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«ΒΙΟΟΙΚΟΝΟΜΙΑ, ΚΥΚΛΙΚΗ ΟΙΚΟΝΟΜΙΑ & ΒΙΩΣΙΜΗ ΑΝΑΠΤΥΞΗ»

Μείωση των εκπομπών CO_2 από τη ναυτιλία

Ανάλυση των δεδομένων που αναφέρονται στο πλαίσιο του κανονισμού EU MRV (2018-2022)

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MSc. in Bioeconomy, Circular Economy & Sustainable Development

Reducing CO_2 emissions from shipping

An analysis of the data reported under the EU MRV Regulation (2018-2022)

by Danai Barka - Patargia

Piraeus, Greece, February 2025

To my family.

I am grateful for your support and encouragement

that have been the driving force behind my every move.

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Σημαντικοί Όροι: ναυτιλία, εκπομπές, απανθρακοποίηση, παρακολούθηση, υποβολή εκθέσεων, επαλήθευση

Περίληψη

Παρά το γεγονός ότι είναι ένας από τους πιο ενεργειακά αποτελεσματικούς τρόπους μεταφοράς, η ναυτιλία συμβάλλει σημαντικά στις παγκόσμιες εκπομπές αερίων του θερμοκηπίου, με κυριότερο το διοξείδιο του άνθρακα. Τα τελευταία χρόνια έχουν αναπτυχθεί πολιτικές με στόχο τη μείωση αυτών των εκπομπών, τόσο σε παγκόσμιο όσο και σε επίπεδο ΕΕ, και έχουν τεθεί στόχοι για έναν βιώσιμο ναυτιλιακό τομέα έως το 2050. Αυτή η διπλωματική εργασία παρουσιάζει μέτρα που έχουν ληφθεί για την βελτίωση της ενεργειακής απόδοσης του στόλου. Επικεντρώνεται στις προσπάθειες της ΕΕ να παρακολουθεί τις εκπομπές CO_2 μέσω της εφαρμογής του συστήματος EU MRV και να αναλύει δεδομένα από τη δημόσια βάση δεδομένων THETIS MRV προκειμένου να αναδείξει τάσεις που έχουν διαμορφωθεί κατά τα έτη 2018 έως 2022. Σκοπός αυτής της διπλωματικής εργασίας είναι να συμβάλει στις συνεχιζόμενες συζητήσεις για την επίτευξη μιας βιώσιμης ναυτιλίας, ενώ με βάση των αποτελεσμάτων αυτής της ανάλυσης, αναγνωρίζει ζητήματα όπως η ανάγκη συνεργασίας και ανταλλαγής γνώσεων, η επένδυση στην καινοτόμο τεχνολογία και η διασφάλιση μιας δίκαιης, βιώσιμης και ταυτόχρονα βασισμένης στην πραγματικότητα μετάβασης.

Reducing CO_2 emissions from shipping

An analysis of the data reported under the EU MRV Regulation (2018-2022)

Keywords: shipping, emissions, decarbonisation, monitoring, reporting, verification

Abstract

Despite being one of the most efficient modes of transport, shipping is a major contributor to global greenhouse gas emissions, with the main one being carbon dioxide. For the last years policies aiming to reduce these emissions have been developed, both at a global and an EU level, and targets have been set towards a sustainable net-zero maritime sector by 2050. This thesis presents policy measures that have been taken towards greening the sector and improving the fleet's energy efficiency. It focuses on the EU's efforts to monitor CO_2 emissions by implementing the EU MRV system and it analyses data from the public THETIS MRV database in order to develop trends that have been formed over the years 2018 to 2022. The purpose of this thesis is to contribute to the ongoing discussions on achieving a sustainable decarbonised maritime sector, while based on the findings of this analysis, it identifies several issues such as the need for cooperation and sharing knowledge, investing in innovative technology and ensuring a just, viable and reality-based transition.

ΤΜΗΜΑ
ΟΙΚΟΝΟΜΙΚΗΣ ΕΠΙΣΤΗΜΗΣ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

ΒΕΒΑΙΩΣΗ ΕΚΠΟΝΗΣΗΣ ΔΙΠΛΩΜΑΤΙΚΗΣ ΕΡΓΑΣΙΑΣ

«Δηλώνω υπεύθυνα ότι το έργο που εκπονήθηκε και παρουσιάζεται στην υποβαλλόμενη διπλωματική εργασία, για τη λήψη του μεταπτυχιακού τίτλου σπουδών, στη «*Βιοοικονομία, Κυκλική Οικονομία και Βιώσιμη Ανάπτυξη*» με τίτλο:

Reducing CO2 emissions from shipping - An analysis of the data reported under the EU MRV Regulation (2018-2022)

έχει γραφτεί από εμένα αποκλειστικά στο σύνολό της. Δεν έχει υποβληθεί ούτε εγκριθεί στο πλαίσιο κάποιου άλλου μεταπτυχιακού προγράμματος ή προπτυχιακού τίτλου σπουδών στην Ελλάδα ή στο εξωτερικό, ούτε είναι εργασία ή τμήμα εργασίας ακαδημαϊκού ή επαγγελματικού χαρακτήρα.

Δηλώνω επίσης υπεύθυνα ότι οι πηγές στις οποίες ανέτρεξα για την εκπόνηση της συγκεκριμένης εργασίας αναφέρονται στο σύνολό τους, κάνοντάς πλήρη αναφορά στους συγγραφείς, τον εκδοτικό οίκο ή το περιοδικό, συμπεριλαμβανομένων και των πηγών που ενδεχομένως χρησιμοποιήθηκαν από το διαδίκτυο. Παράβαση της ανωτέρω ακαδημαϊκής μου ευθύνης αποτελεί ουσιώδη λόγο για την ανάκληση του πτυχίου μου.»

Υπογραφή Μεταπτυχιακού Φοιτητή

Δανάη Μπάρκα - Παταργιά

Ονοματεπώνυμο

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Introduction

Maritime transport is essential for international trade and the economy with over 90% of goods being transported by sea. Shipping is considered the most energy-efficient mode for cargo and passenger transport. However, vessels currently operate mostly on cheap, energy-dense heavy fuel oils which results in shipping to have a significant environmental footprint and to be one of the biggest sources of carbon emissions from the transport sector. The OECD estimates that in 2022, there were 858 million tonnes of CO_2 emissions globally from the shipping industry, compared to 739 million tonnes of CO_2 emissions from air transport which is the second biggest contributor to emissions from transport (OECD, 2023).

The operation of a ship requires the combustion of fossil fuels which results in the production of various substances, GHGs and other air pollutants. This thesis presents all the air emissions originating from ships (CO_2, CH_4, N_2O, black carbon, SO_x, NO_x and particulate matter) and focuses mainly on carbon emissions which is the primary greenhouse gas associated with climate change. The volumes of emissions depend on the amount of fuel used, the individual characteristics of the fuel, and the technologies used on board (engines and emission control equipment). Furthermore, the present thesis provides an overview of the policy framework developed at a global and European level, to regulate the sector's emissions and achieve economic, social and environmental sustainability while considering its complexity, uniqueness and international nature.

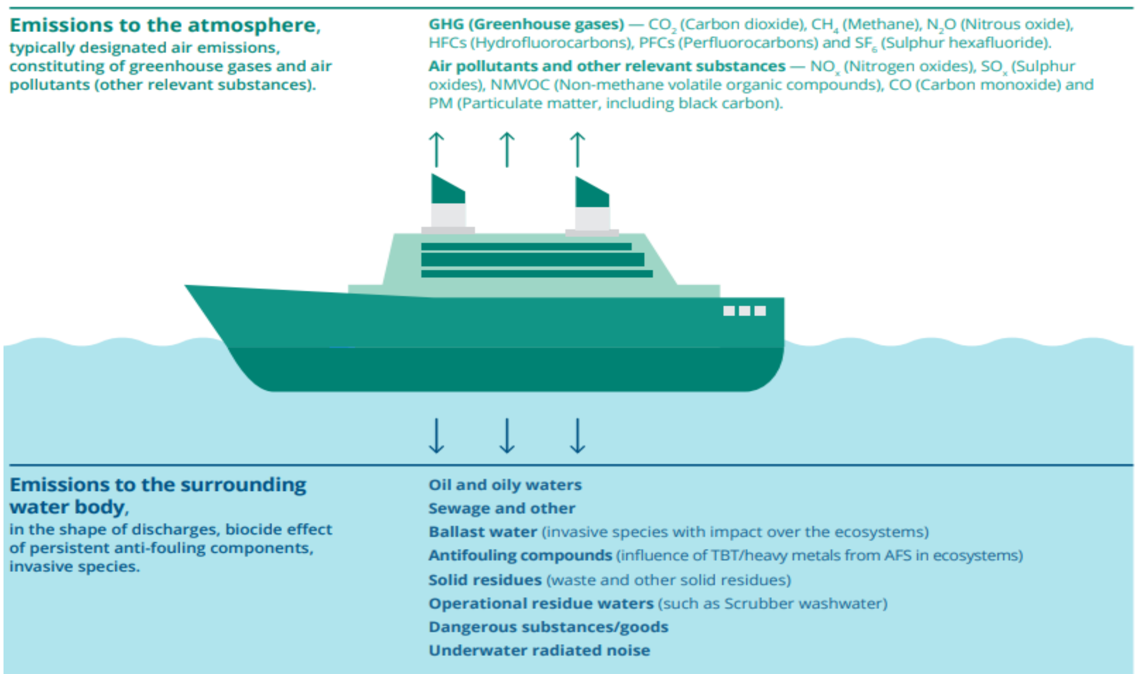
Moreover, this thesis provides a comprehensive analysis of the Monitoring, Reporting and Verification (EU MRV) Regulation system, which is EU's initial step for gaining an accurate insight of the sector's emissions in order to assist in policy development and further research. Although the system has some limitations, the main one being the levels of accuracy of the data reported, MRV is the only system in place that can offer a comprehensive dataset, specifically targeted to evaluate fuel consumption and carbon intensity, providing an ideal source for validating bottom-up estimates (IMO, 2020). In addition, publicly available data derived from the THETIS-MRV database, were used to perform an analysis of the current state as well as to create trends for the years that the Regulation has been implemented, from 2018 to 2022. Particularly, the narrative follows information on the fleet composition, the CO_2 emissions, while the technical and operational efficiency of the fleet falling under the Regulation is being examined along with the impact of international and regional policies and other global events.

