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Critical Analysis of Annex VI of MARPOL: Evaluating the Need for New Restriction Limits to Preserve the Ozone Layer

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Abstract

MAPROL, the International Convention for the Prevention of Pollution from Ships is an essential instrument that addresses marine pollution, whereas Annex VI focuses specifically on combating and regulating the air pollution that is caused by ocean-going vessels. Annex VI's strict regulation that governs Nitrogen Oxide (NOx) emissions and mandates using low-sulfur fuel to reduce the ozone-producing pollutants protects human health and environmental degradation. However, despite these efforts, challenges persist because, ocean-going vessels remain significant contributors to air pollution, emitting NOx, Sulfur Oxide (SOx), and other particular matters which directly or indirectly have dangerous and risky impact on human life and the ozone layer as well.

This paper critically evaluates the effectiveness of Annex VI of MARPOL in maintaining and preserving the ozone layer by assessing whether the current regulatory framework sufficiently mitigates emissions from ocean-going vessels. Firstly, this study examines the existing provisions under Annex VI, focusing on restrictions related to NOx and SOx emissions and their role in reducing ozone depletion. Secondly, it analyzes the impact of ship emissions on atmospheric pollution, supported by statistical data and case studies. Thirdly, the research identifies gaps and challenges in regulatory enforcement and technological adoption. Finally, based on these findings, the paper proposes amendments to Annex VI, including stricter emission limits and the promotion of green technologies. These recommendations are informed by a comprehensive understanding of the current regulatory framework, emerging challenges, and anticipated trends in ship emissions.

Keywords: Annex VI of MARPOL, Ozone Layer, Greenhouse Gas, Air Pollution, and Restriction.

Introduction

The maritime industry, a cornerstone of global trade, plays a pivotal role in the interconnectedness of nations and economies. Yet, amid its indispensable function lies a paradox—while facilitating the movement of goods across borders, maritime activities also contribute significantly to environmental degradation, particularly in terms of air

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pollution. While most environmental efforts focus on land-based pollution, ship emissions are often overlooked, yet they significantly harm human health and the ozone layer.

At the heart of efforts to mitigate maritime pollution lies the International Convention for the Prevention of Pollution from Ships (MARPOL), a comprehensive framework aimed at regulating various forms of marine pollution. Annex VI of MARPOL, specifically dedicated to curbing air pollution from ships, stands as a testament to international cooperation in addressing this pressing issue. However, as the maritime sector continues to expand, propelled by burgeoning global trade demands, the efficacy of existing regulatory measures under Annex VI comes under scrutiny. This study seeks to delve into the intricacies of Annex VI of MARPOL, with a specific focus on evaluating its adequacy in preserving the ozone layer amidst the challenges posed by ship emissions. While Annex VI mandates strict regulations on emissions of nitrogen oxides (NOx) and sulfur oxides (SOx), the paper endeavors to examine whether these measures suffice in safeguarding the ozone layer or if the introduction of new restriction limits is imperative.

The discussion unfolds by elucidating the multifaceted factors contributing to ship emissions and their deleterious effects on the ozone layer. From the historical context of international environmental agreements to the contemporary realities of shipping emissions, a comprehensive understanding of the problem landscape is provided. Moreover, the paper elucidates the current regulatory framework established by Annex VI, outlining its provisions pertaining to NOx, SOx, and other ozone-depleting substances, while also scrutinizing the enforcement mechanisms in place. As the analysis progresses, insights into the current state of ship emissions, gleaned from statistical projections and empirical data, serve as the foundation for extrapolating future scenarios. By examining emission trends and assessing the impact of ongoing regulatory efforts, the paper endeavors to identify gaps and inefficiencies within the existing framework. Subsequently, based on a nuanced understanding of the challenges at hand, the paper proposes pragmatic amendments to Annex VI, advocating for the introduction of new restriction limits aimed at further curtailing emissions and preserving the integrity of the ozone layer.

Crucially, these recommendations are not mere conjectures but are underpinned by a rigorous analysis grounded in empirical evidence and expert insights. The proposed amendments encompass a spectrum of measures, ranging from tiered emission standards and global caps on black carbon emissions to incentivizing low-NOx technologies and fostering industry collaboration. Moreover, the paper underscores the importance of capacity-building and training initiatives to empower maritime professionals in implementing emission reduction strategies effectively.

Methodology

Research Design

This study follows a mixed-methods approach, combining both qualitative and quantitative data. This approach provides a thorough evaluation of Annex VI of MARPOL by examining emission trends and regulatory effectiveness. The research focuses on understanding how NOx and SOx emissions have changed over time and whether current restrictions are enough to protect the ozone layer.

The mixed-methods approach is justified because it allows for a balanced analysis—qualitative data help interpret policy impacts, while quantitative data provide measurable trends. The study aims to answer the following question:

> "Are Annex VI of MARPOL's provisions enough and sufficient to protect and preserve the ozone layer, or are additional restrictions and strategies needed to achieve this aim?"

The objectives include:

a. To look into the emissions of NOx and SOx over the three decades.

b. Analyzing the regulatory framework of Annex VI.

c. Finding gaps and suggesting amendments based on assessments of data.

Data Collection Methods

a. Prior Studies: An organized review of journals, policy documents, and reports of international organization such as IMO, UNEP, NASA, and other authoritative sources is provided in each individual sections, identifying historical and current regulations, challenges, and the impacts from the emissions.

b. Secondary Data Analysis: The data sets were extracted from the institutional reports such as IMO Greenhouse Gas Studies and Lloyd's List, and some peer-reviewed studies and the variables are included as well of the emission levels of NOx, SOx, and black carbon, compliance rates in the ECAs of Emission Control Areas, and lastly statistics of Greenhouse Gas from 1990-2023.

Analytical Tools

a. Emission Trend Analysis: Data of the emissions of NOx and SOx were analyzed using regression model, such as, table, figures, and graphs visualizing and depicting trends and compliance levels highlighting critical areas for regulatory enhancement.

b. Impact Evaluation: By using secondary data and scenario modeling the environmental impact of emissions on the ozone layer was assessed, and tools such as life-cycle assessment were reviewed but not employed directly due to the constraints in resource.

c. Statistical Modeling: Some linear graphs and time series models have been used to analyze the emission trends, and the programming tools MATLAB and R were used to analyze the future impact of potential regulatory amendments.

d. Case Studies: To evaluate compliance, regulatory impact, and operational challenges, selected shipping routes in Baltic Sea and North Sea were analyzed.

e. Scenario Simulation: To evaluate the potential impact of new emission restrictions simulations were conducted, including adoption of green technologies, tiered emission standards, and global black carbon caps.

Methodological Constraints

The variability of secondary data in monitoring practices and regional disparities in reporting could introduce bias and the absence of field measurements could lead to unsatisfactory to some readers as the study relied on the secondary sources.

