PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 27 pp: 8-14

Exploring the Regulatory Framework of Maritime Decarbonization to Achieve IMO GHG Emission Targets

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ABSTRACT

International Maritime Organization (IMO) has established mandatory measures for improving the energy efficiency of ships in accordance with its reduction targets for greenhouse gas (GHG) emissions. In regards to the Paris Agreement, the maritime industry has been under tremendous pressure to reduce emissions of greenhouse gases since its inception. By 2050, the global shipping sector should aim to minimize greenhouse gas emissions by at least half compared to 2008 levels, according to resolutions adopted by the IMO. As part of the UN Sustainable Development Goal 13 (SDG 13), The IMO urges states to act right away in stopping global warming. In order to achieve this goal, efficiency improvements must be combined with the use of alternative low-carbon fuels, as well as an increase in technical energy efficiency through the use of more efficient ship design and energy efficiency technologies (EETs). For the purpose of understanding maritime decarbonization strategy during the transition period and providing energy efficiency and elevating energy efficiency on board, legal aspects, framework, and requirements must be clearly understood for today and the future. There is a transition of the regulations for GHG emission reduction by the early adoption of the Energy Efficiency Design Index (EEDI) Phase 3 requirements for LNG carriers, general cargo ships, container ships, large LPG carriers, and cruise passenger ships. In the original schedule, it was decided to go into effect in 2025. With the aim to solve the shipping industry decarbonization earlier, the IMO decided to implement Phase 3 earlier to be in April 2022 and then enhanced the regulations. To protect the marine environment, the authors of this paper will examine the different rules and procedures that are taken by different organizations and authorities to reduce the impact of GHG emissions on the marine environment. Moreover, the different measures related to GHG emissions from a sustainable point of view, with regard to their impact on climate change, will be compared and analyzed.

Keywords: Decarbonization, Maritime, GHG, Energy Efficiency, IMO, Sustainability

1 INTRODUCTION

Greenhouse Gas Emissions (GHG) arising from common human practices intensify the influence of GHG which negatively contributes to climate change. Mostly, the carbon dioxide (CO2) of the burning of the fossil fuels such as oil, natural gas and coal. The emissions caused by Human increased the atmospheric CO2 by about 50% beyond the levels of pre-industrial. The emissions levels have displayed fluctuation but maintain a persistent pattern across all greenhouse gases (GHGs') throughout the 2010s, averaging 56 billion tons per year [1]. Unfortunately, about 6.7 million people die each year

because of the low quality of the polluted air [2].The major emitters are the electricity generation and the means of transportation; but according to the United States Environmental Protection Agency (EPA), transportation is the largest single source, which is about 27% of USA GHG emissions [3].
At the current emission rates that averaging 6.5 tons per person a year which means that the temperatures before 2030 may increase by about 1.5°C over the pre-industrial levels [4].
In the maritime sector, IMO's Marine Environment Protection Committee (MEPC) restates its responsibility to evaluate and reinforce IMO’s Initial Strategy on the GHG emissions reduction of the shipping, and to adopt in mid-2023 a revised strategy. The MEPC 78th session made headway in the talks toward the modification of the preliminary GHG approach, which was launched during the MEPC session 77 [5].

There is a transition of the regulations for GHG emission reduction by the early implementation of the Energy Efficiency Design Index (EEDI) Phase 3, Fig. 1, requirements for LNG carriers, general cargo ships, container ships, large LPG carriers, and cruise passenger ships. In the original schedule it was decided to go into effect by 2025. With the aim to solve the shipping industry decarbonization earlier, the IMO decided to implement Phase 3 earlier to be in April 2022 and then enhanced the regulations [6]. Also, as a motivation to decarbonization intensity of all vessels by about 40% by year 2030 comparing with year 2008, the vessels should calculate their achieved Energy Efficiency Existing Ship Index (EEXI) to find their energy efficiency, and their annual operational Carbon Intensity Indicator (CII) and associated CII rating. The Carbon strength connects the GHG emissions with the cargo total quantity that are transferred over the covered distance.

