the second regulation, which significantly limits SOx and PM emissions from any fuel used on board. This regulation establishes maximum sulfur levels in fuel, which are gradually reduced over time and expressed as a percentage of a mass fraction (% m/m), with variations in Emission Control Areas (ECA) and other global areas, as presented in Table 1 [4].

Table 1. Maximum Sulfur Content of Marine Fuels.

General Sulfur Requirements	Sulfur Requirements within SECAs *
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020	0.10% m/m on and after 1 January 2015

* Sulfur Emission Control Areas.

Another critical set of amendments adopted by MEPC(62) in 2011 added a new Chapter 4 titled "Regulations on energy efficiency for ships", which entered into effect on 1 January 2013, and is mandatory for all ships of 400 GT and above, trading internationally. While the Kyoto Protocol, adopted by the United Nations Framework Convention on Climate Change in 1997, bound only developed countries by imposing heavier burdens on them, Chapter 4 implied regulations to reduce greenhouse gas emissions from an entire industry sector. Establishing the Energy Efficiency Design Index (EEDI), which requires a minimum energy efficiency level per capacity mile for different ship types and sizes, is the primary mechanism for ensuring technical compliance with Chapter 4 regulations [5]. In other words, it indicates the ship's estimated performance in terms of energy efficiency, both for new ships and ships that have undergone significant conversions [3]. There are two kinds of EEDI to distinguish: attained EEDI and required EEDI. A formula describes the connection between them [3]:

$$Attained\ EEDI \leq Required\ EEDI = \left(1 - \frac{X}{100}\right) \cdot Reference\ line\ value \tag{1}$$

where: X—reduction factor; Reference line value—Provided for each ship type required to calculate EEDI.

The Attained EEDI is the actual calculated and verified EEDI value for a specific ship based on technical documentation. As a result, the Attained EEDI must be equal to or less than the Required EEDI limit prescribed by MARPOL.

Another crucial mechanism required by regulation 22 is the Ship Energy Efficiency Management Plan (SEEMP), which implements methods to improve ship energy efficiency and reduce harmful emissions (carbon intensity) from ships. The SEEMP, in conjunction with the Guidelines for the Development of Ship Energy Efficiency Management Plan, aims to encourage companies to incorporate actions through four procedures: planning, implementation, monitoring, and self-evaluation and improvement [6]. Planning is the most crucial stage, which determines both the current state of ship energy usage and carbon intensity, as well as the expected improvement in ship energy efficiency and reduction in carbon intensity through various options [6]. Once the planning phase is complete, and the appropriate measures have been adopted, it is critical to creating a system for their implementation that is being quantitatively monitored by an established method. Finally, this cycle concludes with a regular self-evaluation, which raises awareness of the quality of efficiency performance determined in SEEMP to achieve continuous and long-term improvement.

The most recent significant milestone was the adoption of Resolution MEPC.328 (76) for all vessels of 5000 GT and above trading internationally, which will come into effect on 1 January 2023. Accordingly, SEEMP Part III will require all ships in that category to have an adequate methodology ready to calculate their attained Carbon Intensity Indicator (CII) and a well-organized plan for achieving the required CII. Baltic and International Maritime Council (BIMCO), one of the most influential shipping associations, adopted and published the new CII Operations Clause for Time Charter Parties on 17 November 2022. The "Clause" was introduced to assist charterers and shipowners during the correct implementation and compliance with the CII regulation [7]. The CII calculates carbon emissions in grams per unit of transport work for each ship and assigns a letter grade from A to E, with A being the best. It is calculated annually as the ratio of total CO_2 (M) emitted to the entire transport work (W), as shown in the formula [8]:

$$Attained\ CII = \frac{M}{W} \quad (2)$$

where,

$$M = FCj \cdot C_{Fj} \quad (3)$$

M—A mass of CO_2 emissions
FC—The total mass of type fuel oil consumed in a calendar year (g)
C_{Fj}—The conversion factor
j—The type of fuel oil

$$W = C \cdot D_t \quad (4)$$

W—Transport work
C—Ship's capacity
D_t—The total distance traveled (Nm)

Following the calculation, if a ship receives a rating of "D" for three consecutive years or an "E" for one year, adequate corrective measures should be established and implemented to achieve a rating of "C" or higher.