Factors of Degradation of Ozone Layers

More or less, people, in general, tend to set aside their thoughts of ships polluting the ozone layer. Having thoughts intensely concentrated on landmass pollution, the pollution from ships is forgotten quickly. To split the truth, there are several factors that are polluting the ocean as well as depleting the Ozone Layer. Some may blame the developed technologies for the going-generation, as the services are giving people good results and adverse effects in every place to think of. However, the reality of ships polluting the oceans and depleting the Ozone Layer does not lie with the new technologies, and it has been happening for a long time. Otherwise, the Ozone Layer would not be in the position it is now.

The stratospheric ozone layer shields the earth from damaging UV rays.[1] According to scientific evidence, several manufactured substances contribute to its depletion. Atmospheric data suggest that the ozone layer is thinning and that an ozone layer hole emerges over Antarctica during particular year periods.[2] Scientists think that man-made substances are to blame for the mentioned harm. These compounds include chlorofluorocarbons (CFCs), which are present in refrigeration systems, solvents, polyurethane foam blowing agents, and halons used in firefighting. These are known as Ozone Depleting Substances or ODS.[3]

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[1] "Basic Ozone Layer Science | US EPA" (*US EPA*, September 17, 2024) <https://www.epa.gov/ozone-layer-protection/basic-ozone-layer-science#:~:text=The%20ozone%20layer%20in%20the,that%20has%20several%20harmful%20effects.>.

[2] "Overview" (*Climate Action*) <https://climate.ec.europa.eu/eu-action/ozone-layer/overview_en>.

[3] Anastasios Gkionakis, "OZONE & OZONE LAYER DEPLETION" (March 9, 2018) <https://www.linkedin.com/pulse/ozone-layer-depletion-tasos-gkionakis>.

The deliberate emission of ODS is forbidden under MARPOL Annex VI, Regulation 12. However, it is critical to comprehend what is meant by "deliberate." Deliberate emissions are ODS during the service, repair, or disposal of systems or equipment. It excludes essential emissions of ODS, such as halon needed to battle a fire, as well as minor releases connected with ODS recycling or recapture.[4]

According to IMO, Managing air pollution from ships, namely toxic gases from ship exhausts, was debated in the run-up to the 1973 MARPOL Convention. However, it was agreed not to incorporate air pollution regulations at the time.

Meanwhile, other areas were debating air pollution. In Stockholm, the United Nations Conference on the Human Environment in 1972 marked the beginning of the significant international collaboration in addressing acidification, sometimes known as acid rain. Several investigations between 1972 and 1977 verified that air contaminants might travel thousands of kilometers before deposition and harm occurred. The harm includes agriculture and forest consequences.

Sulphur dioxide and Nitrogen Oxide deposits create the majority of acid rain in the atmosphere. Sulphur dioxides are produced mainly by coal and oil-burning power plants, whereas nitrogen oxides are produced by vehicle, truck, and ship exhausts.[5]

A ministerial meeting on environmental protection in Geneva in 1979 culminated in the signature of the Convention on Long-range Transboundary Air Pollution by 34 nations and the European Community, the first international legally enforceable instrument to address air pollution issues on a regional scale.[6]

In terms of emissions, the most significant gases are now Sulphur oxides (SOx) and nitrogen oxides (NOx).[7] Annex VI outlines a plan for considerable reductions in both over the following ten years. Establishing Emission Control Areas and strict limitations on fuel Sulphur content in ports are particularly difficult for the maritime sector and its suppliers.[8]

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[4] "Prevention of Air Pollution from Cargo Vapours, Ozone Depleting Substances & Co2 Emissions" (*Ship Business*)<http://shipsbusiness.com/otheremissions.html#:~:text=These%20chemicals%20include%20the%20chlorofluorocarbons,emissions%20of%20ODS%20are%20prohibited.>.

[5] "What Is Acid Rain? | US EPA" (US EPA, May 7, 2024) <https://www.epa.gov/acidrain/what-acid-rain>.

[6] "Geneva Convention on Long-Range Transboundary Air Pollution | EUR-LEX" https://eur-lex.europa.eu/EN/legal-content/summary/geneva-convention-on-long-range-transboundary-air-pollution.html

[7] Alon Khabra, Gad A Pinhasi and Tomer Zidki, "NOX and SOX Flue Gas Treatment System Based on Sulfur-Enriched Organic Oil in Water Emulsion" (2021) 6 ACS Omega 2570 <https://doi.org/10.1021/acsomega.0c04485>.

[8] Protea Ltd, "Marine Emissions Monitoring Systems | Protea Ltd" <https://www.protea.ltd.uk/marine?gclid=CjwKCAjw14uVBhBEEiwAaufYx7QqMrLF_2GFWqWxnhlzBVqSABphMWZVqUtATKpK1KO8u77NliyQ2BoCskUQAvD_BwE.>.

The air emissions from marine traffic are regulated by Annex VI of MARPOL 73/78 (Marine Pollution), promulgated by the IMO in 1997 and subsequently amended.[9] The regulation has been transposed in Europe by Directive 2005/33/EC and in Italy by DM. 205 of November 6, 2007, governing:

a. SOx emissions of sulfur oxide and nitrogen oxides NOx are present in the exhaust gases of internal combustion engines.
b. Emissions of substances deplete the atmosphere's ozone layer (fire and gases).
c. Emissions from incinerators (it prohibits the incineration on board certain products).
d. Emissions of volatile organic compounds (VOCs) from the cargo area of tankers.[10]

Studies report that ships emit large amounts of air pollutants, including nitrogen oxides (NOx) and particulate matter.[11] NOx released from ships can undergo chemical reactions in the atmosphere, forming nitrous acid (HONO) and nitryl chloride (ClNO2), which contribute to the production of hydroxyl (OH) and chlorine (Cl) radicals. These radicals, in turn, recycle NOx, influencing the oxidative capacity of the atmosphere and the formation of secondary pollutants. Also, ship-derived HONO and ClNO2 can suggestively be underrating the impact of ship emissions on radicals and secondary pollutants. It is therefore significant that these nitrogen compounds be included in upcoming models of the influence of ship emissions on air quality.[12]

According to Marine Insight, a study is carried out to govern the maintenance of stipulations prescribed by the MARPOL regulation about hazardous components like ozone-depleting substances along with other pollutants.[13] Based on the primary survey, the certification is awarded to a ship. Below is a list of ozone-depleting substances that are categorically stated in the MARPOL extension.