Through this analysis, the present thesis aims to contribute to the ongoing discussions on sustainable maritime practices and the decarbonisation of the sector, by offering an insight into the impact of policies that are in place while highlighting the importance of international cooperation to achieve the ambitious targets that have been set. To achieve these goals, cooperation is essential, not only among nations but also between the regulators and the industry in order to have realistic and achievable targets, to ensure a wide implementation and to support and foster technological innovation. While different decarbonisation paths are currently being explored, the biggest concern of the industry lays on the issue of cost-effectiveness which is vital to facilitate an equitable sustainable future, as well as the availability of technology, infrastructure and equipment to support the decarbonisation of the maritime sector.

CHAPTER 1

IMPACT OF MARITIME TRANSPORT TO CLIMATE CHANGE AND ACTIONS TO LIMIT THE EMISSIONS

The shipping sector plays a crucial role in facilitating global trade and serving international economies. According to OECD, ocean economy's[1] direct contribution to world economy in 2010 was 1.5 trillion USD or around 3% of world GDP or 2.5% of world GVA (Gross Added Value), a figure that is expected to double by 2030 while according to the same projections, the ocean economy is expected to provide more than 40 million FTE (full-time equivalent) jobs by 2030 (OECD, 2016). Over 80% of the volume of international trade in goods is carried by sea, and the percentage is even higher for most developing countries, while maritime transport is one of the most energy-efficient modes of transport. However, pollution derived from maritime shipping activities has profound implications for air and water quality and marine and estuarine biodiversity as shown in figure 1.1.



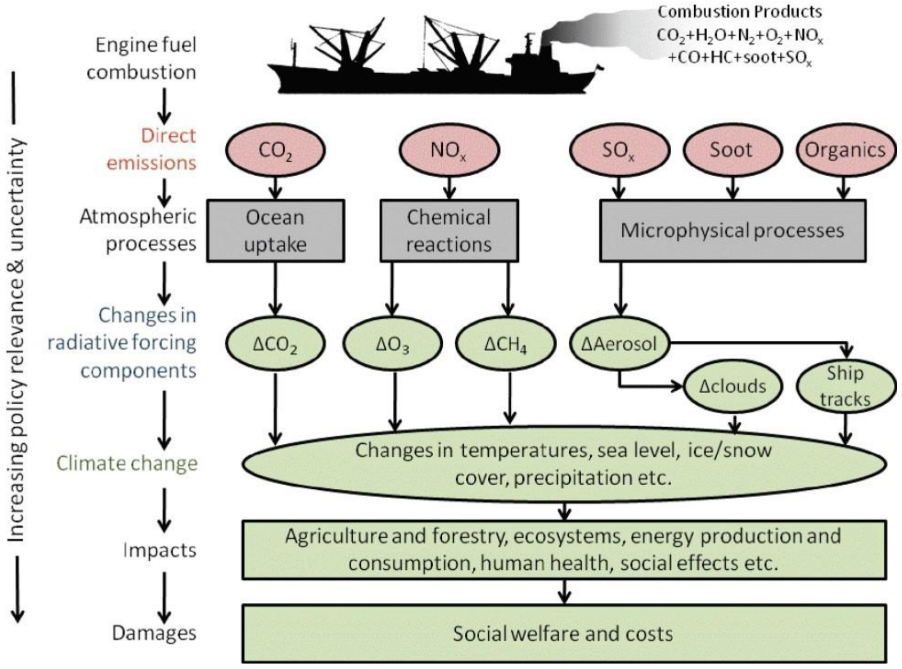
Source: EMSA - EEA, European Maritime Transport Environmental Report, 2021

Figure 1.1: Pollutant emissions to the atmosphere and water body from a generic ship.

[1] Including shipping, port activities, shipbuilding, offshore oil and gas, maritime and coastal tourism, dredging, fisheries, marine manufacturing and construction, maritime safety and surveillance, marine biotechnology, etc.

In an effort to regulate all pollutants derived from shipping, international and regional governing bodies have posed during the years a series of regulatory requirements. The pollutants per ship's activity, the environmental impact and the compliance obligations for the shipping companies are presented in Annex II.

Emissions to the atmosphere or air emissions represent Greenhouse gases (GHG) and other air polluting substances, that have a great impact on the ecosystems, human health and climate change. The shipping industry is a major contributor to GHG emissions with carbon dioxide (CO_2) having the lion's share in both, terms of volumes and potential impact on global warming processes, and thus being the primary concern.



Source: 2nd IMO GHG Study, 2009

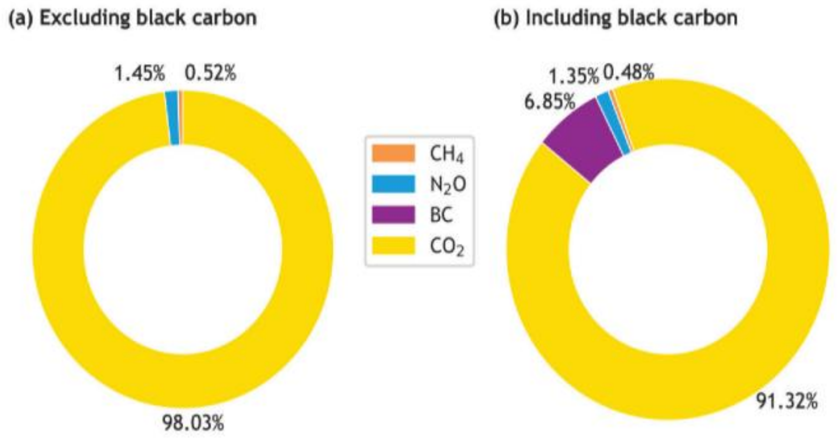
Figure 1.2: Schematic presentation of the overall impacts of emissions from shipping sector on climate change.

1.1 Greenhouse Gases

Greenhouse gases (GHG) constitute a group of gases contributing to global warming and climate change by trapping heat in the atmosphere. According to the Kyoto Protocol (UNFCCC, 1997), GHGs include the non-fluorinated gases (carbon dioxide, methane, nitrous oxide) and the fluorinated gases (hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, nitrogen trifluoride). Policies have been developed to limit GHG emissions from all sectors considering each industry's nature and characteristics, and various measures have been implemented to achieve targets and regulate the volumes of these emissions.

To be able to compare the numbers between the different GHGs, a common unit is used which puts in relation all GHG emissions, CO_2eq (CO_2 equivalent). CO_2-eq is the amount of carbon dioxide (CO_2) emission that would have an equivalent effect on a specified key measure of climate change, over a specified time horizon, as an emitted amount of another greenhouse gas (GHG) or a mixture of other GHGs (IPCC,2023). CO_2-equivalent emissions are commonly used to compare emissions of different GHGs but should not be taken to imply that these emissions have an equivalent effect across all key measures of climate change (IPCC, 2023). Furthermore, CO_2 is considered to have a Global Warming Potential (GWP) of 1. GWP is an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon (20, 100 or 500 years), relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing (IPCC, 2023). In other words, GWPs determine the ratio of heat trapped by one unit mass of a specific GHG to that of the one-unit mass of CO_2 over a specified period.

GHG emissions from shipping have a direct impact on human health and living conditions, contribute to acidification and eutrophication and also influence the radiative forcing of climate (Corbett, Winebrake et.al. 2007). GHGs coming from ships include mainly CO_2 as the result of the combustion of fossil fuels in the ship's combustion machinery (main engine, auxiliary engines, boilers). Methane (CH_4) may be emitted by ships using gas or dual fuel engines or from cargo tanks in LNG carriers. Refrigerants are used in various types of machinery on board (air conditioning, cargo cooling) and various gases are used including HFCs, PFCs and SF_6. Black carbon is not classified as a GHG, but it is a potent climate pollutant with an especially large short-term warming effect. It represents the second most significant contributor in shipping' emissions (6,85%, Figure1.3).



Source: Fourth IMO GHG Study, 2020

Figure 1.3: Comparison of the contribution of individual species to voyage based international GHG emissions (in CO_2e) in 2018

The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.8% in 2018 (IMO, 2020). The GHG emissions of shipping have increased from 977 million tonnes in 2012 to 1.076 million tonnes in 2018, showing a 9.6% increase (IMO, 2020). When looking into the EU's GHG inventory (produced under UNFCCC), maritime transport contributed 13.5% of the total EU GHG emissions from transport in 2018, which is almost as high as aviation's contribution (transport work is not considered).

These emissions are projected to increase from 90% to as much as 130% of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios (Fourth IMO GHG Study, 2020). If the climate change impact of shipping activities grows as projected, it would undermine the objectives of the Paris Agreement[2], a global framework to avoid dangerous climate change by limiting global warming to well below +2°C and pursuing efforts to limit it to 1.5°C. To limit GHG emissions an increase in the use of renewables instead of fossil fuels, a switch from coal to gas for power generation and improvements in energy efficiency are required. On that regard, action is being taken on a global level and new measures are under discussion to curb the GHG emissions.

[2] Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016.

1.1.1 CO_2

CO_2 (carbon dioxide) mainly originates from the combustion of fossil fuels. To calculate CO_2 emissions (as well as SO_x and black carbon), the most common method is on a fuel basis, where pollutants are calculated depending on the amount of pollutant found in the fuel used and the engine type. In particular, the emissions are calculated by multiplying the fuel consumption by a default fuel-based emission factor. Those values are usually based on the latest available values of the Intergovernmental Panel for Climate Change (IPCC). The level of CO_2 emissions is also related to the technical characteristics of the vessel (shape, dimensions of the hull, etc.) the efficiency of the engine and its overall performance taking into account weather conditions, navigation practices and load.