In terms of technical means, according to the formula, every ship of 400 GT or greater, including vessels that have undergone significant conversions, is required to obtain its Energy Efficiency Existing ship Index (EEXI) once in a lifetime [9]:

$$Attained\ EEXI \leq Required\ EEXI = \left(1 - \frac{y}{100}\right) \cdot EEDI\ reference\ line\ value \quad (5)$$

where, y—EEXI reduction factor concerning the EEDI reference line (The EEDI reference line values should be calculated following Annex VI regulations 24.3 and 24.4.) (%).

In summary, existing ships will be required to meet technical efficiency standards within EEXI based on the required EEDI, whereas ships delivered after 1 January 2023, will already be built under the required EEXI value.

2.2. IGF Code

Since using LNG as a fuel was initially associated with LNG carriers that used boil-off gas from their cargo, the need for a legitimate instrument relevant to using LNG as a fuel was unessential. At the time, the only instrument applicable to the use of LNG as a fuel was The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), imposing standards for ships carrying liquefied gases at sea, which was adopted on 17 June 1983 [10]. On 1 July 1986, The International Convention for the Safety of Life at Sea (SOLAS) Chapter VII made the Code mandatory for all ships transporting such cargo to promote safe transport and handling [11].

According to Clarkson Research [12], the number of LNG-powered vessels has been steadily increasing since 2012 (Figure 2). As a result, the number of LNG-capable vessels increased to 816 in the third quarter of 2022.

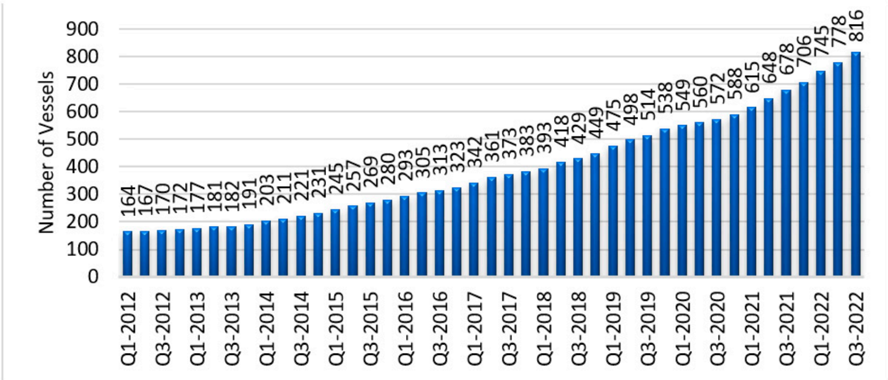

Figure 2. Development of LNG Capable Fleet.

It is important to note that 61% of those 816 vessels are LNG Carriers. Furthermore, based on the 2022 order book, it is seen that only 33% of the 708 orders are for LNG Carriers, and the rest is for other types of vessels (Figure 3).

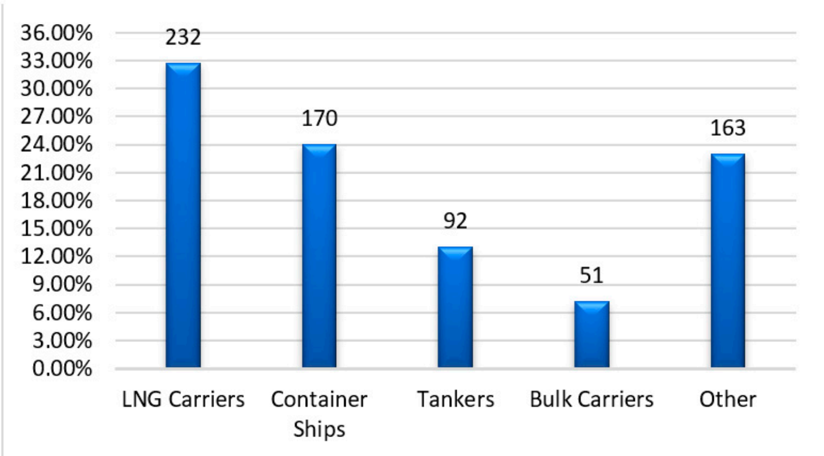

Figure 3. LNG Capable Vessels Order Book (2022).