Stipulation 12: Ozone Depletion Substances

CFCs: These include Trichlorofluoromethane (CFC11), Dichlorodifluoromethane (CFC12) and Chloropentafluoroethane (CFC15)[14]

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[9] Giuseppe Langella and others, "Ship Engines and Air Pollutants: Emission during Fuel Change-over and Dispersion over Coastal Areas" (2016) 7 International Journal of Energy and Environmental Engineering 307 <https://doi.org/10.1007/s40095-016-0211-7>.
[10] ibid.
[11] Yang Zhang and others, "Driving Factors of Ship-Induced Nitrogen Dioxide Concentrations over Coastal Seas of China: Implications for Ship Emission Management" (2024) 373 Journal of Environmental Management 123894 <https://doi.org/10.1016/j.jenvman.2024.123894>.
[12] Jianing Dai and Tao Wang, "Impact of international shipping emissions on ozone and $PM_{2.5}$ in East Asia during summer: the important role of HONO and $ClNO_2$" (2021) 21 Atmospheric Chemistry and Physics 8747 <https://acp.copernicus.org/articles/21/8747/2021/>.
[13] KaranC, "What Are Ozone Depleting Substances on Ships?" (*Marine Insight*, February 8, 2022) <https://www.marineinsight.com/environment/what-are-ozone-depleting-substances-on-ships/>.
[14] ibid

Halon (Organic Compound): These include two sub-categories where the first category compounds have been banned from being used in ships with a construction date of May 19, 1995 and the second category compounds have been banned from being used in ships with a construction date of January 1, 2020. The first type compounds are R11 to R13, R111 to R115 and R211 to R217, while some of the second type compounds include R21, R22, R31 and R271; Methyl Chloroform,15 Methyl Bromide, Bromochlorodifluoromethane, Bromotrifluoromethane.

Per MARPOL Annex VI, an ozone-depleting substance record book must be kept and maintained onboard. Apart from the ozone depletion substances, the other pollutants listed in the MARPOL regulations' extension are Oxides of Nitrogen (Stipulation 13), Oxides of Sulphur (Stipulation 14), and Organic Compounds volatile in nature (Stipulation 15).[16]

Effects Ozone Layer

Maritime transference is a key basis of climate change and air pollution. Shipping emissions cause severe impacts on health and the environment. According to a source, the effects of emissions emerge especially in territorial waters, inland seas, canals, straits, bays, and port regions. The most important impacts of air pollution are climate change, reduction of ozone layer thickness, acid rains, and the corruption of air quality.[17]

With an increasing number of ships touring every day to unique elements of the world, the air pollutants are at the upward push and are one of the primary worldwide concerns. Nitrogen Oxides (NOx) and Sulphur Oxides (SOx) are the most crucial pollution from a ship's emissions. These gases have detrimental outcomes on the ozone layer within the troposphere region of the earth's surroundings, which ends within the greenhouse impact and global warming.[18] Both NOx and SOx are combustion products that can be emitted into the surroundings in the shape of smoke.[19]

As a result, the ozone layer keeps reducing, creating ozone depletion, which means less protection from the sun's rays and more exposure to UVB radiation at the Earth's surface. Studies have shown that in the Antarctic, the amount of UVB measured at the surface can

[15] "Ozone Depleting Substances(ODS)" (October 25, 2018) <https://kochimmdclass4.blogspot.com/2018/10/25ozone-depleting-substancesods.html>.

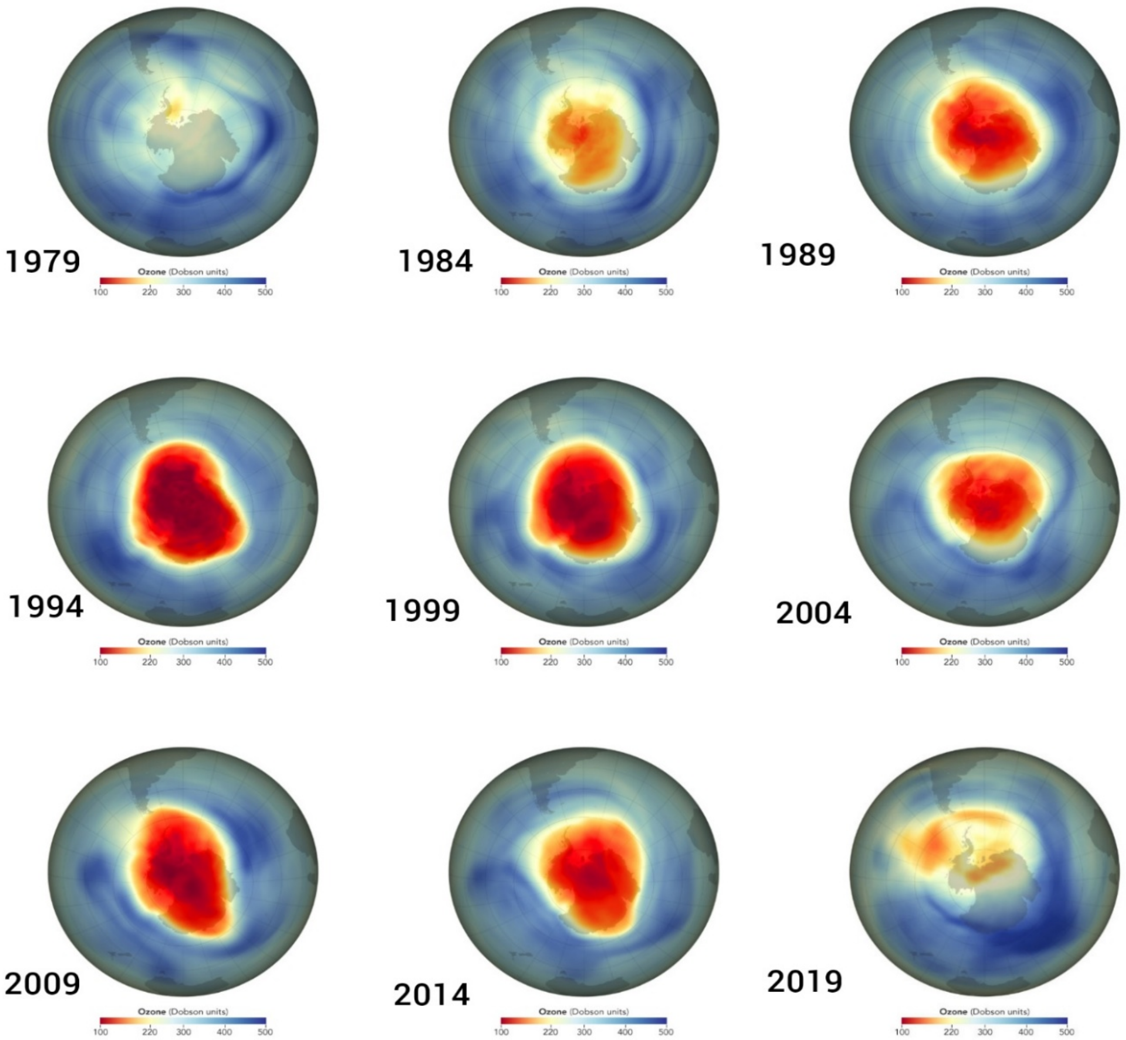
[16] KaranC, *Supra* Note 13.