According to the International Maritime Organization (IMO)[3], maritime transport is responsible for approximately 2-3% of global CO_2 emissions annually (IMO, 2020 third IMO GHG study 2014). In 2018, international shipping emitted an estimated 1,056 million tonnes of CO_2, which accounted for around 2.89% of global anthropogenic CO_2 emissions (International Energy Agency, 2020 CO_2 emissions from fuel combustion 2020). According to the Fourth IMO GHG Study, CO_2 is the dominant source of shipping's climate impact when calculated on a GWP-100-year basis, accounting for 98%, or 91% if black carbon (BC) is included, of total international GHG emissions (in CO_2e) (Figure 1.3).

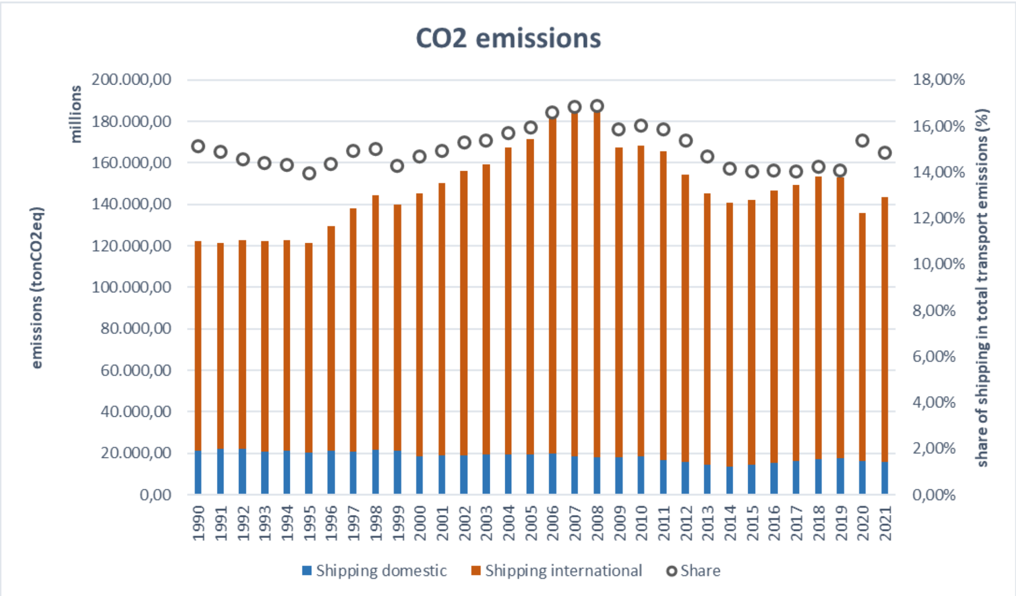
At an EU level, maritime transport represents 3 to 4% of the EU's total CO_2 emissions, or over 124 million tonnes of CO_2 in 2021 (MRV,2022). Figure 1.4, which is based on the EU's GHG inventories, illustrates the emissions from international and domestic shipping from 1990 up to 2021 as well as the shipping sector's share of total transport emissions. The CO_2 emissions reached a peak in 2008 which reflects the growth of international trade and the increase in demand for maritime transport. From 2008 until 2015 emissions followed a downward trajectory which was mainly due to the economic downturn in Europe that resulted in reduced transport demand globally. In addition, the economic crisis forced shipowners to reduce their vessels' speeds (slow steaming) as a result of trying to reduce their operational expenses. Limiting the fuel consumption resulted in limiting CO_2 emissions from the sector which could also be complemented by technical improvements in ship efficiency. Furthermore, after 2008 various international agreements and regulations were set in place which is also a reason why

[3] International Maritime Organisation (IMO) is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships.

emissions seem to be decreasing. It should be highlighted that even though growth of the sector is still being observed and is expected to continue over the next decades, the emissions seem to have a relative decreasing trend which suggests a decoupling between the two factors.

In 2020, another major decrease is observed, due to the COVID-19 pandemic which posed limitations to the industry with less ships operating and less voyages being made. In 2021, shipping accounted for more than 14% of the CO_2 emissions from transport but still remained below the 2008 peak. It should be noted that the shipping sector is highly reliant to the use of fossil fuels (main fuel used is residual fuel oil followed by gas/diesel oil) and therefore, when compared to other means of transport a high share of CO_2 emissions is expected.

GHG emissions from international shipping increased in 2021 due to the economic recovery and were around 26% above 1990 levels (EEA,2023). In 2021, international shipping accounted for 129 million tonnes CO_2-eq (compared to 121 million tonnes in 2020) (EEA, 2023). According to the same EEA report, considering only international navigation, CO_2 accounted for 98,8% of the total GHG emissions from international shipping in the EU for 2021.



Source: Author's calculations

(data: EU inventories: www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer)

Figure 1.4: CO2 emissions from shipping and share in total transport emissions.

Note: The emission inventories from which these data were extracted, are based on the volumes of fuel sold for domestic and international waterborne navigation purposes. Based on information on the port of departure and port of arrival, the division between domestic and international shipping is then calculated. Emissions from waterborne navigation between the ports of different EU Member States are recorded as international emissions. Furthermore, it should be noted that data for the fishing sector is not included in this dataset.

The differences observed between data reported under the MRV Regulation and in the EU's inventories, are due to the different approaches and methods in calculations and therefore are not directly comparable. For example, the MRV data have a different threshold (the regulation is applied to ships over 5.000 GT[4]) which is not the case when it comes to the estimations from the inventories that are based on fuel volumes sold.

1.1.2 CH_4

Methane (CH_4) is an important contributor to climate change, having 28-36 times greater GWP (on a 100-year timescale) and 84-87 times more GWP (on a 20-year timescale) compared to CO_2. Methane also affects air quality and is a contributor to ozone formation which is the cause of various health problems. Methane has a much shorter atmospheric lifetime than CO_2, but it is a much more potent greenhouse gas, absorbing much more energy while it exists in the atmosphere (IEA, 2021).

In general, approximately 1/3 of global anthropogenic methane emissions come from the energy sector (mainly oil and gas, but also coal and bioenergy) while methane has commercial value as it is saleable in the form of natural gas (IEA, 2021). When it comes to shipping, methane may be emitted to the atmosphere by ships using gas or dual fuel engines or from the cargo tanks in LNG (liquified natural gas) carriers. LNG (85%-95% of LNG is methane) is already being used as a fuel while it is also being explored as a more widespread alternative marine fuel solution due to its low carbon factor. As a matter of fact, according to Shell's LNG outlook 2022, 30% of the large new ship orders (in terms of GT) are for LNG-fuelled vessels in 2021. Furthermore, according to DNV's Alternative Fuels Insight (AFI, https://store.veracity.com/premium-access-alternative-fuels-insight-afi) which provides data on the energy transition trends and the ships using alternative fuels, 539 LNG fuelled ships are on order for 2028 showing a clear swift of the market towards the use of liquified natural gas as a fuel.

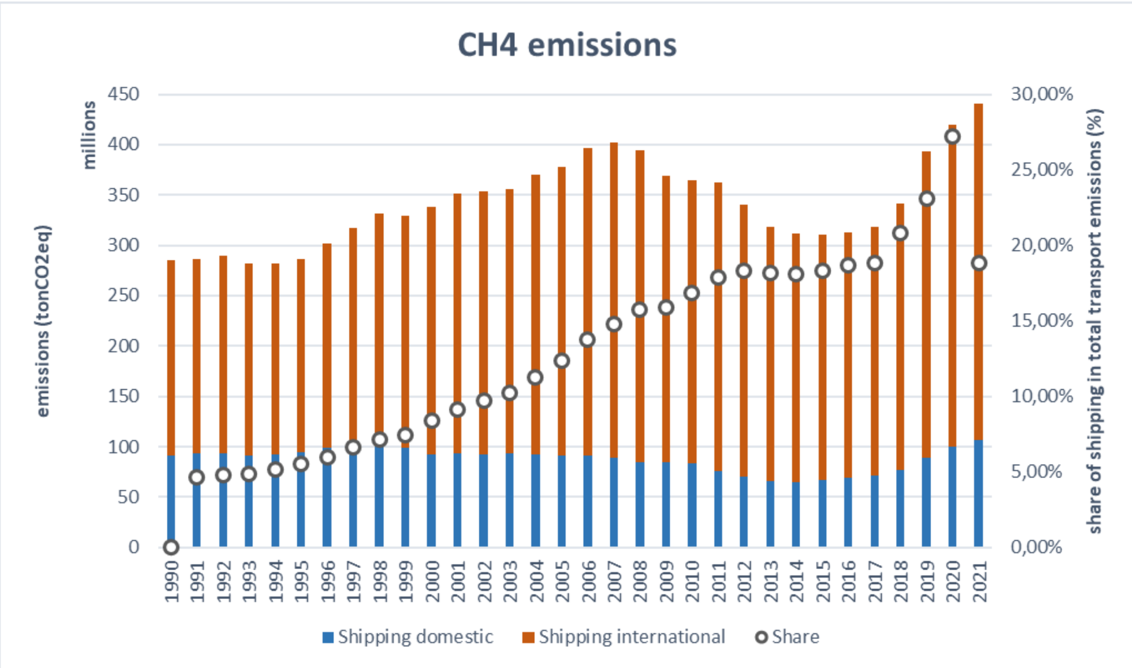
The main argument regarding the inclusion of LNG in the future bunker mix is that the presence of methane in these high volumes, reduces the overall environmental benefit. When

[4] Gross tonnage or GT is a function of the moulded volume of all enclosed spaces of a ship and is determined by the formula $GT=K_1V$, where: V = Total volume of all enclosed spaces of the ship in cubic metres and K1 = 0.2 + 0.02log10V (International Convention on Tonnage Measurement of Ships, IMO, 1969).

methane is used as a fuel, a percentage is not fully combusted in the engine, and it is released as unburned gas in the atmosphere. This is called methane slip and accounts for a small percentage of the fuel used which depends on the type and size of the engine.

At a global level, total LNG use in international shipping increased by 28-30% over the period 2012-2018, but over the same period emissions of methane are estimated to have increased by 151-155% (IMO, 2020). According to the Fourth IMO GHG Study, this faster growth of methane emissions than the use of LNG itself is a result of the growth of the LNG fuelled fleet and the shift in the mix of machinery technologies being used over the period studied (shift away from steam turbines to dual-fuel internal combustion engines which emit more methane).