These figures show that the maritime industry is significantly shifting towards sustainability, with increasing numbers of LNG-powered vessels in its various segments. The constant increase in the LNG capable fleet and the diversity of the order book suggest a positive outlook for the LNG bunker industry, which has the prospect of playing a vital role in the global energy transition. With the expected increase in the number of vessels powered by LNG in the coming years, it is clear that the demand for LNG as a fuel will be limited to more than just the segment of LNG carriers that use boil-off gas. The growing interest in other types of vessels, such as container ships, tankers, bulk carriers, and others, shows that the industry is investing significant efforts in developing new technologies to reduce emissions and comply with environmental regulations, which will undoubtedly lead to the more sustainable and balanced growth of the LNG market bunkering in the future.

Furthermore, with the growing recognition of LNG as a cleaner transition fuel and the increasing number of LNG-powered vessels entering the market, it is necessary to ensure that the required infrastructure, safety regulations, and high-level training are in place to support their safe and efficient operation.

However, the use of low-flashpoint fuels (LFF), such as LNG, which has a flashpoint of −175 °C, was not regulated or even approved within the scope of SOLAS, which generally prohibited using low-flashpoint fuels less than 60 °C. Thus, as the demand for and use of LNG as a propellant grows, so does public awareness of the need for a specific code to govern such use.

As a result of the experience and knowledge gained through the IGC Code and the Interim Guidelines on safety for natural gas-fueled engine installations in ships [13], the MSC.391(95) adopted the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) on 11 June 2015. Simultaneously, new part G is introduced in SOLAS Chapter II-1, which requires the application of the IGF Code to all ships using LFF for which the building contract is placed on or after 1 January 2017, or whose keels are laid or are at a similar stage of construction on or after 1 July 2017, or which are delivered on or after 1 January 2021 [14].

The purpose of the IGF Code is to provide international standards for ships using LFF as fuel in terms of machinery, equipment, and systems required to minimize risk to the vessel, crew, and environment. It is divided into five major parts that cover all aspects necessary for the safe and effective use of such fuels [15]:

- Part A—General;
- Part A-1—Specific requirements for ships using natural gas as a fuel;
- Part B-1—Manufacture, workmanship, and testing;
- Part C-1—Drills and emergency exercises;
- Part D—Training.

Indeed, since the IGF Code covers a broad range of applications for LFF as fuel, only some of its sections are directly related to LNG bunkering. As a result, the chapters and sections critical to the safe execution and monitoring of the operation mentioned above have been targeted and presented.

Section 3.2 lists the Functional Requirements that serve as the foundation for other requirements imposed by this Code. In addition, this section prescribes the safety and reliability of a whole LNG bunkering system, its components, and machinery to ensure safe and reliable operation [15].

Chapter 8, called Bunkering, is entirely dedicated to the operation of the same name with an emphasis on constructive aspects related to the location and details of the bunker station to ensure adequate and valid systems on board, through which the fuel will be carried out seamlessly without unwanted effects on the ship, people, and the environment. This chapter lists the above Functional Requirements and bunker station regulations that require bunker stations to be installed on an open deck for adequate natural ventilation. In addition, proper installation of connections, piping, and hull and deck structures is required to prevent damage to the ship's structure in the event of an LNG spill. Furthermore, the Regulations for bunkering systems ensure that the bunkering system is set up to prevent the unwanted release of gas to the atmosphere during the bunkering operation, as well as that a fuel purge line must be provided through which the pipeline is purged off the remainder of the cargo after the procedure is complete. Finally, it is also essential to have a ship-shore link (SSL) or an equivalent means that allows automatic and manual activation of the emergency shutdown system (ESD) in case of need [15].