[17] Halil Saraçoğlu, Cengiz Deniz and Alper Kılıç, "An Investigation on the Effects of Ship Sourced Emissions in Izmir Port, Turkey" (2013) 2013 The Scientific World Journal 1 <https://www.hindawi.com/journals/tswj/2013/218324/>.

[18] Metta Naveen Kumar, "Explained: SOx(Sulphur Oxides) and NOx(Nitrogen Oxides) Emissions from Ships." (*Marine Engineers Knowledge*) <https://www.marineengineersknowledge.com/2021/06/explained-soxsulphur-oxides-and.html>.

[19] Remco Timmermans, "Monitoring Ship Pollution from Space" (*Groundstation*, August 31, 2022) <https://www.groundstation.space/monitoring-ship-pollution-from-space/>.

double during the annual ozone hole.[20] The figure below shows the Ozone Hole that has been created over years.



Source: NASA Earth Observatory, "World of Change: Antarctic Ozone Hole"[21]

According to Nasa Earth Observatory, "In the early years of the 21st century, annual ozone holes roughly stabilized. Year-to-year fluctuations in area and depth are caused by variations in stratospheric temperature and circulation. Colder conditions result in a larger area and lower ozone values in the center of the hole. The models here, suggest that the concentration of chlorine and other ozone-depleting substances in the stratosphere will not return to pre-1980 levels until the middle decades of the 21st century. Scientists have already seen the first definitive proof of ozone recovery, observing a 20 percent decrease in

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[20] "Health and Environmental Effects of Ozone Layer Depletion | US EPA" (*US EPA*, September 11, 2023) <https://www.epa.gov/ozone-layer-protection/health-and-environmental-effects-ozone-layer-depletion>.

[21] NASA Earth Observatory, "World of Change: Antarctic Ozone Hole" https://earthobservatory.nasa.gov/world-of-change/Ozone

ozone depletion during the winter months from 2005 to 2016. In 2019, abnormal weather patterns in the upper atmosphere over Antarctica dramatically limited ozone depletion, leading to the smallest hole since 1982. Models predict that the Antarctic ozone layer will mostly recover by 2040."[22]

Also, according to some sources, the depletion of the ozone layer has damaging effects on human health,[23] animals, the environment and marine life.[24] Studies establish that a rise in UV-B rays causes a higher risk of skin cancer and plays a weighty role in malignant melanoma development, sunburns, rapid ageing, eye cataracts, blindness, and a weakened immune system. Direct exposure to ultraviolet radiation also leads to animal skin and eye cancer.[25]

UV-B rays negatively affect plant crops. It may lead to minimal plant growth, smaller leaf size, flowering and photosynthesis in plants, and lower quality crops for humans.[26] And the decline in plant productivity would, in turn, affect soil erosion and the carbon cycle. Planktons and zooplankton are greatly affected by UV-B rays which are higher in the aquatic food chain. If the plankton declines, it would likely have a wide-reaching impact on all ocean life in the lower food chain.[27]

Current Situation of Affecting Factors Ships' Emission

With 80 %–90 % of world trade being passed by ships; Shipping plays a vital part in the transport of goods around the world. The total number of ships and the relatively high emission factors of air pollutants of ship engines have an extreme impact on the environment and human health even though shipping is an effective way of transport. Studies say the design of the ships' engine that operates at high temperature and pressure & the high fuel sulfur content that is used in shipping fuel makes the NOx and SO2 emission

[22] ASA Earth Observatory, *Supra* Note 21

[23] M Norval and others, "The Human Health Effects of Ozone Depletion and Interactions with Climate Change" (2011) 10 Photochemical & Photobiological Sciences 199 <https://doi.org/10.1039/c0pp90044c>.

[24] Ozone Hole Website, "Ozone Depletion & Aquatic Life - Ozone Hole Website" (*Ozone Hole Website*, February 11, 2019) <https://www.ozone-hole.org.uk/14.php#:~:text=If%20ozone%2Dlayer%20depletion%20reached%2015%%20over%20temperate,would%20die%20before%20reaching%20their%20reproductive%20age.>.

[25] The Skin Cancer Foundation, "UV Radiation - the Skin Cancer Foundation" (*The Skin Cancer Foundation*, September 20, 2024) <https://www.skincancer.org/risk-factors/uv-radiation/#:~:text=Unprotected%20exposure%20to%20UVA%20and,including%20cataracts%20and%20eyelid%20cancers.>.

[26] "Human Activities Affecting the Environment" <https://filaantro.org/blog/human-activities-affecting-the-environment>.

[27] Bs Web Team, "Ozone Layer Depletion: Cause, Effects, and Solutions" *www.business-standard.com* (September 16, 2020) https://www.business-standard.com/article/current-affairs/ozone-layer-depletion-cause-effects-and-solutions-120091601697_1.html.

higher respectively.[28] However, IMO (International Maritime Organization) has limited the emission by MARPOL Annex VI protocol by setting global limits.

There is also another fact which is often neglected that, the regulation of ship emissions is not only an environmental concern but also a human right issue, for instance, Article 25 of Universal Declaration of Human Rights (UDHR) highlights the right to health and well-being, which is threatened by this air pollution caused through the maritime sector and this negative effects on public health highlight the need for a rights-based approach to policy development. Furthermore, the Annex VI aligns with the United Nations' Sustainable Development Goals or SDGs, especially Goal 3 & Goal 13 which are Good Health and Well-Being, and Climate Action respectively. Furthermore, it is urgent to note that the ship emissions affects the disadvantage communities disproportionately, especially those near ports, canals, and coastal areas where maritime activity is centered, with significant exposer to pollutants such as NOx and SOx leading to health impacts and accelerating existing inequalities.

According to IMO, "The greenhouse gas (GHG) emissions, including carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), expressed in CO2e of total shipping (international, domestic and fishing) have increased from 977 million tons in 2012 to 1,076 million tonnes in 2018 (9.6% increase). In 2012, 962 million tons were CO2 emissions, while in 2018, this amount grew by 9.3% to 1,056 million tons of CO2 emissions. The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018."[29]