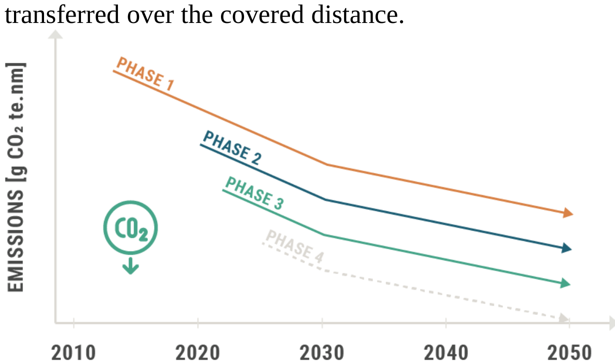

Figure 1: The Energy Efficiency Design Index (EEDI) Phase 1, 2 and 3 implementation per time frame [7].,

The MARPOL Annex VI amendments are effective as of 01/11/2022. Certification’s prerequisites of CII and EEXI came into force on 1st of January 2023. So, the first annual report is completed in 2023 and the initial ratings will be given in year 2024. Part of IMO's commitment are the measures laying on its initial strategy 2018 on the GHG Emissions Reduction generated by vessels in order to decrease the carbon strength from all vessels by year 2030 by 40% in comparison to year 2008 [8].

This paper will investigate the different rules and procedures that are taken by the different organizations and authorities to reduce the GHG emissions’ impacts to protect the marine environment. Also, to compare and analyze the different measurements which are related to the GHG emissions from a sustainable point of view which respectively has an impact on climate change.

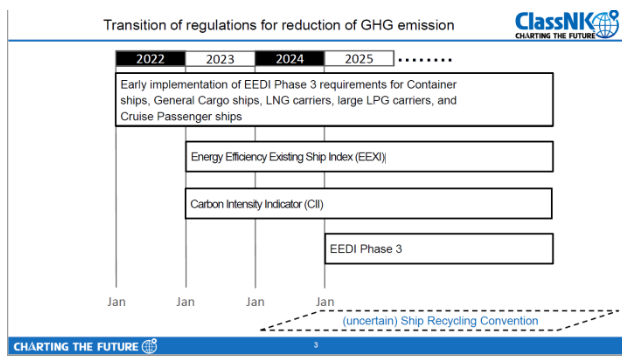

Figure 2: Transition of regulation for reduction of GHG emissions [9].

2 SHORT, MID AND LONG-TERM MEASURES TO REDUCE GHG EMISSIONS

On July 15, 2011, a significant milestone was achieved when international mandatory measures were established by the IMO to enhance the energy efficiency of ships as shown in Figure 3. By proactively engaging in further initiatives, including the implementation of enhanced regulatory frameworks and the endorsement of the Initial IMO GHG strategy in 2018, significant steps have been taken to tackle greenhouse gas emissions within the maritime industry. In order to limit temperature, rise in 2100 to 1.5 °C, the Intergovernmental Panel on Climate Change (IPCC) emphasizes that a zero GHG emissions level must be achieved for all sectors by at least 2050. Under Paris Agreement, many Governments like Japan, U.S.A., U.K., EU countries, Argentina, Brazil, Republic of Korea, Mexico, South Africa declared their determination to aim for zero GHG emissions by 2050. A proposal was made that international shipping should aim zero GHG emissions by 2050.