Section 15.4 deals with establishing the necessary controls on the filled tank using level indicators and overflow controls for LNG fuel tanks. Each tank must have at least one device to measure its filling level so that reading can determine this value at any time. The devices must be designed to operate in the pressure and temperature ranges specified for each tank, and they can be indirect (weighing or in-line flow measurement) or closed devices (radio-isotopes, ultrasonic, etc.). Furthermore, each liquefied gas tank must be equipped with a high liquid level alarm, overfill alarm, high-pressure alarm, and, if necessary, a low-pressure alarm that will give visual and audible signals on the bridge, the central control station with a permanent crew or the safety center on board when activated [15].

Section 15.5 establishes regulations for bunkering control, which define the expected protection measures for the LNG bunkering interface of the recipient ship. In short, bunkering operation control must be provided at a safe location sufficient distance from the bunkering station. From this location, the entire operation can be continuously monitored, including current pressure, temperature, and tank filling level, acceptance and control of all available alarms, and the ability to activate the ESD system in an emergency [15].

Section 18.4 directly relates to the LNG bunkering operation via prescribed procedures, planning, and responsibilities documented and confirmed in the international regulatory framework. In addition to the responsibility primarily based on signed documents by the master or representative of both parties (recipient and bunkering provider), this section also provides methods to review the systems necessary for the operation's management, automation, and security. Furthermore, the procedures essential for the effective checking of the systems and equipment required for the start of the process, such as the checking of hoses, couplings, remote-controlled valves, etc., and the establishment of ship bunkering source communications using devices that meet the expected standards in all segments, are also foreseen. When all the conditions for transfer have been established, appropriate warning signs must be placed at all relevant points, and only persons necessary for the procedure's success must be allowed to proceed into the area of the immediate performance of the bunker operation [15].

Following the adoption of the IGF Code, the next step was to create appropriate instruments to develop regulations for implementing training, education, and certification of crew members on board ships subject to the Code's regulations. As a result, resolution MSC.396(95) amended the STCW Convention on 11 June 2015, adding a new regulation V/3 (Mandatory minimum requirements for the training and qualifications of masters, officers, ratings, and other personnel on ships subject to the IGF Code) to the existing chapter V (Special training requirements for personnel on certain types of a ship) [16]. On the same day, resolution MSC.397(95) amended the STCW Code to expand and elaborate on the technical details required by regulation V/3 of the STCW Convention. Thus, a new section, A-V/3, has been added, containing a table outlining the minimum competencies and knowledge required for basic and advanced training on ships [17].

3. Technical Standards

A standard, in general, is a written document that specifies conditions, specific requirements, quality standards, or characteristics that can be used to ensure the suitability of materials, products, processes, and services. Standards for LNG bunkering are developed and defined by technical experts through a process of knowledge sharing and consensus building. Therefore, they are critical for bridging the gap between high-level instruments and their provisions' operational or technical implementation [18]. International Organization for Standardization (ISO), the world's largest developer of international standards with 167 national standards bodies, has been responsible for most standards related to various aspects of LNG bunkering [19]. Through its Technical Committees ISO/TC8 and ISO/TC67, ISO produces standardization for ships and marine engineering (design, construction, training, etc.) and in the oil and gas industry, including low-carbon energy [20,21].

ISO/TS 18683:2021: Guidelines for safety and risk assessment of LNG fuel bunkering operations. This technical specification has been established due to the revision of ISO/TS 18683:2015 [22]. It describes the properties of LNG, potential hazards associated with its use, storage requirements, and minimum requirements for the design and operation of the entire LNG facility, including the interface between the LNG supply facility and the receiving ship. Furthermore, it specifies crew training requirements, i.e., the operators in charge of the safe performance of LNG bunkering operations and functional requirements for the equipment used during operations to ensure their safety. A strong emphasis was placed on improving safety through a structured approach to risk assessment, which determines its ultimate acceptability, as well as the relentless determination of controlled areas and safety zones. It applies to the provision of ships for inland trade and maritime navigation and addresses LNG supply scenarios involving LNG from shore or ship, mobile-to-ship, and ship-to-ship [23].