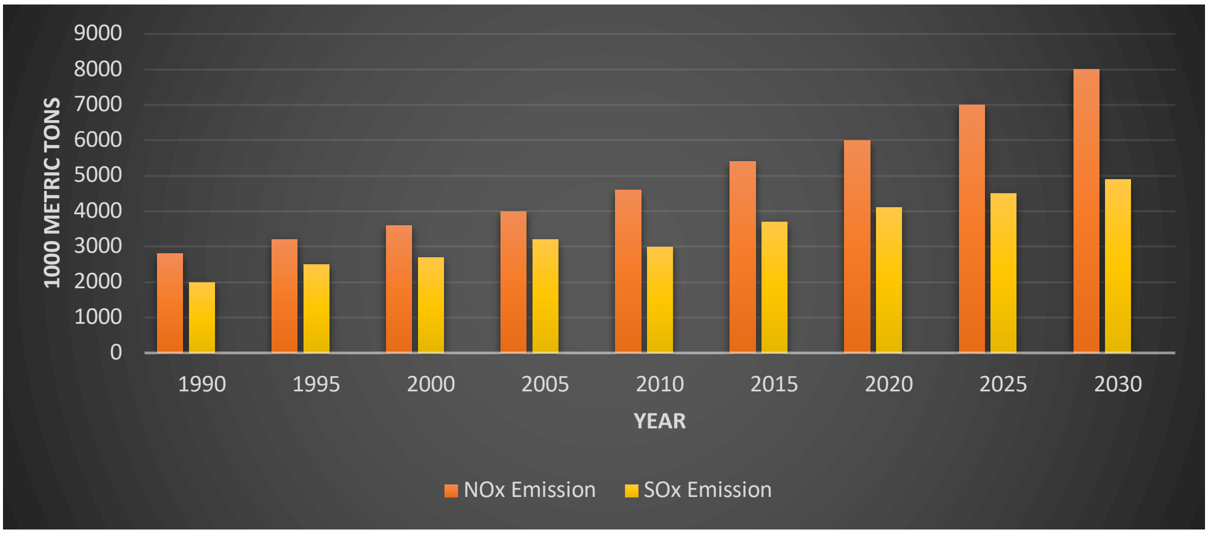

Figure 1: Emissions NOx (a) and SOx (b) 1990–2030 international shipping.

[28] Kai Krause and others, "Estimation of Ship Emission Rates at a Major Shipping Lane by Long-Path DOAS Measurements" (2021) 14 Atmospheric Measurement Techniques 5791 <https://doi.org/10.5194/amt-14-5791-2021>.

[29] "Fourth Greenhouse Gas Study 2020" <https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx>.

Source: Sea Transport Air Pollution [30]

The changing patterns of this figure outline the historical and projected trends of NOx and SOx emissions from the international shipping, underscoring some fractional success of MARPOL Annex VI in mitigating emissions since its implementation. Though the emissions of SOX have been reduced and aligned with global sulfur cap policies, the slower decline of the emissions of NOx explains gaps in enforcing stringent NOx reduction technology.

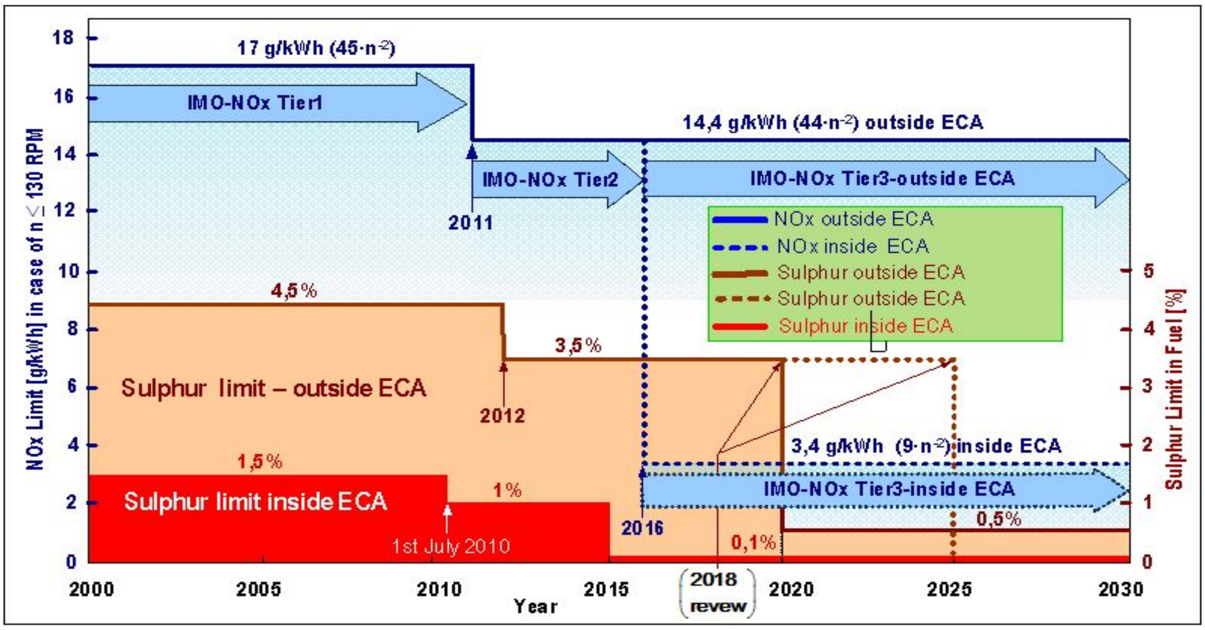

Figure 2: Reduction of NOx and Sulphur in fuel on the global and ECA limit

Source: Sea Transport Air Pollution [31]

By comparing NOx and Sulfur fuel content reductions between global and ECA specific limits, this figure highlights the control measures within ECAs, visualizing reflects which heightened regulatory scrutiny and technological adoption that are required in these areas. But the major difference between global and ECA limits leads to an enforcement challenge, especially in the areas which lack robust monitoring systems.

[30] Ivan Komar and Branko Lalić, "Sea Transport Air Pollution," *InTech eBooks* (2015) https://www.intechopen.com/chapters/48071

[31] ibid.