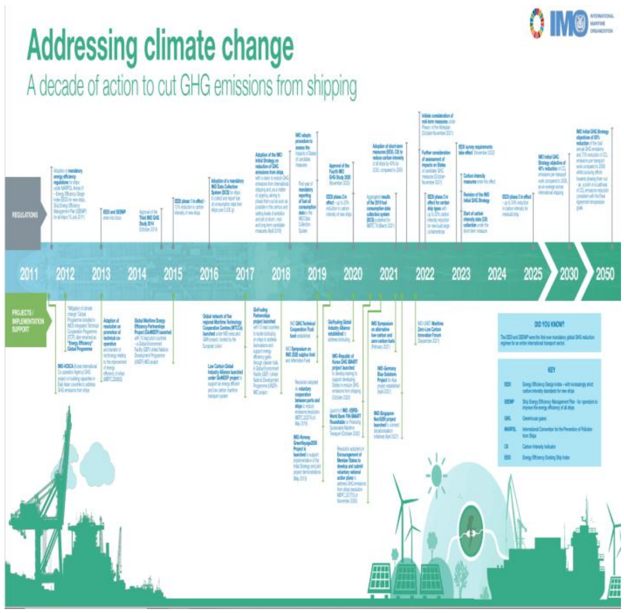

Figure 3: The visual representation illustrating the fundamental measures and supportive measures undertaken by the IMO to cut emissions from ships. [9].

IMO performing a comprehensive capacity building and technical assistance program to support the effective implementation of the Initial GHG strategy with several global projects. This introductory approach for reducing GHG emissions from shipping outlines core aspirations and primary objectives compared with 2008 which are cutting the annual GHG emissions from international shipping by at least 50% by 2050 by phasing out GHG emissions from shipping and a reduction in the carbon intensity of international shipping to reduce CO_2 emissions per transport work by at least 40% by 2030 and towards 70% by 2050. The work plan for consideration of mid and long-term measures are:

- Phase I from 2021 to 2022: Collection and preliminary assessment of suggestions for implementing measures.
- Phase II from 2022 to 2023: evaluation and selection of measures for further development and implementation.
- Phase III starting from 2023: measures development for statutory requirements [9].

2.1 Short-term measures

The proposed initiatives are specifically targeted toward achieving the objectives of the IMO Initial GHG Strategy, which seeks to decrease the carbon intensity of shipping vessels by 40% by 2030, relative to the 2008 levels. These measures, to be made obligatory under MARPOL Annex VI, encompass the implementation of the Energy Efficiency Existing Ship Index (EEXI), the adoption of an annual operational carbon intensity indicator (CII), and the establishment of a CII rating system. By enforcing these measures, the aim is to effectively address greenhouse gas emissions in the maritime sector and promote enhanced energy efficiency.

There are many ways that can be done by a vessel to improve its rating through various measures, see figure 4, such as:

- Hull cleaning to reduce drag.
- speed optimization.
- installation of low energy light bulbs.
- installation of solar/wind auxiliary power for accommodation services; etc.

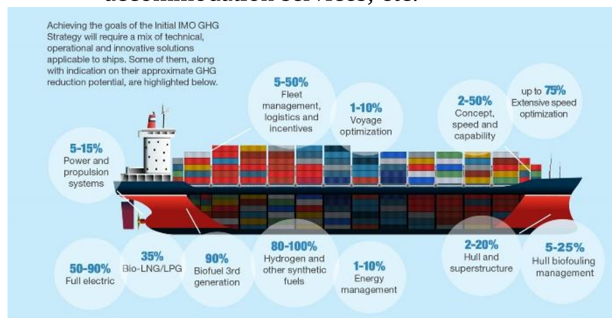

Figure 4: The possible solutions of design, economic and operation [10].

2.2 Mid and Long -term measures

MEPC 76 in June 2021 established a roadmap for selecting mid- and long-term measures, incentivizing the transition from fossil fuels to low- and zero-carbon alternatives in international shipping. This aims to expedite the adoption of sustainable energy sources, reduce greenhouse gas emissions, and achieve decarbonization in the global maritime industry.

MEPC 78 agreed with advancing to Phase II, for further development of proposals for mid-term measures such as [9].

- IMO Maritime Research Fund (IMRF) : US$ 2 per ton of marine fuel should be funded to IMRF, which will be used for development of low/zero carbon technologies.
- Feebate : Ships using fossil fuels pay for the levy and ships using zero-emission fuels receive rebate.
- IMSF&R (International Maritime Sustainability Funding and Reward) : Using CII mechanism, ships above the upper benchmark level pay funding contributions, and ships below the lower benchmark level receive rewards.
- ECTS (Emission Cap-and-Trade System): Based on an annual cap on GHG emissions, each ship is required to acquire and surrender allowance for GHG emissions by auctioning.
- GFS (GHG Fuel Standard): Each ship calculates the GFS value, expressed in the mass of GHG emissions

per unit of energy used (gCO2e/MJ). The reduction factor for GFS will be enhanced year by year.