At an EU level and according to the EU inventories produced under the UNFCCC, CH_4 emissions from shipping started to increase again after 2015 with an almost 27% share of shipping in the total emissions from transport in 2020 (Figure 1.5). Since methane has a high global warming potential, this increase is quite concerning and calls for immediate action at international level. In 2021, the share has decreased to around 19% probably due to an increase in methane emissions from the other transport modes (road, rail, air).



Source: Author's calculations

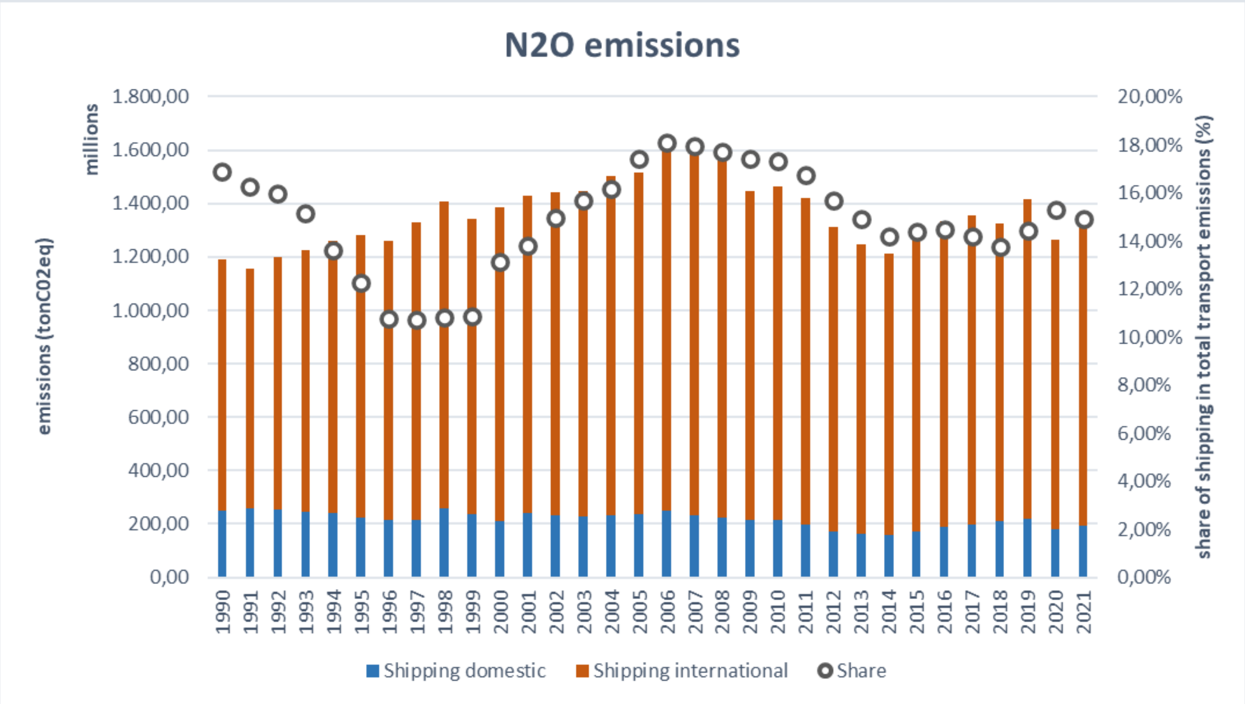
(data: EU inventories: www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer)

Figure 1.5: CH_4 emissions from shipping and share of shipping in total transport emissions.

1.1.3 N_2O

Nitrous oxide is emitted from human activities such as agriculture, land use, fuel combustion, sewage management and industrial processes. On a global scale, over 40% of total N_2O emissions come from human activities (IPCC, 2021). N_2O emissions from ships are produced during fossil fuel combustion when nitrogen in the air or fuel is oxidised in the high temperature environment of the ship's engine, and the volumes depend on the type of fuel and the combustion technology, maintenance and operating practices.

According to the inventories and as shown in figure 1.6, from 2015 onwards, emissions seem to more or less stabilize. In 2020 the impact of COVID-19 pandemic lowered also the N_2O emissions, while in 2021, shipping accounted for more than 15% of the total N_2O emissions from transport. Overall, the levels of N_2O emissions from the sector imply the need to develop stricter and more robust international regulations.



Source: Author's calculations
(data: EU inventories: www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer)

Figure 1.6: N_2O emissions from shipping and the share of shipping in total transport emissions.

1.1.4 Black carbon

Black carbon (BC) or Elementary Carbon (EC) is the second largest contributor to climate change after CO_2. Black carbon is a small light-absorbing dark particle that contributes to atmospheric warming while when sinking to the earth as precipitation, it darkens snow and ice. High concentrations of black carbon on ice and snow significantly reduce solar energy reflected back into space and accelerate melting (Hansen and Nazarenko, 2004). This is the case in the Arctic, where direct emissions of black carbon from ships contribute more to warming than elsewhere, which adds to temperature increases that are already much faster than in other parts of the world (Lack et al., 2015).

Black carbon released from ships depends on the type of fuel burned and the engine characteristics. From engines burning ultra-low-sulphur heavy fuel oils (ULSFO) can range from 65 % to 75 % of the particulate matter mass, while international maritime transport is thought to contribute to about 1-2 % of global black carbon emissions (EMTER, 2021). Black carbon emissions are currently not regulated directly at an international level, but the IMO and the Arctic Council are committed to investigate deeper various policy options. It should be noted that BC is not classified as a GHG, while the best way to calculate its GWP is still debatable.

1.2 Air pollutants

Air pollutants from ships include nitrogen oxides (NO_x), sulphur oxides (SO_x), non-methane volatile organic compounds (NMVOC), ozone depleting substances (ODSs), carbon monoxide (CO) and particulate matter (PM). Ships emit air pollutants to the atmosphere as a result of various combustion and energy transformation purposes that take place onboard.

NO_x are a collection of gases of different combinations of nitrogen and oxygen that cause lung inflammation when inhaled, interact with VOCs to create ground-level ozone (O_3) which is harmful to humans as well as to crop and vegetation productivity, cause acidification of soil and water and flood ecosystems with excess nitrogen nutrients leading to toxic algal blooms in coastal waters and decreases water oxygen levels (US EPA, 1999). NO_x emissions are regulated on an international level in Annex VI of the MARPOL Convention on pollution from ships (2006) which introduces requirements on ships with marine diesel engines of over 130 kW output power and are applied in three different tiers. Despite the fleet's adoption of Tier II and

III compatible machinery to comply with the regulation, a 1.2% rise in overall emissions was observed between 2012 and 2018 which was though at a lower rate than the total fuel consumption increase (5.6%) (Fourth IMO GHG Study, 2020).

SO_x are a collection of gases of different combinations of sulphur and oxygen that cause lung inflammation and acidification of soil and water (acid rain). SO_x emissions from ships depend on the content of the sulphur in the fuel burned in the main and auxiliary engines but also in other combustion machinery such as oil-fired boilers. Furthermore, during the combustion, PM is also released into the atmosphere. PM is a collection of solid and liquid particles formed during fuel combustion that can be inhaled from humans and absorbed into the bloodstream causing very serious health problems. Particulate matter is also a key component of smog, which refers to a noxious mixture of O_3 and PM that often appears ad a haze in the air and has various adverse effects on health and the environment.

To reduce these emissions from ships, the sulphur content of marine fuels has been regulated globally with the establishment of SECA's (SO_x Emission Control Areas). In 2020, a global sulphur limit of 0.50% m/m sulphur content was introduced (Global Sulphur Cap) forcing all ships sailing worldwide to either use a compliant fuel or continue use HSFO (high sulphur fuel oil with a content up to 3.50%) but must be equipped with an alternative emission abatement method, such as the operation of an Exhaust Gas Cleaning System (scrubber) on board. At an EU level, inside the SECA areas and while the ship is at berth (in any port, inside or outside a SECA) a limit of 0.10% sulphur content is applied (Directive (EU) 2016/802).

1.3 Policy framework to limit GHG emissions from ships

A significant work has been done to support the decarbonisation of shipping, both at international and EU level, in order to achieve its environmental sustainability. Despite the complexity caused by the international nature of the maritime industry, international organisations have been working to establish a policy environment that will be able to foster this transition. In order to develop measures and avoid setting unrealistic targets, organisations work alongside professionals, experts, industry representatives, associations, governments and non-governmental bodies. To reduce GHG emissions in the maritime transport, there was initially a need to establish and effectively implement an emissions monitoring system as a first step for emissions management.

A table with all the regulations that are in place and described in the following sections, is provided in Annex III.

1.3.1 Regulatory actions at IMO level

Recognizing the need to address maritime emissions, the IMO has been actively working on developing and implementing regulations to curb CO_2 emissions from the shipping industry. This can be achieved through the development of design-based measures (hull and superstructure optimisation, use of lower carbon fuels, optimise power and propulsion systems, etc.) and operational measures (lower speeds, voyage optimisation, etc.)

At MEPC 62 in July 2011, IMO introduced and adopted mandatory energy efficiency regulations for ships under MARPOL Annex VI, which entered into force in 2013 and represented the first set of mandatory energy efficiency measures for any transport sector. These measures can achieve reductions in fuel consumption and therefore in CO_2 emissions on a capacity basis and are the EEDI (Energy Efficiency Design Index) for new ships and the SEEMP (Ship Energy Efficiency Management Plan) for all ships.

EEDI is a technical standard that aims to encourage the use of more energy efficient equipment and engines for the design of new ships above 400 GT in order to reduce the environmental impact. EEDI establishes a minimum level of energy efficiency per capacity mile (based on an empirical regression line) depending on the ship type and size, aiming to reduce their carbon intensity. EEDI provides a specific figure for an individual ship design where the lower the EEDI the more energy efficient the ship is and is calculated by a formula based on the technical design parameters for a specific ship. In other words, EEDI sets an amount of emissions permitted when producing a unit of transport work (in gr of CO_2 / tonne mile). EEDI is implemented in three phases, the first one being achieving a reduction level of 10% compared to the reference line calculated from the average efficiency for ships (built between 2000-2010). This level is tightened until 2022 onwards when a 30-50% reduction is set for containerships, large gas carriers, general cargo ships, LNG carriers and cruise ships depending on the type. EEDI covers approximately 85% of the CO_2 emissions from international shipping as it includes the largest and most energy intensive segments of the world merchant fleet (IMO,2014)

SEEMP is an operational mechanism to improve the energy efficiency of a ship in a cost-effective manner. It also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example the Energy Efficiency Operational Indicator (EEOI) as an optional monitoring tool. EEOI is an index used to calculate the CO_2 emitted per transport work, which automatically means that EEOI is calculated on a per voyage basis (tonnes of CO_2 per tonne mile or TEU or passengers). The lower the EEOI, the more efficient the ship.