ISO 20519:2021: Ships and marine technology—Specification for bunkering liquefied natural gas-fueled vessels. The specified standard prescribes the minimum requirements that LNG bunkering systems and equipment must meet to operate safely. It was created by revising the first edition of ISO 20519:2017 [24], which is being revoked and applies to all ships in national and international navigation. It applies in various situations and regulatory regimes and consists of the five elements listed below [25]:

1. Hardware: Liquid and vapor transfer systems;
2. Operational procedures;
3. Requirement for the LNG provider to provide and LNG bunker delivery note;
4. Training and qualifications of personnel involved;
5. Requirements for LNG facilities to meet applicable ISO standards and local codes.

ISO 21593:2019: Ships and marine technology—Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas. This document establishes minimum safety, functional, and labeling requirements, as well as testing procedures for dry-disconnect/connect couplings for LNG hose bunkering systems. In addition, the interfaces, dimensions, and designs are also prescribed so that the couplings are correctly designed to withstand the numerous anticipated tests. In this way, technical requirements are met that will ensure the compatibility and safety of using couplings in different conditions, regardless of the contractor, provided that they are manufactured and tested by the specific requirements of this standard. The specified standard currently applies to coupling sizes ranging from DN 25 (Diametre Nominal (DN)—The size of a pipe, inner diameter (mm)) to DN 200 and does not apply to Quick Connect Disconnect Coupling System (QCDC) [26].

Bearing in mind a significant number of existing standards, directly or indirectly related to LNG bunkering operations, for the brevity of this paper, the standards recognized as the most relevant and most appropriate to the topic were selected and listed. In addition to the already mentioned ISO, numerous other international and national organizations are actively working on developing and publishing new standards, and in the context of LNG bunkering, The International Electrotechnical Commission (IEC) and European Norms (ENs) certainly stand out.

4. Industry Guidance

The methods of use of the guidelines should support achieving the desired results in a specific narrow area of activity by guiding best practices related to safety, procedures, equipment, and other factors, which is necessary with LNG bunkering operations. It is only about recommendations or instructions that only serve as help and are not framed by any statute that would make them legally binding. However, in today's world of intense globalization and increased competition, most companies actively apply guidelines relevant to their field of activity to provide the best possible service to clients and thus achieve the best possible business. Guidelines differ significantly depending on the publisher and content and should be used following the needs and goals of the company. For example, one guide may be more oriented towards risk assessment and acceptance methods, while another may narrowly specialize in the distribution of responsibilities and the operational aspect of the operation. The table below lists some of the available LNG bunkering guidelines that can be effectively used to improve the operation flow (Table 2) [18,27–33].

The use of LNG as a clean fuel source in the maritime transport sector is on the rise, and it is advisable for stakeholders involved in LNG bunkering to follow the guidelines outlined in the table. These guidelines provide a comprehensive overview of the various aspects of LNG bunkering, from planning and risk assessment, through the functional requirements of the design and development of LNG bunkering facilities to the LNG bunkering operations themselves. Adherence to these guidelines can positively contribute to minimizing potential adverse environmental impacts and increasing safety, and they will inevitably become increasingly important as the use of LNG as a marine fuel grows. Compliance with these guidelines certainly goes a long way toward building trust among stakeholders and demonstrates a commitment to responsible, proven, and sustainable practices while promoting safety and efficiency. However, it is essential to note that these guidelines are not comprehensive and will generally need to be adapted and selected according to specific circumstances or contexts.

Table 2. The List of LNG Bunkering Guidelines.

Title	Publisher
Development and Operation of Liquefied Natural Gas Bunkering Facilities	Det Norske Veritas and Germanischer Lloyd (DNV-GL)
Gas as a Marine Fuel: Safety Guidelines	The Society for Gas as a Marine Fuel (SGMF)
Guidance on LNG Bunkering to Port Authorities and Administrations	European Maritime Safety Agency (EMSA)
Guidelines on LNG Bunkering	Bureau Veritas (BV)
LNG Bunker Checklist Ship to Ship	International Association of Ports and Harbors (IAPH)
LNG Bunkering Guidelines	International Association of Classification Societies (IACS)
LNG Bunkering Technical and Operational Advisory	American Bureau of Shipping (ABS)
Standard for a Liquefied Natural Gas (LNG) Bunker Checklist Bunker Station to Ship	Central Commission for the Navigation of the Rhine (CCNR)

Therefore, operators must be equipped with adequate knowledge to make independent judgments and decisions and consult with relevant experts to ensure that their operations are carried out safely and efficiently, thus contributing to the continued growth and development of LNG bunkering.