3. ALTERNATIVE FUELS

Currently, we are significantly off track from aligning with the Paris Agreement's 1.5 °C trajectory. The international and domestic shipping sectors collectively consume approximately 12.6 EJ of energy annually, which equates to about 300 million tons of fossil fuels and results in around 1.2 GtCO2eq emissions when considering the entire well-to-wake (WTW) perspective. In order to achieve a 45% reduction in emissions by 2030 compared to 2010 levels, we must limit fossil fuel consumption to around 6 EJ, which constitutes approximately half of the global fleet's total energy demand. To attain this objective, we can utilize a combination of two strategies: implementing energy efficiency measures to reduce the overall energy demand of the global fleet, and substituting fossil fuels with low-emission alternative fuels. By employing these approaches, we can work towards meeting the emissions reduction target while promoting sustainable practices in the shipping industry (11).

There is a shortage of expertise using and implementing biofuels in the maritime sector. Providing biofuels to the maritime industry also poses a hurdle. The cost of food, the availability of land, and social considerations are only a few of the variables that restrict the development of sustainable biofuels. The stability of biofuel storage and oxidation are additional issues. Yet, the shipping sector may assist in creating a sizable market for biofuels through legislation, regulations, incentives, and technological and structural advancements [12].

However technically possible, the creation of a substantial hydrogen infrastructure is needed for production, transportation, storage, and port services. Burning hydrogen-air mixtures by high combustion temperatures, which can produce considerable NOx emissions [13].

Using farm and urban waste to produce electrolytic H_2 and CO_2 may be a viable way to create natural gas. Also, In the transition to a post-carbon economy and the adoption of completely organic agriculture practices, this process offers a potential solution as it can provide the necessary methane for ammonia production. Therefore, the second method is better in the long run. The reaction heat and CO_2 emissions from industrial operations can be repurposed to achieve efficiencies of 55–56% [14].

The carbon intensity of ships can be decreased or eliminated by using alternative fuels. As alternative fuels, LNG and hydrogen are being utilized. According to DNV GL, LNG has a 40% lower volumetric energy density than diesel. When the storage system is taken into account, LNG has a volumetric energy density that is around one-third that of diesel. Lower volumetric energy densities than LNG are found in liquid hydrogen, ammonia, and methanol. Hence, biodiesel has a similar energy density as diesel [15].

The storage of liquid hydrogen presents a notable challenge due to the need for additional volume to accommodate layers of materials, vacuum insulation, and structural arrangements required to maintain its extremely low temperature. Furthermore, hydrogen safety is a significant concern due to its volatile and flammable nature, requiring careful attention and mitigation strategies to address potential risks effectively [15].

Ammonia serves as a versatile fuel that can power various engines and fuel cells, as opposed to hydrogen. LNG and liquid hydrogen can be kept at temperatures and pressures much lower than ammonia. Ammonia has already been moved, and there is a global infrastructure for storing and exporting it because it is one of the top three chemicals transported annually. Ammonia's primary drawbacks are its toxicity and environmental impact [16].

Electricity Batteries provide zero-emission propulsion and are up to twice as efficient as traditional fuels, a diesel generator is an example of this. The noise level produced by these engines is lower than that produced by traditional engine systems. Alternative energy sources, such as batteries, present a notable advantage over conventional fuels in terms of operational expenditure. The ongoing decline in battery prices, coupled with significant advancements in their performance, contributes to reduced costs. This trend makes batteries an increasingly attractive option, offering potential savings and enhanced efficiency when compared to traditional fuel sources. As a result, the economic viability of alternative energy technologies continues to improve, further driving their adoption in various applications. Among the most significant disadvantages of batteries are their low volumetric density and weak energy density per mass unit (approximately 150 times lower than diesel). Battery production consumes a significant amount of energy, and the capital expenditures for a large battery system are greater than those for a conventional propulsion system [17].