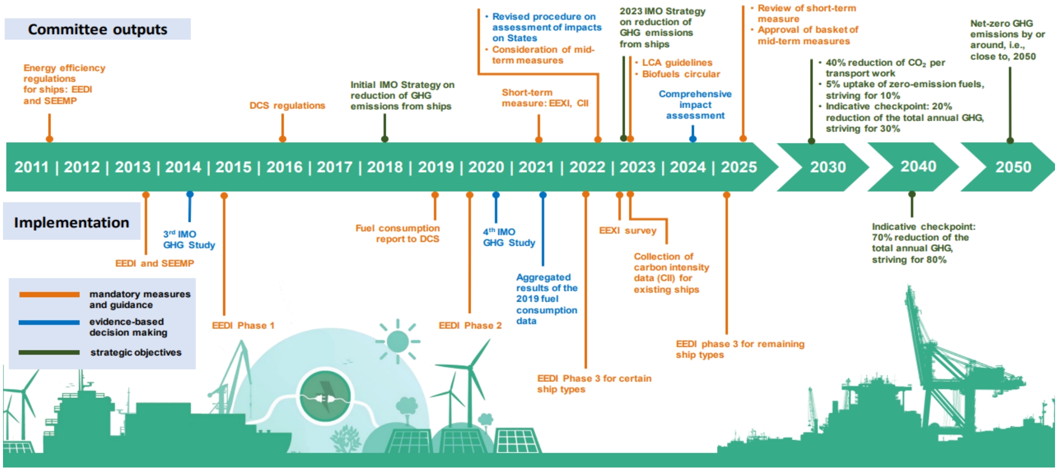
In 2016, IMO adopted the mandatory IMO Data Collection System (IMO DCS) to collect fuel oil consumption data with the first reporting year being 2019. In particular, ship owners of ships above 5.000 GT engaged in international shipping must report information on fuel consumption of their ships to the Flag States which subsequently report the aggregated data to the IMO (for more information see chapter 2.2).

In April 2018, IMO's initial strategy on reducing GHG emissions aims to cut the shipping industry's total annual CO_2 emissions by at least 40% by 2030 and achieve a 50% reduction by 2050, compared to 2008 levels (IMO, 2018 Initial IMO strategy on reduction of GHG emissions from ships). These targets reflect the industry's commitment to aligning with the goals of the Paris Agreement and mitigating the impacts of climate change. Furthermore, in July 2023, IMO took a further step by committing to new targets for GHG emissions reductions and to develop and adopt in 2025 a basket of measures, delivering on these targets (MEPC 80). Particularly, IMO agreed on a revision of its GHG Strategy to set a goal of net zero emissions from ships 'by or around, i.e., close to, 2050', considerably increasing the level of ambition. A trajectory has also been agreed with indicative checkpoints set at lowering GHG emissions from ships by at least 20% - striving for 30% - by 2030 and at least 70% - striving for 80% - by 2040, in comparison to 2008 levels. The strategy also sets an important target of at least 5% - striving for 10% - uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources by 2030. These levels of ambition and indicative milestones consider the lifecycle GHG emissions from marine fuels with the objective of reducing emissions within the boundaries of the energy system of international shipping. The IMO decided that additional GHG reduction measures shall be agreed-upon by 2025 to reach the targets. These measures should comprise a standard regulating the gradual reduction of the marine fuels' GHG intensity, and a maritime GHG emissions pricing mechanism. They will be developed on the basis of a comprehensive impact assessment ensuring that they effectively reduce emissions from the sector, while contributing to a level playing field and a fair and equitable transition that leaves no one behind.

In June 2021, IMO adopted short-term technical and operational measures aiming to reduce the carbon intensity of all ships by at least 40% by 2030, compared to 2008. These measures combine technical and operational approaches to improve fleet's energy efficiency.

Within the EEXI framework, existing vessels above 400 GT are required to calculate their attained Energy Efficiency Existing Ship Index (EEXI) which sets levels equivalent to EEDI levers and therefore creating a level-playing field among the fleet. Achieving the required EEXI implies that several technical means to improve the carbon intensity of the existing ships must be implemented like for example engine/shaft power limitation, waste heat recovery systems, wind assisted propulsion, etc. IMO defined a simplified version of the EEDI in order to cover also ships that were built before 2013 (which are not covered by the EEDI), the Estimated Index Value (EIV). To provide a better understanding of the EIV, according to a study conducted by Delft in 2015 which tried to analyse the EIV's of ships entered the fleet since 2009, after linking the ships in Clerksons Register and the IMO database the authors concluded that on average the EEDI value is smaller than the EIV and therefore came to a conclusion that EIV is an overestimation of the EEDI.

Furthermore, the Carbon Intensity Indicator (CII) determines the annual reduction factor needed to ensure continuous improvement of the ship's operational carbon intensity within a specific rating level. It is mandatory for ships above 5.000 GT to collect and report fuel consumption data in which basis the rating is assigned from A to E. A ship rated poorly for three consecutive years has have to submit a corrective action plan, to show how the required index would be achieved. The performance level is be recorded in the ship's SEEMP while there are several operational means to improve the carbon intensity like for example speed optimization, weather routing, Just-in-time arrival, retrofitting vessels with more efficient engines, use of alternative fuels, etc.



Source: www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

Figure 1.7: IMO's regulatory action to curb GHG emissions from shipping.

1.3.2 Regulatory actions at EU level

At an EU level, the European Green Deal, a set of policy measures that aims to make Europe the first climate neutral continent by 2050 by reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels. The EU contributed less than 8% of global GHG emissions in 2018, when compared with 15% in 1990 (EEA, 2020). However, emissions from transport have not fallen enough.

Several actions have been taken to make sure maritime transport plays its role in achieving climate neutrality in Europe by 2050. Under the ''fit-for-55'' package of measures published on 14 July 2021, a variety of proposals to tackle maritime transport's contribution to climate change have been made, focusing on limiting CO_2 emissions from ships. These measures aim to allow the creation of an environment to facilitate the uptake of cleaner fuels by supporting the demand, distribution and supply. This 'basket of measures' includes the revision of the EU Emissions Trading System (EU ETS) and its extension to the maritime sector, a new FuelEU Maritime Regulation, the Alternative Fuel Infrastructure Directive (AFID) revision into a new Regulation, the Renewable Energy Directive (RED) revision and, finally the revision of the Energy Taxation Directive (ETD) that sets taxation scheme of marine fuels. In addition, Horizon Europe and the Innovation Fund will continue supporting research and innovation towards the decarbonisation of the sector.

As of January 1st, 2024, the EU ETS has been extended to maritime transport emissions covering CO_2 emissions from all large ships (above 5.000 GT) that enter EU ports regardless of their flag. In addition, it is expected that EU ETS will also cover methane and nitrous oxide emissions as of 2026. All net emissions from maritime transport are included in the overall ETS cap, which defines a maximum amount of GHG that can be emitted. Practically, shipping companies are to purchase and use emission allowances for each tonne of CO_2 reported, following a timeline that becomes stricter over the years (2025 surrender allowances for 40% of their emissions. 2026 for 70% and finally for 2027 and onwards 100% of their reported emissions). As a result, the EU is aiming to push for increased energy efficiency and use of low-carbon solutions as well as support the reduction of the significant price gaps between traditional and alternative fuels by creating and shaping a carbon pricing system in which the market itself sets the price on CO_2 emissions.

It should be noted that EU Maritime ETS is the first Emissions Trading System to be implemented to the maritime sector, while globally at this moment there are thirty systems in force for other industries such as aviation, waste, road transport, industry, etc. Establishing higher costs for CO_2 emissions would have an impact on fuel and transport costs, as well as capital costs for shipowners to be able to comply with the regulations while stay competitive (for example installation of abatement technologies). The increased costs are highly likely to cause a shift to other modes of transport like rail or road (Wang et al., 2021).

Furthermore, as of 2025, the FuelEU maritime Regulation aims to raise the demand for marine renewable and low-carbon fuels by establishing a maximum limit on the GHG content of energy used by ships. The limit will become more and more ambitious over time reaching 80% by 2050. Additionally, the regulation encourages the adoption of zero-emission technology while the ships are at berth. which translates into the use of onshore power supply (OPS) or other alternative zero-emission technologies in ports for containerships and passenger ships. This goal is to be supported also by the revision of the Directive on Deployment of Alternative Fuels Infrastructure (AFID) which will establish mandatory targets for shore-side electricity supply at ports. To be able to increase the share of renewable and low-carbon fuels in the future maritime fuel mix, the EU, with the revision of the RED Directive, aims to increase the target of renewable energy sources in the overall energy mix to a minimum of 40% by 2030. Finally, a revision of the ETD would introduce a tax on marine fuel and energy products per GJ which would be based on the type of fuel used. In other words, ETD sets a minimum required tax on the use of energy.

Moreover, European companies, are also encountering a growing pressure to reduce transport emissions because of the new EU policy on Corporate Sustainability Reporting (CSRD), which makes it obligatory for them to report their Environmental, Social and corporate Governance (ESG) data. This is expected have a large impact also on the maritime sector, as it would create a demand for greener solutions.

To limit CO_2 emissions, the initial and most important step for the EU was to find a way to measure them and thus building a comprehensive picture of a starting point. On this regard, in 2015, EU developed the MRV (Monitoring, Reporting and Verification) Regulation (EU 2015/757), which concerns the monitoring, verification and reporting of CO_2 emissions from maritime transport. EU MRV became mandatory in 2017, and its goal was to track fuel consumption of the fleet sailing in EU waters and CO_2 emissions from EU shipping activities. In particular, it is applicable to commercial vessels of more than 5.000 GT calling at EU ports. A thorough presentation of the regulation is included in chapter 2, as well as the differences between EU MRV and IMO DCS regulations.