The mentioned (or some other) guides should be used exclusively to help ensure the operation's safety and efficiency and document the procedures followed rather than as a definitive source of knowledge or law.

5. Discussion

Given the increasing use of LNG as a fuel for ships, it is conceivable that regulations, standards, and recommendations will further develop and tighten accordingly. That is especially true since methane is a potent greenhouse gas with multiple times more powerful global warming potential than carbon dioxide, and its unprofessional or negligent handling can do more harm than good in preventing future air pollution. In order to try to overcome this challenge, the competent authorities have established a certain regulatory framework, presented in this paper, which contains regulations, standards, and guidelines that include measures to ensure the safe and efficient handling, storage, and implementation of LNG bunkering operations, valuing the requirements to reduce harmful emissions. However, referring to the information that approximately 3.2–3.4% of produced natural gas leaks into the atmosphere before being burned, with the global average leakage rate estimated to be around 2.2% [3] in combination with the data from Figure 1 on the constant increase in the number of LNG ready ships, it can be concluded that the increasing number of such vessels will consequently contribute to the rise in harmful methane emissions. Measuring methane emissions is a technically very demanding process, and it is primarily necessary to better understand them and accurately define the exact amount of emissions, their sources, and causes. In general, the release of methane from LNG vessels can be attributed to the unintentional release of methane during vessel operations, such as leaks, gas-freeing operations, or due to methane slip from engines. Accordingly, it is necessary to measure the number of methane emissions to obtain accurate data for different types, sizes, and ages of ships, types of cargo tanks, insulation technologies, and undoubtedly for different versions of the propulsion system. Then an appropriate regulatory framework that is structured in detail and individually applied to each case could be established to achieve the most optimal results. Taking into account the data from Figure 2 related to the order book, which shows the future increase in the variety of ships that can use LNG as a fuel (excluding LNG carriers), the question arises about the readiness and competence of the crew who have no prior experience in working with LNG. Safely handling such fuel requires specialized and advanced knowledge and skills due to its specific characteristics and possible safety risks. Therefore, it is necessary to improve the system of continuous evaluation and consequently to increase and modernize the training and preparation, reducing the risks of handling LNG to the lowest possible level. Of course, all the above also refers to the acceleration of the development of the infrastructure inevitable for the performance of LNG bunkering operations, which must follow the increase in demand for this fuel and which must also be carried out following the prescribed regulations, as well as to meet the expected standards and employ highly qualified personnel.

Moving ahead, it is crucial to constantly monitor and evaluate the effectiveness of existing regulations and develop new ones to the satisfaction of all stakeholders to achieve the set environmental goals. Furthermore, the focus on energy efficiency and sustainability entails constant innovation and development of new systems and components, i.e., improvement of existing ones, which ultimately requires appropriate action and adaptation of regulations that will ensure their application in a safe, efficient, and responsible manner.

6. Conclusions

Since it has been scientifically proven that air pollution has a deleterious impact on climate change and has evolved into a severe global issue, there was a need to establish strong and clear regulations for the control of harmful emissions from ships and consequently also for an appropriate regulatory regime that will encourage such activities. The adoption of the MARPOL Convention made a big step in this direction by the IMO as the primary international convention on preventing pollution from ships, especially by adopting the IGF Code, which is closely specialized for ships using gases or other low-flashpoint fuels. The IGF code is a good initiative since it introduces legally enforceable regulations on using LNG as a marine fuel and bunkering regulatory requirements. Given the inherent risk of accidents in bunkering operations and the need to maintain a high safety level, the IGF code's importance is substantial.