4. ELECTRICITY'S IMPACT ON REDUCING GREENHOUSE GAS EMISSIONS IN MARINE APPLICATIONS:

The majority of emissions from ships come from the burning of fossil fuels, which also leads to air pollution and negative impacts on human health. In recent years, there has been growing interest in using electricity as a means of reducing emissions in marine applications.

One of the main ways that electricity can help reduce emissions in marine applications is through the use of electric propulsion systems. These systems use electric motors to drive the ship's propellers, instead of traditional combustion engines. Electric motors are highly efficient and produce no emissions at the point of use, making them an attractive alternative to traditional engines. In addition, electric propulsion systems can be powered by renewable sources of electricity, such as wind or solar power, which further reduces emissions.

According to a report by the International Maritime Organization (IMO), electric propulsion systems could help reduce greenhouse gas emissions in the shipping industry by up to 70% by 2050. This would have a significant impact on global emissions, helping to mitigate the worst impacts of climate change.

In addition to electric propulsion systems, electricity can also be used to power auxiliary systems on board ships. For example, lighting, heating, and cooling systems can all be powered by electricity, reducing the need for fossil fuel-powered generators. This can lead to significant reductions in emissions and air pollution.

Another way that electricity can help reduce emissions in marine applications is through the use of shore power. Shore power (SP) enables ships to connect to the electrical grid while in port, allowing them to switch off their engines and use electricity instead. This can significantly reduce emissions and improve air quality in port cities[18-19]. In fact, a study by the California Air Resources Board found that the use of shore power in the Port of Long Beach reduced emissions of nitrogen oxides (NOx) by up to 98% and particulate matter (PM) by up to 55% [20].

The discharge of the supplied SP is intricately linked to the methods and origins employed in producing electricity, and it is conveyed from operational regions to the power plants situated apart from port zones. Therefore, it is essential to take into account the production chain of the SP supply when assessing the environmental advantages of vessels powered by batteries. Electricity generation worldwide is still primarily reliant on fossil fuels, with coal and natural gas being major sources of electricity generation, according to the IEA. In 2018, coal accounted for 38.8% of electricity generation, natural gas accounted for 23.1%, nuclear energy accounted for 10.6%, and hydroelectricity accounted for 16.4% [21].

The greenhouse gas emissions (in metric tons of CO_2 equivalent) for two scenarios: one without electricity and one with electricity in maritime transportation are shown in Table 1 and Table2.

Table 1: GHG Emissions without Electricity [22].

Category	Emissions (metric tons CO_2e)
Fuel combustion	500,000
Auxiliary engines	50,000
Cargo operations	100,000
Total	650,000

Table 2: GHG Emissions with Electricity [23].

Category	Emissions (metric tons CO_2e)
Fuel combustion	100,000
Electricity production	50,000
Auxiliary systems	10,000
Cargo operations	100,000
Total	260,000

The emissions for the "with electricity" scenario assume the use of renewable sources of electricity. The emissions from fuel combustion are significantly reduced in this scenario due to the use of electric propulsion systems instead of traditional combustion engines. However, there are additional emissions associated with the production of electricity, which must be taken into account. Overall, the "with electricity" scenario results in a significant reduction in GHG emissions compared to the "without electricity" scenario.

According to the International Energy Agency (IEA), renewable electricity capacity increased by 45% between 2015 and 2020, and is expected to grow by another 50% by 2025. According to a report by the International Renewable Energy Agency (IRENA), renewable energy has the potential to power almost all of the world's shipping fleet by 2030, and reduce the sector's greenhouse gas emissions by up to 95% compared to conventional fuels. The use of solar panels on ships is becoming increasingly common, with companies such as Ciel & Terre and Eco Marine Power developing solar panel systems specifically for marine applications. After examining the data on electricity production, it was found that renewable sources accounted for almost 28% of the electricity supply in 2020. Furthermore, it is predicted that by 2050, Renewable energy has the ability to fulfill as much as 60% of the worldwide electricity demand, indicating a significant opportunity for sustainable power sources to play a substantial role in meeting global energy needs. [24]. Based on statistical data, several countries including Austria, Sweden, Denmark, Latvia, and Portugal have shown that renewable sources accounted for more than half of their electricity mix in 2018. Specifically, Austria had the highest percentage at 73%, followed by Sweden at 66%, Denmark at 62%, Latvia at 53%, and Portugal at 52% [25]. Countries with a high proportion of renewable sources in their electricity mix offer a "green" alternative fuel option for vessels [26].