At this point, there is no regulation directly covering CH_4 and N_2O emissions from shipping and therefore there is no monitoring tool to measure these emissions. The calculations and projections are usually based on modelled data (i.e., STEAM) and inventories while more solid data are expected to become available once new regulatory framework comes into force. From January 2024 the scope of the MRV expands to include methane and nitrous oxide emissions which are also important contributors to GHG emissions from shipping. In addition, from January 2025, general cargo ships between 400 and 5.000 GT, and offshore ships of 400 GT and above will fall under the scope of the amended MRV Regulation (EU 2023/957), which will cover an even larger number of ships and emissions in EU waters. Therefore, a clearer insight on the emissions from ships will become available after the first reporting years (from 2025 onwards) while trends will also be developed in the coming years.

1.3.3 Meeting the targets

To achieve the international goals and comply with the policies aiming to reduce emissions, several strategies and solutions are currently being used by the industry. Reducing emissions means mainly reducing the fuel consumption or in other words increasing the ship's efficiency. Taking into account that fuel costs usually represent around 50% of the ship's operational costs, limiting the consumption has always been an area of special attention for all ship operators and owners. Through technical and design-based improvements shipping has achieved noteworthy reduction in fuel consumption, resulting in lower CO_2 emissions on a capacity basis (tonne-mile) (Miler, Szczepaniak, 2014). In addition, the effective implementation of the SEEMP and the proper use of all the available measures and tools, should benefit the shipping sector directly by cost improvements and indirectly by reduction of GHG emissions (Miler, Szczepaniak, 2014). Ways for ships to limit their fuel consumption and thus their GHG emissions include design, operational as well as management solutions:

- **Slow steaming**. Operating at lower speeds reduces the fuel consumption and therefore not only the CO_2 emissions but also the operational costs. Slowing down ships by a few knots can result in substantial fuel savings however, this method is not applicable for all types of cargo and markets since it increases the time of the voyage having an impact on delivery times and scheduling. Therefore, a more compatible term used is 'speed optimization'.
- **Route optimization / voyage planning.** Optimizing route planning and utilizing advanced weather routing systems can help ships avoid unfavourable weather conditions and take advantage of favourable currents, reducing fuel consumption and emissions. This requires accurate weather forecasting since the dependence of the ship on weather conditions affects scheduling.
- **Improving hull design and retrofitting**. Enhancing the hull form and reducing the water resistance can improve fuel efficiency (optimising bulbous bows, hull coatings, and hull appendages) keeping always in mind the port and canal restrictions. Furthermore, existing ships can undergo retrofits and upgrades to improve energy efficiency like for example installing more efficient propeller, optimizing air conditioning and ventilation systems or upgrading auxiliary equipment. The installing of an energy efficient engine can lead to lower fuel consumption and therefore compliance with the regulations. Although, the huge investment costs for retrofitting or replacing these systems make this a not very appealing choice for the shipowners.
- **Waste heat recovery**. Recovering waste heat from the ship's engines and utilizing it for power generation or other onboard processes can improve overall energy efficiency and reduce emissions.
- **Use of wind assisted or wind powered propulsion**. Employing wind assisted technologies (wind sails or rotors) can harness wind power to complement the ship's

main propulsion system and thus reduce the fuel consumption and lower the emissions. Of course, this would mean dependence on the wind conditions and would require investments on equipment. Furthermore, solar power (solar photovoltaic cells) could be used to cover onboard energy needs. Solutions like these can contribute to a reduction in carbon intensity of the fleet.

- **Energy storage** using batteries and cold ironing. Shore side electrical power to the ship at berth while the main and auxiliary engines are off can lead to significant fuel savings.
- **Using lower or zero carbon fuels**. The use of alternative fuels would limit to the minimum or completely eliminate CO_2 emissions. Fuels like LNG, biofuels, hydrogen or ammonia are currently being explored as near-future solutions for the maritime sector. Considerations may arise on the fact that bunkering infrastructure is not currently available at a wide scale as well as the fact that the costs between conventional and non-conventional fuels are widely different. Furthermore, there is the problem of compatibility on a technical level with the engines currently on the market. While biofuels could be used by existing engines, requiring minimum modifications, other fuels like ammonia or hydrogen would require new engines to be installed. Another concern from the shipowners is the absence of a regulatory framework which would ensure the availability of such fuels, a market-based mechanism to ensure affordable prices as well as safety related concerns.
- **Improved maintenance and operations.** Regular maintenance and optimal operational practices (proper hull cleaning, propeller polishing, optimizing trim and ballast) can contribute to fuel efficiency while extend the lifespan of the engine and the equipment.
- **Fleet management and logistics operations.** By implementing Just-in-time operation, GHG emissions and air pollutants are reduced through the optimization of the sailing speed which equals to fuel consumption reduction due to engine efficiency and through the reduction of ship's manoeuvring or waiting at anchorage. Furthermore, reducing the time spent at anchorage can result in less congestion and port traffic as well as other risks of safety and security, like accidents, collisions, attacks or piracy).
- **Carbon capture and storage (CCS).** CCS is a technology currently being examined as an alternative or current solution, in the absence of mature applications for clean fuels as well as the uncertainty over whether the demand could be met. Proposals related to onboard carbon capture were discussed during the IMO MEPC 79 and 80. It refers to

the capture of carbon from the direct emissions from the ship, it's separation and then storage or transport. The uniqueness of CCS for the shipping industry results from the fact that there is limited space to utilize on board the ship. Furthermore, the design and placing of the CO_2 storage tank on board the vessel must be taken into consideration as well as the ship characteristics (power limitations, operational patterns, etc.). In addition, ship's nature of constantly sailing offshore, may result in system stability issues.

CHAPTER 2

MEASURING CO_2 EMISSIONS WITH EU MRV AND IMO DCS

To limit CO_2 emissions from shipping by developing policies at both EU and global level, the initial need was to implement a CO_2 emission monitoring system which would work as a first step for CO_2 emission management. In other words, to be able to limit the emissions we first need to be able to measure them.

2.1 EU strategy - MRV Regulation

In 2015, Regulation (EU) 2015/757 on the monitoring, reporting and verification of CO_2 emissions from ships (hereafter referred to as the MRV Regulation) was adopted and entered into force in January 2018. This legislation was the first approach for the inclusion of maritime transport emissions in the EU's greenhouse gas reduction commitments and the foundation for policy measures in the context of the European Green Deal. The main objectives of this piece of regulation are to collect accurate and verified data on the CO_2 emissions, to provide transparency by publishing these data and to support policy discussions as well as stimulate the uptake of energy efficiency investments in the sector.

To begin with, the shipowner's obligation to continuously monitor each ship's CO_2 emissions, fuel consumption, cargo transported, distance travelled, and other operational and technical energy efficiency at a per voyage level is introduced, based on the previously approved/verified monitoring plan, followed by the submission of an annual report for each of their ships (Emissions report). Subsequently, the companies submit the aggregated annual data to the EC (European Commission) and to the Flag State authorities, after an accredited verifier has approved and verified the report. The EC publishes the data on the THETIS-MRV website, which are freely accessible through tables showing the emissions per ship for that reporting period. The following figure shows a diagrammatic representation of the EU MRV.

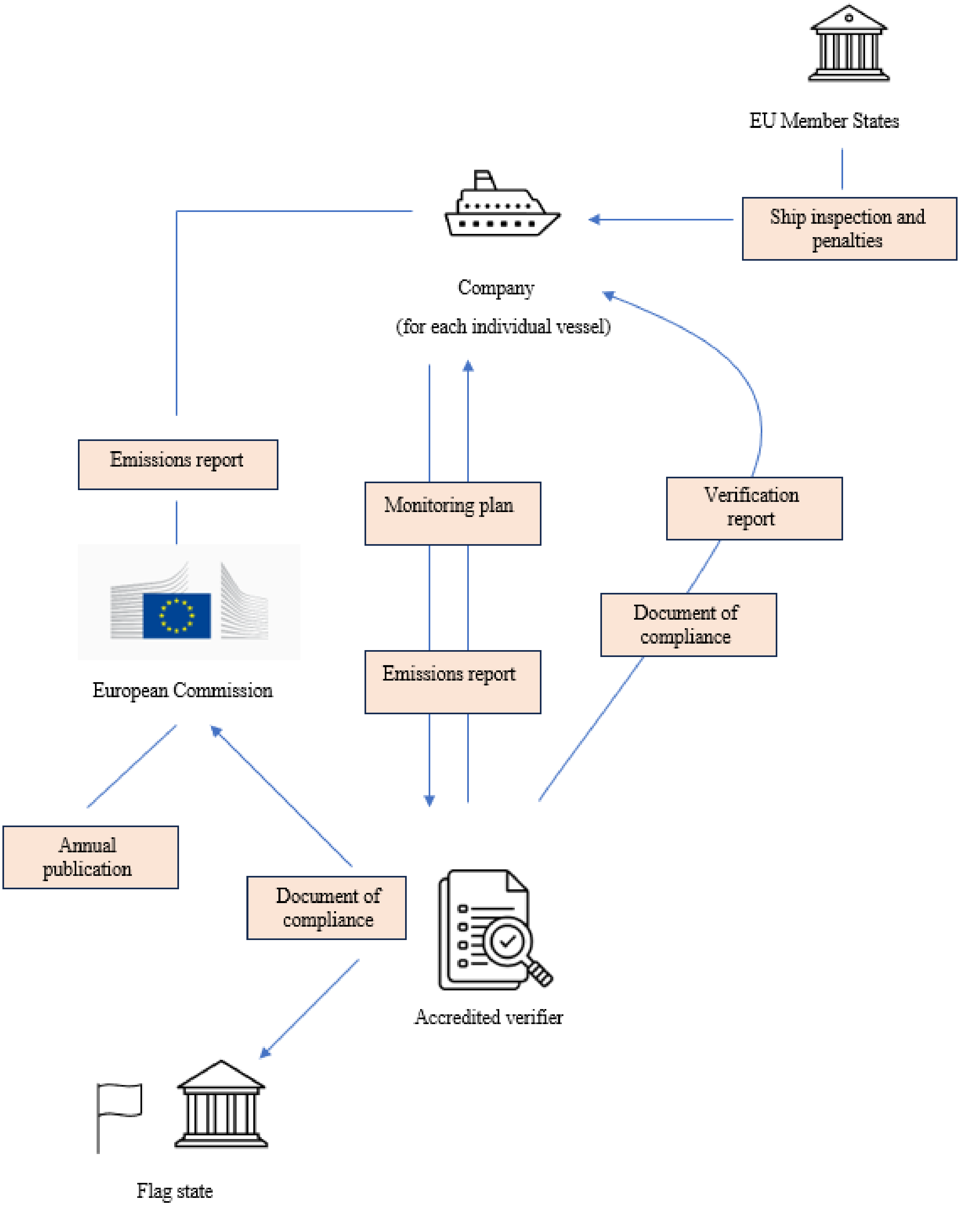


Figure 2.3: Diagrammatic representation of EU MRV

2.1.1 Scope

The MRV regulation applies to all ships above 5.000 gross tonnage (GT) loading or unloading cargo or passengers at ports in the EEA (European Economic Area)[5] regardless of their flag. The regulation covers ships that carry out voyages from, to or within two ports in the EEA when transporting goods or passengers for commercial purposes. In particular:

- Intra or domestic voyages (voyages between two EEA ports)
- Extra or international voyages (voyages to or from an EEA port). It should be noted that only the last leg of the voyage is covered, for example, if a ship departs from Singapore to Antwerp the emissions accounted for the whole voyage must be reported. However, if this ship calls into another port that is not in the EEA, the emissions to be reported will only be from that port to Antwerp. Therefore, the emissions to be reported are those released during the voyage from the last port of call to a port under the jurisdiction of an EEA country and from that port to the next port of call.
- At berth (emissions occurring when the ship is moored or anchored whilst loading, unloading or hoteling).

Despite limiting the monitoring requirements to large ships and thus including around 55% of all ships calling into EEA ports, the Regulation covers around 90% of all CO_2 emissions (EU 2015/757). For proportionality and subsidiarity reasons, military vessels, naval auxiliaries, fish-catching or fish-processing ships, wooden ships, ships not propelled by mechanical means, or government ships used for non-commercial purposes are excluded.

2.1.2 Monitoring procedure

Shipping companies must for all their ships, monitor and report the CO_2 emissions from the combustion of fuels making sure to prevent any data gaps and inconsistencies and to make sure that the data is neither systemically nor knowingly inaccurate. Therefore, they shall use the

[5] The European Economic Area (EEA) consists of the Member States of the European Union (EU) and three countries of the European Free Trade Association (EFTA) (Iceland, Liechtenstein and Norway; excluding Switzerland) and came into force on 1 January 1994. It seeks to strengthen trade and economic relations between the contracting parties and is principally concerned with the four fundamental pillars of the internal market, namely: the free movement of goods, people, services and capital (Glossary:European Economic Area (EEA) - Statistics Explained (europa.eu))

same monitoring methodologies over time assessed by the verifying companies. The whole process of the monitoring must be thoroughly described in the monitoring plan.

2.1.2.1 Monitoring plan

The company must submit the monitoring plan to the verifier without undue delay and no later than two months after each ship's first call in a port under the Regulation. This plan considers the ship's design, it's technical performance and its emission sources. The monitoring plan includes the following:

(a) the identification and type of the ship, including its name, its IMO identification number, its port of registry or home port, and the name of the shipowner

(b) the name of the company and the address, telephone and e-mail details of a contact person

(c) a description of the following CO_2 emission sources on board the ship: main engines, auxiliary engines, gas turbines, boilers and inert gas generators, and the fuel types used. For each one of the emissions sources, technical characteristics must be included (type, performance, installation date and other features). This information is necessary for more accurate and reliable control of the emissions. In addition, it is necessary to provide a summary of the types of fuel the ship uses or can potentially use (HFO, LFO, LPG, LNG, MDO, MGO, other fuel types i.e., biofuels, hydrogen, etc)

(d) a description of the procedures, systems and responsibilities used to update the list of CO2 emission sources over the reporting period. Particularly, the company must report who is responsible for the procedures, the exact place where all the information is kept, etc.

(e) a description of the procedures used to monitor the completeness of the list of voyages, meaning the description of the procedure followed to maintain an up-to-date list of voyages which are included or excluded from the regulation.

(f) a description of the procedures for monitoring the fuel consumption of the ship, including:

(i) the method chosen for calculating the fuel consumption of each CO_2 emission source, including, where applicable, a description of the measuring equipment used,

(ii) the procedures for the measurement of fuel uplifts and fuel in tanks, a description of the measuring equipment used and the procedures for recording, retrieving, transmitting and storing information regarding measurements, as applicable,

(iii) the method chosen for the determination of density (convert volumes to mass by using measurement systems onboard, as per BDN measured by the supplier or from a test analysis made by an accredited laboratory)

(iv) a procedure to ensure that the total uncertainty of fuel measurements is consistent with the requirements of this Regulation, where possible referring to national laws, clauses in customer contracts or fuel supplier accuracy standards

(g) single emission factors used for each fuel type, or in the case of alternative fuels, the methodologies for determining the emission factors, including the methodology for sampling, methods of analysis and a description of the laboratories used, with the ISO 17025 accreditation of those laboratories, if any.

(h) a description of the procedures used for determining activity data per voyage, including:

(i) the procedures, responsibilities and data sources for determining and recording the distance

(ii) the procedures, responsibilities, formulas and data sources for determining and recording the cargo carried (may be in different units depending on the type of cargo and the type of ship) and the number of passengers

(iii) the procedures, responsibilities, formulas and data sources for determining and recording the time spent at sea between the port of departure and the port of arrival, including time travelled through ice when applicable

(i) a description of the method to be used to determine surrogate data for closing data gaps. In particular, since the risk of data gaps should be minimized, the company can use surrogate data to determine emissions where missing, calculated by using an alternative method which has to be described.

(j) a revision record sheet to record all the details of the revision history (for example, change of ownership, addition of new emission sources, etc.)

(k) the monitoring plan may also contain information on the ice class of the ship and/or the procedures, responsibilities, formulas and data sources for determining and recording the distance travelled and the time spent at sea when navigating through ice.

Companies shall use standardised monitoring plans based on templates. Those templates, including the technical rules for their uniform application, shall be determined by the Commission by means of implementing acts.

Based on their monitoring plan, companies are monitoring the CO_2 emissions for each of their individual ships on a per-voyage and an annual basis by applying the chosen method for determining the volumes of emissions as set out in the Regulation and their monitoring plan. Therefore, for each ship arriving to or departing from and for each individual voyage to or from an EEA port, companies shall monitor and report the following:

- Monitoring on a per-voyage basis

Companies monitor parameters like the port of departure and port of arrival including the timestamp, the amount and emission factor for each type of fuel consumed in total, the volumes of CO_2 emitted, the distance travelled, the time spent at sea, the cargo carried and the transport work. It should be noted that a company is exempted from the obligation to monitor this information on a per-voyage basis for a specific ship, if all of the ship's voyages start from or end to a port under the Regulation and the ship, according to its schedule, performs more than 300 voyages during the reporting period.

- Monitoring on an annual basis

For each calendar year, companies monitor the amount and emission factor for each type of fuel consumed in total, the total aggregated CO_2 emitted as well as the aggregated emissions from all voyages to, from or between the ports that fall under the Regulation and those emitted while at berth, the total distance travelled, the total time spent at sea, the total transport work and the average energy efficiency. According to the regulation, the average energy efficiency must be monitored by using at least four indicators: fuel consumption per distance (total annual fuel consumption/total distance travelled), fuel consumption per transport work (total annual fuel consumption/total transport work), CO_2 emissions per distance (total annual CO_2 emissions/total distance travelled) and CO_2 emissions per transport work (total annual CO_2 emissions/total transport work).

2.1.2.2 Methods for monitoring CO_2 emissions

For the purposes of calculating CO_2 emissions, the following formula shall be applied:

$$CO2\ emissions = \ fuel\ consumption * emission\ factor$$

Fuel consumption includes the fuel consumed by main engines, auxiliary engines, gas turbines, boilers and inert gas generators. Emission factors (as set out in the latest values of the IPCC) are used, unless the company uses data on fuel quality set out in the Bunker Delivery Note (BDN). The fuel emission factors define the tonnes of CO_2 emitted per tonne of fuel burned on-board for combustion purposes and thus are tank-to-wake emissions (TtW). Furthermore, different fuels have different emissions factors and appropriate emission factors should be applied for biofuels and other alternative non-fossil fuels.

Table 2.1: Emission factors for marine fuels (Resolution MEPC.245(66), IMO, 2014)

Fuel type	Reference	Lower calorific value (kJ/kg)	Carbon Content	Emission factor (t-C0$_2$/t-fuel)
Diesel/Gas oil	ISO 8217 Grades DMX through DMB	42.700	0,8744	3,206
Light fuel oil (LFO)	ISO 8217 Grades RMA through RMD	41.200	0,8594	3,151
Heavy fuel oil (HFO)	ISO 8217 Grades RME through RMK	40.200	0,8493	3,114
Liquified petroleum gas (LPG)	Propane	46.300	0,8182	3,000
	Butane	45.700	0,8264	3,030
Liquified natural gas (LNG)		48.000	0,75	2.750
Methanol		19.900	0,375	1,375
Ethanol		26.800	0,5217	1,913

According to the regulation, there are four methods that can be used to accurately monitor CO_2 emissions and are selected by the company that has full responsibility for ensuring its implementation. Methods A, B and C are based on fuel consumption, while method D is based on direct measurement of emissions. The actual consumption is recorder as calculated using one or a combination of the methods below. Any combination of these methods can be used following an assessment conducted by the verifier if it supports the overall accuracy of the measurement.