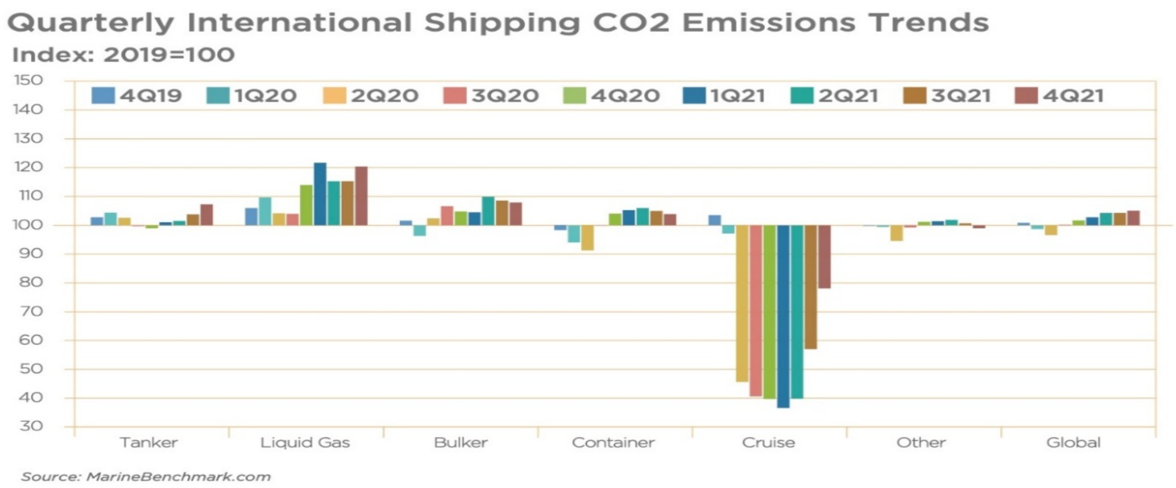

Figure 3: Quarterly International Shipping CO2 Emission Trends
Source: Shipping Emissions Rise 4.9% in 2021[32]
Tracking quarterly variations in CO2 emissions, this figure reveals a steady increase of the contributions of greenhouse gas from the maritime sector, with these trends conflicting with IMO's aim to reduce the GHG emissions by 50% by 2050. The data in this figure emphasize the urgency of implanting alternative low carbon fuels and operational efficiency measures to bridge the gaps between regulatory targets and actual outcomes.

According to Lloyd's List website, "Emission estimates are based on automatic identification system movements and cover international shipping and vessels more than 100 dwt. In 2021, 833m tonnes of CO2 was emitted based, compared with 794m tonnes in 2020 and 800m tonnes in 2019, according to figures provided by SSY (Simpson Spence & Young). Shipping accounts for some 3% of the world's emissions. About 75% of the global fleet of bulk carriers and tankers will not be able to comply with new technical metrics mandated by the IMO and which come into force in January 2023, unless they take remedial action, the report said."[33]

Ship emissions disproportionately affect disadvantaged communities, particularly those near ports, canals, and coastal areas where maritime activity is concentrated. These populations often experience higher exposure to pollutants like NOx and SOx, leading to severe health impacts and exacerbating existing inequities. Similarly, maritime workers, who are often from lower socio-economic backgrounds, face direct exposure to harmful pollutants during their operations. Addressing these disparities is critical to ensuring equity in global carbon regulations and protecting vulnerable groups from the adverse effects of maritime pollution.

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[32] "Shipping Emissions Rise 4.9% in 2021" (*Lloyd's List*, January 24, 2022) https://lloydslist.maritimeintelligence.informa.com/LL1139627/Shipping-emissions-rise-49-in-2021#:~:text=In%202021%2C%20833m%20tonnes%20of,3%25%20of%20the%20world's%20emissions.
[33] ibid.

A better understanding of numerous critical characteristics will minimize the uncertainty in the calculation of ship emission rates. Better information of the exact location of the emission location, i.e., the position of the ship's funnel, is necessary, for example. Similarly, a greater understanding of the emission height, i.e., the height of the ship's funnel and the water level at the moment of measurement, is necessary. It would be beneficial to employ more advanced models to characterize the form and development of the plume. Furthermore, a measuring geometry with a shorter light path across the river would make it simpler to identify pollution plumes from small-emission boats, increasing the possibilities of determining emissions from ships.[34]

Ongoing restriction from Annex VI

NOx Emission Standards

The regulation of nitrogen oxides (NOx) emissions from diesel engines is governed by stringent measures outlined in Regulation 13 of MARPOL Annex VI. These measures primarily involve obtaining an Engine International Air Pollution Prevention (EIAPP) Certificate, signifying compliance with survey and certification requirements. This certification is mandatory for ships using marine diesel engines over 130 kW, except for those designated solely for emergency use.

Table 1. MARPOL Annex VI NOx emission limits

Tier	Date	NOx Limit, g/kWh		
		$n < 130$	$130 \leq n < 2000$	$n \geq 2000$
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96
† In NOx Emission Control Areas (Tier II standards apply outside ECAs).				

Table 1: MARPOL Annex VI NOx Emission Limits (Source: Emission Standards: IMO Marine Engine Regulations)

Source: Emission Standards: IMO Marine Engine Regulations[35]

This table provides the details of NOx emission standards for marine diesel engines, segmented into tiers based on ship construction dates and operating conditions, reflecting the phased approach of Annex VI to curb the emissions and emphasizes how the incremental tightening of standards aligns with MARPOL's aims and objectives to mitigate ozone depleting emissions.

[34] Krause et al., *Supra* Note 28.

[35] "Emission Standards: IMO Marine Engine Regulations" https://dieselnet.com/standards/inter/imo.php#:~:text=The%20NOx%20emission%20limits%20of,on%20liquid%20or%20dual%20fuel.

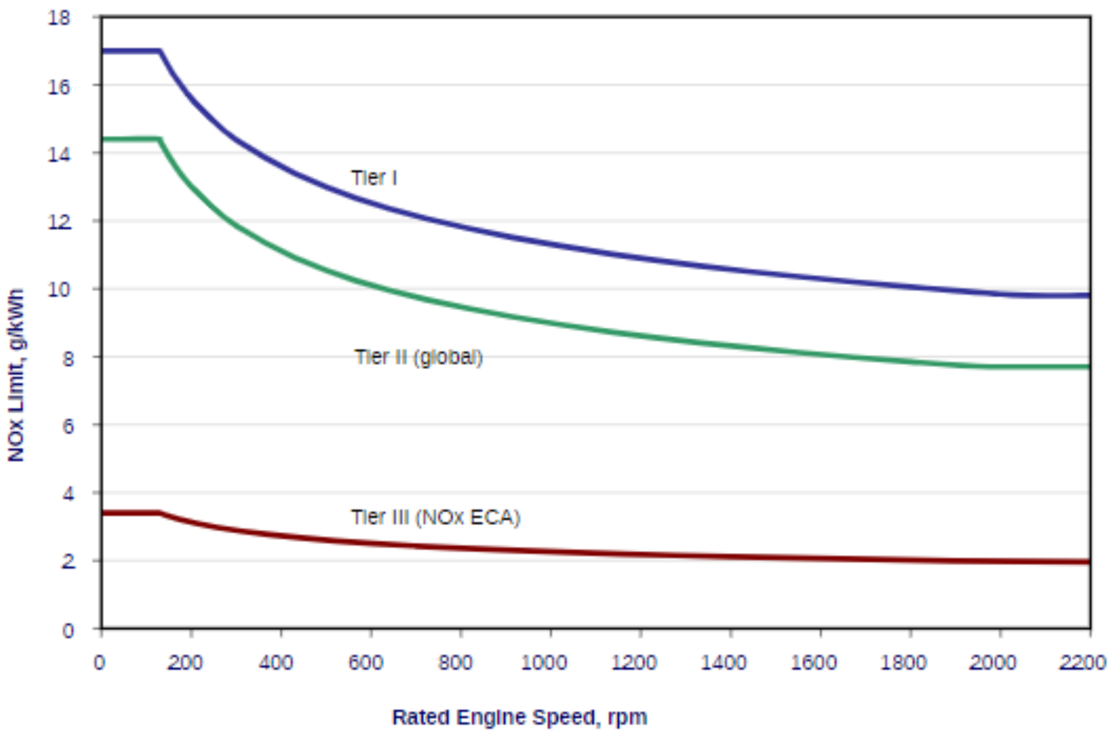

Figure 4: MARPOL Annex VI NOx Emission Limits (Source: Emission Standards: IMO Marine Engine Regulations)

Source: Emission Standards: IMO Marine Engine Regulations[36]

By providing a tiered breakdown of NOx emissions limits based on ship construction dates, this figure emphasizes the progressions of strict regulatory standard under Annex VI of MARPOL, highlighting the gradual implementation of Tier III limits within ECAs and also the data shows challenges, such as the slower adoption of Tier III-compliant technologies on older ships and leniency provided to smaller vessels.