5. CONCLUSION

As a part of its Greenhouse Gas (GHG) emission reduction targets, the International Maritime Organization (IMO) has implemented mandatory measures to improve energy efficiency of ships. Since its inception, the maritime industry has been under tremendous pressure to reduce greenhouse gas emissions. A resolution adopted by the IMO requires shipping companies to reduce greenhouse gas emissions by 50% by 2050. UN Sustainable Development Goal 13 (SDG 13) calls on governments to combat climate change immediately. To achieve this goal, efficiency improvements must be combined with alternatives low-carbon fuels, as well as an increase in technical energy efficiency through better ship design and energy efficiency technologies.

Onboard energy efficiency offers industry-wide prospects for decarbonization that are both affordable and have a large potential to cut emissions. by making efficiency gains of just 8%, or 1% year until 2030.

For every 12.6 EJ of energy we create, we require almost 300 million tons of fossil fuel oil, which emits more than one gigatons of greenhouse gases. According to present projections, it is predicted that alternative fuel production capacity won't be able to keep up with demand in the ensuing decades. We must start today in order to guarantee adequate alternative fuel capacity in 2030 and beyond. The idea of increasing fleet and vessel efficiency is nothing new to the maritime sector. Several significant energy efficiency improvements have been created and put into practice by companies.

As a result, there are currently a variety of technical options and operational strategies that can result in large energy savings, such as applications for voyage optimization to increase energy efficiency. Operational steps including cleaning the hull and propellers, organizing the cruise, and using the weather route are often taken first. Compared to typical operating procedures, these processes may save significant amounts of fuel (up to 15%), making them win-win solutions that simultaneously lower fuel expenditures and emissions. The marine sector is primarily interested in methane, methanol, ammonia, and bio-oil/e-diesel as alternative fuel sources. Other marine players are also thinking about hydrogen.

Despite this, hydrogen is unlikely to be employed in deep-sea transportation due to its poor volumetric energy density, negative effects on deck and cargo space, need for high-pressure and low-temperature storage, and issues with flammability. In maritime applications, electricity may be quite useful but it also has significant drawbacks. Due to the high expense of constructing the necessary electrical infrastructure, some ship owners may find it challenging to adopt electric propulsion systems. Also, certain areas might not have access to sustainable energy sources like wind and solar power. Therefore, the use of electricity in maritime applications has the potential to dramatically lower greenhouse gas emissions and enhance the sustainability of the shipping sector.

Shore power, auxiliary systems, and electric propulsion systems all present options for lowering emissions and enhancing air quality. The advantages of employing electricity in maritime applications are obvious, despite the obstacles that still need to be solved, and it is expected that these technologies will be more commonly used in the future.

In order to reduce GHG emissions, the marine sector must immediately initiate joint decarbonization activity. Energy efficiency is the most effective strategy before accomplishing the goals of alternative fuels. The industry must assist the organization if the IMO is to strengthen its regulatory goals in relation to energy efficiency.

6. REFERENCES

1."Chapter 2: Emissions trends and drivers" . Ipcc_Ar6_Wgiii. 2022.