In today's highly competitive business environment, where a small group of prominent sellers dominates, only the ones with the finest quality of service will prevail. Following that thought, is it wise to think that guidelines provided to reach specific standards are purely advisory? Guidelines usually refer to mandatory requirements from the relevant policies while giving advice and suggestions on how to properly implement them using slightly more adapted language than the strictly legal form of the policies. Therefore, it is prudent to avoid making a clear cut between high-level instruments as obligatory and guidelines and standards that at first glance appear to be optional but in the way of keeping up with the competition and progress will be considered compulsory.

Introducing the CII clause in charter parties will undoubtedly raise controversies and discussions about its correct operational and commercial use. The CII could be a good starting point for stimulating development, improving cooperation, and working relations between different parties, and for the future reshaping of charter parties for decarbonization as a central idea. However, after BIMCO recently released the CII Operations Clause for Time Charter Parties, one gets the impression of creating confusion in the relationship between shipowners and charterers and their specific role in their implementation. Although the clause allows both parties to work together, in good faith, to establish a written plan to meet CII, it cannot guarantee that the plan will be successful nor provide alternatives or guidance in the event of failure. In the opinion of many, an ideal solution for the fair division of rights and obligations between charterers and shipowners has not been found at the time, and only time will tell whether it will be widely applied or encounter more significant obstacles.

This research paper attempted to present and consolidate the existing regulatory instruments closely related to LNG bunkering operations to regulate the release of harmful emissions from ships. Furthermore, it can serve as a foundation for the eventual evaluation of their effectiveness and their future creation and precise modeling to satisfy all participants in the business process and environmental protection. Progressively strict regulations and requirements on the prevention of harmful emissions encourage the development of their innovation and creativity by applying advanced strategies to achieve the highest possible energy efficiency and the durability and reliability of the used systems and components.

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References

1. S&P Global. Available online: https://www.spglobal.com/en/ (accessed on 4 November 2022).
2. Fourth IMO GHG Study 2020 Full Report. Available online: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx (accessed on 5 December 2022).
3. International Maritime Organization. *MARPOL: Articles, Protocols, Annexes and Unified Interpretations of the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the 1978 and 1997 Protocols: Incorporating All Amendments in Force on 1 January 2017/IMO*, 6th ed.; International Maritime Organization: London, UK, 2017.
4. International Maritime Organization. Amendments to the Annex of The Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 Relating Thereto (Revised MARPOL Annex VI). 2010. Available online: https://www.epa.gov/sites/default/files/2016-09/documents/resolution-mepc-202-62-7-15-2011.pdf (accessed on 21 December 2022).
5. Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from ships, 1973, as Modified by the Protocol of 1978 Relating Thereto (Inclusion of Regulations on Energy Efficiency for Ships in MARPOL Annex VI). 2011. Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.203(62).pdf (accessed on 3 June 2022).
6. Annex 8 Resolution MEPC.346(78) (Adopted on 10 June 2022) 2022 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP). Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.346(78).pdf (accessed on 12 September 2022).
7. CII Operations Clause for Time Charter Parties. 2022. Available online: https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/cii-operations-clause-2022 (accessed on 12 January 2023).
8. MEPC.352(78)-2022 Guidelines on Operational Carbon Intensity Indicators and the Calculation Methods (CII Guidelines, G1). Available online: https://www.ccs.org.cn/ccswzen//articleDetail?id=202212210561846752 (accessed on 9 July 2022).
9. Annex 1 Resolution MEPC.328(76) Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution From Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto 2021 Revised MARPOL Annex VI. Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.328(76).pdf (accessed on 29 January 2023).
10. International Maritime Organization. Adoption of the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC CODE). Available online: https://www.imo.org/en/ourwork/safety/pages/igc-code.aspx (accessed on 17 February 2023).
11. SOLAS Consolidated Edition. 2018. Available online: https://www.samgongustofa.is/media/english/SOLAS-Consolidated-Edition-2018.docx.pdf (accessed on 14 October 2022).
12. Clarkson Research Services Limited 2022. Shipping Intelligence Network Timeseries. September 2022. Available online: https://sin.clarksons.net/ (accessed on 12 July 2022).