Control standards are tiered based on the ship's construction date and outlined in the NOx Technical Code 2008. Tier III applies in Emission Control Areas (ECAs), while Tier II applies elsewhere. Some small ships may be exempt from Tier III engine installation. Ships constructed after specific dates in designated ECAs must adhere to Tier III standards.

Engines are certified individually or within groups, with tests conducted based on defined duty cycles. Recognized Organizations may oversee certification on behalf of flag States. Each certified engine must have an approved Technical File onboard, detailing compliance and survey regime. Major engine conversions are subject to regulations, with criteria based on conversion nature. Regulation 13.7 allows retrospective NOx certification for certain engines, potentially mitigating Tier III compliance. Constraints aim to minimize cost and performance impact. Chapter 7 of the NOx Technical Code outlines additional

[36] ibid.

requirements for engine maintenance and compliance verification. Vigilance ensures adherence throughout the engine's service life.[37]

Pre-2000 marine diesel engines, falling under the 2008 Annex VI amendments, must adhere to Tier I standards if installed on ships built between January 1, 1990, and December 31, 1999, with specific criteria. Engine emissions are assessed through ISO 8178 cycles, although debate surrounds the potential inclusion of not-to-exceed (NTE) testing in Tier III standards. Testing typically employs distillate diesel fuels, despite real-world usage of residual fuels, with additional technical guidelines outlined in the mandatory "NOx Technical Code" under "Resolution 2".[38]

Sulfur Emission and Content Fuel

Regulation 14 mandates strict controls on sulphur oxides (SOx) emissions from ships. The sulphur content in fuel oil must not surpass 4.5% m/m globally. In designated SOx emission control areas, including the Baltic and North Sea areas, this limit drops to 1.5% m/m. Alternatively, ships can employ approved exhaust gas cleaning systems to limit SOx emissions to 6.0 g SOx/kW·h or less.

Table 2. MARPOL Annex VI fuel sulfur limits

Date	Sulfur Limit in Fuel (% m/m)	
	SOx ECA	Global
2000	1.5%	4.5%
2010.07	1.0%	
2012		3.5%
2015	0.1%	
2020		0.5%

Table 2: MARPOL Annex VI Fuel Sulfur Limits (Source: Emission Standards: IMO Marine Engine Regulations)

Source: Emission Standards: IMO Marine Engine Regulations[39]

Presenting data on Annex VI fuel sulfur limits, this table outlines the sulfur content limits in fuel oil globally and in SOx ECAs and illustrates stringent sulfur limits for ships operating within designated areas to reduce the emissions of sulfur.

[37] "Nitrogen Oxides (NOx) – Regulation 13" (*imo.org*) <https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx>.

[38] Emission Standards: IMO Marine Engine Regulations, *Supra* Note 35.

[39] ibid.

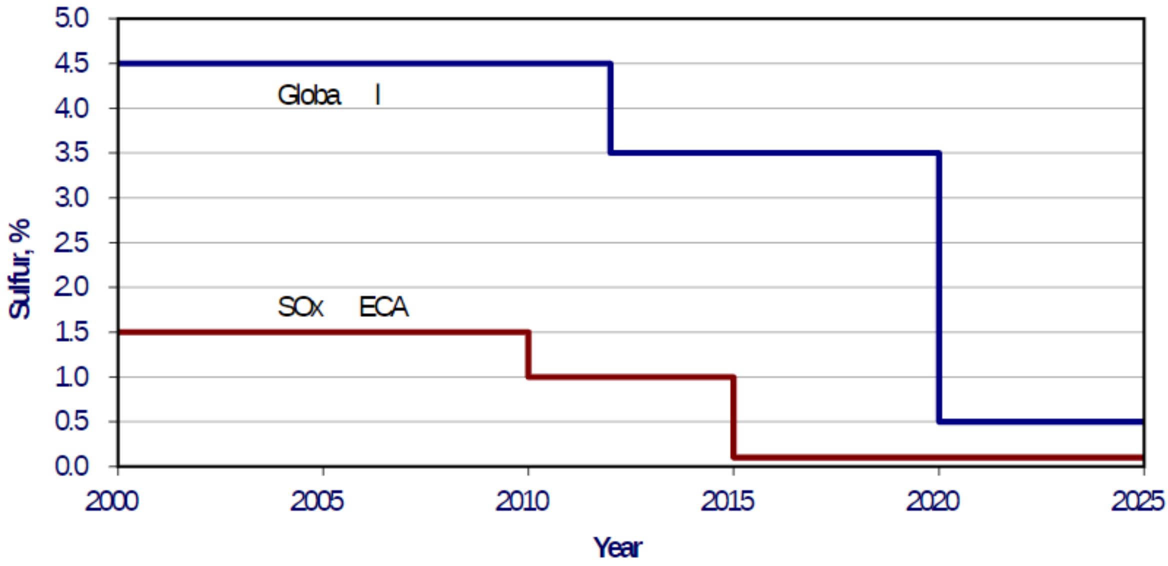

Figure 5: MARPOL Annex VI Fuel Sulfur Limits (Source: Emission Standards: IMO Marine Engine Regulations)

Source: Emission Standards: IMO Marine Engine Regulations[40]

Showcasing the declining sulfur content limits in marine fuel, both globally and within ECAs, this figure's visual highlights the success of Annex VI of MARPOL in promoting low-sulfur fuels and the adoption of scrubber technologies, though it reveals the significant difference in the standard of sulfur between ECAs and non0ECAs regions, outlining potential enforcement issues in areas without strict controls. This inconsistency explains the gap in the uniform global enforcement, suggesting that expanding and extending restrictions like ECA to more regions could enhance global compliance with targets to reduce sulfur.