2. "Data Review: How many people die from air pollution?". Our World in Data. https://ourworldindata.org/data-review-air-pollution-deaths, accessed at 05.04.2023

3. "Carbon Pollution from Transportation US EPA, OAR ". https://.epa.gov. accessed at 06.04.2023

4. Intergovernmental Panel on Climate Change (4 April 2022). "IPCC: Climate Change 2022, Mitigation of Climate Change, Summary for Policymakers"

5.Marine Environment Protection Committee (MEPC) - 78th session, 6-10 June 2022

6. Resolution MEPC 324 (75); 2021 Revised MARPOL Annex VI, Resolution MEPC 328 (76)

7. EEDI Phase 3 - How to Improve Ratings, Achieve Compliance and Future-Proof Fleets | LinkedIn

8 .EEXI and CII - ship carbon intensity and rating system

9.ClassNK technical seminar, 2021

10. IMO’s work to cut GHG emissions from ships, https://www.dnv.com/maritime/hub/decarbonize-shipping/key-drivers/regulations/imo-regulations/ghg-vision.html, accessed at 06.04.2023

11. Maritime Decarbonization Strategy 2022, A decade of change, Fonden Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022

12. Panoutsou, C., Germer, S., Karka, P., Papadokostantakis, S., Kroyan, Y., Wojcieszyk, M., Maniatis, K., Marchand, P., & Landalv, I. (2021). Advanced biofuels to decarbonise European transport by 2030: Markets, challenges, and policies that impact their successful market uptake. Energy Strategy Reviews, 34, 100633. https://doi.org/10.1016/j.esr.2021.100633

13. Osman, A.I., Mehta, N., Elgarahy, A.M. et al. Hydrogen production, storage, utilisation and environmental impacts: a review. Environ Chem Lett 20, 153–188 (2022). https://doi.org/10.1007/s10311-021-01322-8
14. Nnabuife, S. G., Ugbeh-Johnson, J., Okeke, N. E., & Ogbonnaya, C. (2022). Present and Projected Developments in Hydrogen Production: A Technological Review□. Carbon Capture Science & Technology, 3, 100042. https://doi.org/10.1016/j.ccst.2022.100042
15. Alternative fuels: the options, DNV Report, 2018
16. http://www.chem4us.be/liquid-ammonia-a-green-fuel-for-the-transport-sector/, accessed 04.04.2023
17. EMSA European Maritime Safety Agency ,EMSA Maritime Battery Study, Electrical Energy Storage for Ships, Report No.: 2019-0217, Rev. 04 Document No.: 11B59ZDK-1, 2020
18. E. A. Sciberras, B. Zahawi, D. J. Atkinson, A. Juandó, and A. Sarasquete, "Cold ironing and onshore generation for airborne emission reductions in ports," Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ., vol. 230, no. 1, pp. 67–82, 2016, doi: 10.1177/1475090214532451.
19.Y. Peng, X. Li, W. Wang, Z. Wei, X. Bing, and X. Song, "A method for determining the allocation strategy of on-shore power supply from a green container terminal perspective," Ocean Coast. Manag., vol. 167, no. October 2018, pp. 158–175, 2019, doi: 10.1016/j.ocecoaman.2018.10.007.
20. "httpsww2.arb.ca.govour-workprogramsocean-going-vessels-berth-regulation."
21. "IEA. Global Electricity Generation Mix by Scenario, 2018, Stated Policies and Sustainable Development Scenarios 2040. 2019." https://www.iea.org/data-and-statistics/charts/global-electricity-generation-mix-by-scenario-2018-statedpolicies- and-sustainable-development-scenarios-2040 (accessed Apr. 01, 2023).
22. "International Maritime Organization (IMO). (2018). Fourth IMO GHG Study 2017." httpswww.imo.orgenOurWorkEnvironmentPollutionPreventionAirPollutionPagesGreenhouse-Gas-Study-2014.aspx (accessed Mar. 25, 2023).
23. "California Air Resources Board Inventory," 2019. https://ww2.arb.ca.gov/resources/documents/shore-power
24. I. Y. L. Hsieh, M. S. Pan, Y. M. Chiang, and W. H. Green, "Learning only buys you so much: Practical limits on battery price reduction," Appl. Energy, vol. 239, no. August 2018, pp. 218–224, 2019, doi: 10.1016/j.apenergy.2019.01.138.
25."Eurostate. Wind andWater Provide Most Renewable Electricity. 2020. Available online."
26. "DNV. Decarbonization in Shipping. 2021."