13. International Maritime Organization Resolution MSC.285(86) (Adopted on 1 June 2009) Interim Guidelines on Safety for Natural Gas-fuelled Engine Installations in ships. Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.285(86).pdf (accessed on 12 January 2023).
14. International Maritime Organization. MSC 392 95. 2016. Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.392(95).pdf (accessed on 14 July 2022).
15. International Maritime Organization. *IGF Code: International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels*; IMO: London, UK, 2016.
16. International Maritime Organization. MSC 396 95. 2016. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/HumanElement/Documents/MSC.396(95).pdf (accessed on 15 February 2023).
17. International Maritime Organization. MSC 397 95. Available online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.397(95)NotyetavailableonIMODOCS.pdf (accessed on 11 September 2022).
18. Guidance on LNG Bunkering to Port Authorities and Administrations EMSA Guidance on LNG Bunkering to Port Authorities/Administrations 2 Cover Image Courtesy: AGA EMSA Guidance on LNG Bunkering to Port Authorities/Administrations. 2017. Available online: https://www.emsa.europa.eu/publications/inventories/item/3207-guidance-on-lng-bunkering-to-port-authorities-and-administrations.html (accessed on 18 June 2022).
19. ISO—About, Us. Available online: https://www.iso.org/about-us.html (accessed on 31 October 2022).
20. *ISO_TC 8*; Ships and Marine Technology. ISO: Geneva, Switzerland, 1947.
21. *ISO_TC 67*; Oil and Gas Industries Including Lower Carbon Energy. ISO: Geneva, Switzerland, 1947.
22. *ISO/TS 18683*; Standards Publication Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships. International Organization for Standardization: Geneva, Switzerland, 2015.
23. *ISO—ISO/TS 18683:2021*; Guidelines for Safety and Risk Assessment of LNG Fuel Bunkering Operations. Available online: https://www.iso.org/standard/76811.html (accessed on 31 October 2022).
24. *ISO 20519:2017*; Ships and Marine Technology—Specification for Bunkering of Liquefied Natural Gas Fuelled Vessels. International Organization for Standardization: Geneva, Switzerland, 2017.
25. *ISO 20519:2021*; Ships and Marine Technology—Specification for Bunkering of Liquefied Natural Gas Fuelled Vessels. ISO: Geneva, Switzerland. Available online: https://www.iso.org/standard/80842.html (accessed on 31 October 2022).
26. *ISO 21593:2019*; Ships and Marine Technology—Technical Requirements for Dry-Disconnect/Connect Couplings for Bunkering Liquefied Natural Gas. International Organization for Standardization: Geneva, Switzerland, 2019.
27. DNV GL. Recommended Practice DNV GL as Development and Operation of Liquefied Natural Gas Bunkering Facilities. 2015. Available online: https://www.dnv.com/ (accessed on 11 January 2023).
28. Safety Guide Bunkering V2 DRAFT. Available online: https://www.marineinsight.com/guidelines/the-ultimate-guide-to-fuel-oil-bunkering-process-on-ships/ (accessed on 7 December 2022).
29. Marine. Guidelines on LNG Bunkering Guidance Note NI 618 DT R00 E. 2014. Available online: http://www.veristar.com (accessed on 13 December 2022).
30. IAPH: LNG Bunker Checklist Ship to Ship. Available online: https://sustainableworldports.org/wp-content/uploads/iaph_lng_bunker_checklist_ship_to_ship_final_v3.7a_incl_guidelines.pdf (accessed on 20 January 2023).
31. ACS: LNG Bunkering Guidelines; No. 142. Available online: https://iacs.org.uk/download/1962 (accessed on 2 February 2023).
32. MPenfold. ABS | LNG Bunkering Technical and Operational Advisory | 01 LNG Bunkering Technical and Operational Advisory. Available online: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_LNG_Bunkering_Advisory.pdf (accessed on 28 October 2022).
33. CCNR. Standard for a Liquefied Natural Gas (LNG) Bunker Checklist Bunker station to Ship Edition 1.0 Adopted by the Police Regulations Committee on 27 October 2021. Available online: https://www.ccr-zkr.org/ (accessed on 13 February 2023).