Documentation of fuel sulphur content is required, and ships using different fuels must ensure complete flushing of systems before entering SOx emission control areas. Exemptions are granted for the initial 12 months after the regulation's enforcement or the designation of a new SOx emission control area. The regulation emphasizes compliance monitoring and technological advancements in emission control methods. It underscores the importance of environmental protection while allowing flexibility in implementation. Compliance with these regulations ensures a significant reduction in harmful SOx emissions, contributing to cleaner air and healthier marine ecosystems.[41]

Greenhouse Gas Emissions

MARPOL Annex VI, Chapter 4, enforces two key measures to tackle greenhouse gas emissions from ships. The Energy Efficiency Design Index (EEDI) mandates a minimum energy efficiency standard for new vessels, while the Ship Energy Efficiency Management

[40] ibid.

[41] "Annex VI - Regulation 14 - Sulphur Oxides (SOx)" <http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_VI/r14.htm>.

Plan (SEEMP) focuses on improving operational efficiency for existing ships. These regulations, applicable since January 2013 for ships over 400 gross tonnage, aim to reduce the environmental impact of maritime activities. Flexibilities were initially provided to waive EEDI compliance for certain vessels under construction. The IMO's April 2018 Initial Strategy targets a 50% reduction in greenhouse gas emissions from ships by 2050, advocating for strengthened EEDI requirements, operational enhancements, and exploration of low-carbon fuels.[42]

Other Provisions

MARPOL Annex VI addresses additional environmental concerns. It prohibits deliberate emissions of ozone-depleting substances and incineration of certain products onboard ships. Compliance is ensured through periodic inspections, with ships receiving an International Air Pollution Prevention Certificate upon successful assessment. Special regulations, effective from July 1, 2024, restrict heavy fuel oil usage in Arctic waters, except for specific operational needs and safety purposes until July 1, 2029.[43]

Challenges for Developing Maritime Stakeholders

Some unique challenges in complying with the strict requirements of Annex VI are faced by small-scale and developing-world maritime stakeholders with limited financial resources, access to technology, and technical expertise which hinder these stakeholders from implementing advanced emissions reduction measures, such as low-NOx technologies or exhaust gas cleaning systems, raising questions about the fairness of global environmental policies and threaten their economic viability.

Amendment Suggestion

Tiered Emission Standards

This paper suggests introducing a tiered system for emission standards that considers vessel type, age, and fuel type. This system would differentiate between existing vessels and newbuilds, taking into account technological advancements. The gradual transition would minimize economic burden, encourage fleet renewal, and accelerate emission reduction efforts.

Global Cap on Black Carbon Emissions

Another recommendation is to set a global cap on black carbon (BC) emissions from marine engines. BC particles, primarily emitted by diesel engines, contribute significantly to both climate change and ozone depletion. Implementing such a cap would effectively curb their release, thereby protecting the ozone layer and mitigating climate impact simultaneously.

[42]Emission Standards: IMO Marine Engine Regulations, *Supra* Note 35.

[43] ibid.

Promotion of Green Technologies

Encouraging the adoption of green technologies like fuel cells, wind-assisted propulsion, and solar panels is essential. These alternatives reduce reliance on fossil fuels, resulting in lower emissions and advancing sustainable shipping practices. Such measures align with global environmental goals and contribute to long-term ozone layer protection.

Incentivize Low-NOx Technologies

Financial incentives for vessels equipped with low-NOx technologies, such as selective catalytic reduction, are proposed. Nitrogen oxides (NOx) emissions contribute to tropospheric ozone formation, indirectly affecting the stratospheric ozone layer. Incentivizing the adoption of cleaner technologies not only encourages investment but also reduces the overall impact of NOx emissions.

Research on Ozone-Depleting Substances (ODS)

Collaborating with scientific institutions to conduct research on ozone-depleting substances (ODS) used in ship equipment, such as refrigerants and fire suppressants, is recommended. ODS emissions directly harm the ozone layer. Comprehensive research would inform decisions on phasing out ODS and promoting eco-friendly alternatives, contributing significantly to ozone protection efforts.

Strengthen Port State Control (PSC)

Enhancing Port State Control (PSC) inspections related to Annex VI compliance is crucial. Rigorous inspections ensure adherence to emission limits and proper functioning of exhaust gas cleaning systems (scrubbers). Strengthening PSC measures would deter non-compliance and maintain a level playing field among ship operators, thereby bolstering ozone protection initiatives.

Collaboration with Industry Stakeholders

Engaging shipowners, classification societies, and engine manufacturers in policy discussions is vital. Industry expertise is essential for the effective implementation of regulatory measures. Collaborative efforts would lead to the development of holistic solutions, practical insights, and smoother policy adoption processes, ultimately contributing to enhanced ozone protection.

Capacity Building and Training

Investing in training programs for maritime professionals on emission reduction techniques is recommended. Disseminating knowledge ensures the proper operation of emission control systems, empowering seafarers to actively contribute to ozone protection efforts. Capacity building initiatives play a crucial role in fostering a culture of environmental stewardship within the maritime industry.

Conclusion

In conclusion, this critical analysis emphasizes the urgent necessity for a thorough reassessment of Annex VI of MARPOL concerning the preservation of the ozone layer. Despite Annex VI's considerable efforts in regulating air pollution from ships, the current provisions appear inadequate to effectively safeguard the ozone layer amidst the escalating challenges posed by ship emissions. The analysis delves into the multifaceted factors contributing to ship emissions and their detrimental effects on the ozone layer, underscoring the pivotal role of maritime activities in global environmental degradation. Although Annex VI imposes stringent regulations on nitrogen oxides (NOx) and sulfur oxides (SOx) emissions, it becomes evident that these measures alone may not suffice to mitigate the adverse impact on the ozone layer.

Empirical data and statistical projections illustrate a troubling trend of increasing greenhouse gas emissions from the maritime sector, exacerbating the challenges of ozone layer depletion. Despite ongoing efforts under Annex VI, such as NOx emission standards and sulfur content restrictions in fuel, persistent gaps and inefficiencies within the existing regulatory framework are apparent. In response to these findings, pragmatic amendments to Annex VI are proposed, advocating for the introduction of new restriction limits and innovative measures to further curtail emissions and preserve the integrity of the ozone layer. These recommendations are rooted in a rigorous analysis informed by empirical evidence and expert insights, aiming to address the evolving challenges posed by ship emissions effectively.

Key recommendations include implementing tiered emission standards, setting a global cap on black carbon emissions, promoting green technologies, incentivizing low-NOx technologies, conducting research on ozone-depleting substances, strengthening port state control measures, and fostering collaboration with industry stakeholders. Investing in capacity building and training programs for maritime professionals is emphasized to ensure the proper implementation of emission reduction techniques. In essence, the proposed amendments represent a holistic approach towards enhancing ozone layer protection within the maritime sector, emphasizing the importance of international cooperation, technological innovation, and regulatory enforcement in addressing this pressing environmental challenge. By adopting these measures, policymakers can mitigate the adverse effects of ship emissions on the ozone layer and contribute to a more sustainable future for our planet.

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