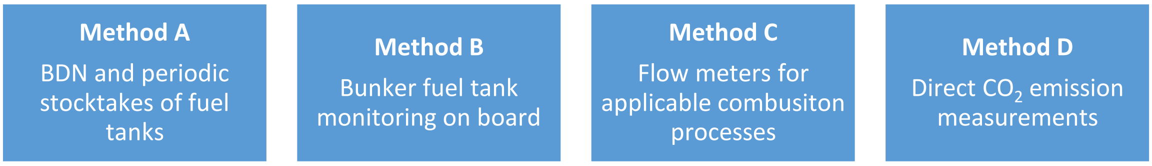


Figure 2.2: Available methods to monitor a ship's fuel consumption.

A. Bunker Fuel Delivery Note (BDN) and periodic stocktakes of fuel tanks

A BDN is a document prepared by the fuel supplier and signed by the master of the vessel after the completion of the delivery of marine bunker fuel. It serves as a record of how much bunker is delivered and contains information about the fuel like the type, the quantity, the density and the sulphur content. Under MARPOL Annex VI regulations, the BDN is mandatory to be kept on board for three years after the delivery of the bunker fuel and to be available for inspection purposes.

The measurement is made by using the quantity and type of fuel (as defined on the BDN) in combination with periodic stocktakes of fuel tanks that are based on tank readings. In particular, the fuel consumed over a period (meaning the time between two port calls or within a port) is: the fuel at the beginning of the period, plus deliveries, minus fuel available at the end of the period and de-bunkered fuel between the beginning of the period and the end of the period.

$$\begin{aligned} &Fuel\ consumption\ (over\ a\ period) = \\ &\qquad fuel\ at\ the\ beggining\ of\ the\ period + bunkered\ fuel\ (as\ per\ BDN) \\ &\qquad - fuel\ at\ the\ end\ of\ the\ period + debunkered\ fuel \end{aligned}$$

This method can be used only when BDN are available on board the ships (for verification purposes) and, as per the regulation, this method should not be used when cargo is used as a fuel like for example if LNG boil-off is used.

The accuracy of the data from the Bunker Delivery Notes varies, since it depends on the way the quantity of fuel was determined. BDNs have an accuracy level of 1-5% (Bunkerspot, 2009), suggested by ship crew members to often report on more fuel being delivered than stated in the BDN. The periodic stocktake of fuel tanks on board is based on fuel tank readings which must be carried out by methods like automated systems, soundings and dip tapes. Any manual readings can affect the accuracy of the measurement when the ship is not in calm weather conditions. Any uncertainty that is associated with any of these measurements must be stated in the monitoring plan. It is important to highlight the fact that volume changes depending on the temperature and therefore, the figures must be corrected taking into account the temperature at the time of the measurement.

In addition, the amount of fuel must be converted from volume to mass when applicable. For that, actual density values must be used, determined by measurement systems on-board or as stated on the fuel invoice or BDN delivered by the fuel supplier, whereas in the cases that this is not available, a standard density factor for the relevant fuel type can be used following an assessment by the verifier.

B. <u>Bunker fuel tank monitoring on board</u>

The calculation of the fuel consumption is based on fuel tank readings for all the fuel tanks on-board, which must occur daily when the ship is at sea and each time the ship is bunkering or de-bunkering. The actual fuel consumed over a period is equal to the difference between two readings. The readings must be carried out by appropriate methods like automated systems, soundings and dip tapes and the procedure and uncertainties related to these measurements must be presented in the monitoring plan.

As before, the amount of fuel must be converted from volume to mass when applicable. For that, actual density values must be used, determined by on-board measurement systems or as stated on the fuel invoice or BDN delivered by the fuel supplier or as measured in a test analysis conducted in an accredited fuel test laboratory.

C. <u>Flow meters for applicable combustion processes</u>

For this measurement method, data from all fuel flow meters that are linked to relevant CO_2 emission sources that fall under the Regulation are combined and determine the total fuel consumption. The flow meters allow to determine the amount of fuel that is flowing through the pipes to the engines and boilers. The calibration methods applied, and the uncertainty associated with the flow meters must be specified in the monitoring plan. For different types of flow meters there are different levels of accuracy. To avoid any type of inaccuracies, the equipment must be regularly calibrated.

To convert in units of mass, density can be determined using on-board-measurement systems or as measured by the fuel supplier at fuel uplift on the BDN or invoice.

D. Direct CO_2 emissions measurements

Fuel consumption is being calculated using measured CO_2 emissions and the applicable emission factor of the relevant fuels. Basically, this method is based on the determination of CO_2 emission flows in exhaust gas stacks (funnels) by multiplying the CO_2 concentration of the exhaust gas with the exhaust gas flow. This method allows also for the monitoring of other emissions like SO_2 or NO_x. Convenience is another advantage, as it does not require much involvement of the crew members. The calibration methods and the uncertainty associated with the devices that are used for the measurements must be presented in the monitoring plan. According to the Centre for Tankship Excellence (2011), CO_2 stack emissions can be monitored to an accuracy of +/-2%.

2.1.3 Contents of the emissions report

The emissions report must be submitted by the 30th of April of each reporting year and includes:

(a) data identifying the ship and the company, including the name of the ship, the IMO identification number, the port of registry or home port, the ice class of the ship, if included in the monitoring plan, the technical efficiency of the ship (the Energy Efficiency Design Index (EEDI) or the Estimated Index Value (EIV) in accordance with IMO Resolution MEPC.215 (63), where applicable), the name of the shipowner, the address, the name and address of the company and the place of business, as well as contact details.

(b) the identity of the verifier that assessed the emissions report.

(c) information on the monitoring method used and the related level of uncertainty.

(d) the results from annual monitoring of the parameters.

The emissions report is submitted via the THETIS-MRV portal by the shipping company. The above data become publicly available and are being included in the annual report of the European Commission.

2.1.4 Verification procedures and activities

Accredited verifiers are to ensure that both, the monitoring plans and the emission reports are accurate and in compliance with the Regulation. Following their assessment, the verifiers issue a verification report. The verifier should check that all the mandatory information is included, that a thorough description of the emissions sources is included and that all the measurement equipment, systems and procedures are described. In addition, the verifier should review all the data and data sources and methodologies used and assess the risk control methods applied by the company to reduce uncertainty associated with the accuracy. Any misstatements or non-conformities identified by the verifier are to be corrected by the company in a timely manner. Furthermore, the verifier should make sure that all the applicable guidelines are met, compliance to the regulations is achieved as well as to provide guidance and consultation to the companies in order to develop an accurate data management system. Finally, the verifier may conduct spot-checks to determine the reliability of the reported data.

The MRV Regulation states that verifiers should be independent and competent legal entities and should be accredited by national accreditation bodies in order to ensure impartiality. The verifier should be independent from the company or the operator of the ship and therefore, neither the verifier nor any part of the same legal entity shall be a company or ship operator, the owner of a company, or be owned by them, nor shall the verifier have relations with the company that could affect its independence and impartiality.

2.1.5 The role of the Member State's Administration

Under the MRV, the EU Member State's obligation consists of the following activities:

- Establish a system of penalties to be imposed in the case of non-compliances found during the ship's inspection. According to the regulation those penalties are to be *'effective, proportionate and dissuasive'*.
- In case of non-compliance and the imposition of a penalty, the Member State must notify the Commission, EMSA, the other Member States and the flag State.
- The Member State has the right to issue an expulsion order for the ship which implies that the ship cannot enter any of its ports until the company has fulfilled its obligations.

2.1.6 Costs resulting from the implementation of the regulation for the shipping companies

For the shipping companies, being in compliance with the MRV regulation involves several costs which vary and depend on the size of the company, the number of the vessels they operate, the types of vessels, the vessels' technical characteristics, the existing infrastructure and technologies on board, etc. Although it is complex to estimate these costs without access to the vessels and company's data, the following, are some of the most important costs associated with aligning with the regulation's requirements.

a. Systems for data collection and monitoring. There is a need to invest in systems and other equipment in order to collect and monitor the factors related to the fuel consumption, the distance travelled and other information that is required to calculate CO_2 emissions. This involves not only the initial installation costs but also the periodic maintenance, calibration and proper documentation of such equipment, in order to ensure the reliability and accuracy of the data. According to the regulation, there are four acceptable methods for determining CO_2 emissions: using the BDNs and stocktakes of the fuel tanks, by monitoring the bunker fuel tank on board, by using flow meters or by directly measure the emissions. Depending on the method chosen, installation of flow meters, sensors and other monitoring equipment may be needed.

However, there is a standard update that a ship makes to the company on a daily basis, the noon report. The noon report includes information on the ship's position, speed, distance travelled, fuel consumption, weather conditions, cargo information, etc. Keeping into account that this information is already being reported, the data collection for the implementation of the MRV is not a significant burden.

b. Personnel training costs. Crew members onboard the vessel as well as employees ashore must be properly trained to understand the regulation and its requirements, to operate the equipment properly to avoid any type of tampering of the measurements, to have an in-depth knowledge of the vessel's operating profile and to be able to minimise the risk of inaccuracy when collecting and processing the information received. This type of training is usually carried out by external training academies or internal by the Chief Engineers or other experts.

c. New software. Companies may need to invest in data logging systems that are crucial since the collected data must be logged and stored for reporting and verification purposes, as well as specialized data processing software to manage analyse the collected information. Depending on the reporting system the company uses, the cost could vary between 1.000-4.000

euros per year. This software may offer more than the storing and processing of the data and the production of the reports, like making calculations for the performance of the vessel. Bigger companies tend to have their own software developed but smaller ones tend to perform manual entry of the data that usually takes a lot of time. Moreover, some systems have the ability to identify mistakes in the reported data through various checks and validations, which certainly saves a lot of the administrative burden at the end of the reporting year, but they are usually more expensive.

d. Administrative and legal costs. These are costs including administrative expenses, such as communication with the Authorities or managing the documentation, and legal counselling expenses to ensure compliance and continuous following any changes in the regulatory framework.

e. Penalties. In case of non-compliance with the regulation, penalties may be applied. According to the regulation, Member States should lay down rules on those penalties which should be communicated to the national authorities that are responsible for ensuring compliance and imposing these fines.

f. Third-party verifier costs. A third-party verifier must be hired by the company to verify the Monitoring Plan and the Emissions Report. Of course, these costs vary since they are based on the size, the vessel's characteristics, the size of the company's fleet, the services that the verifying company will provide, its expertise and name in the industry, etc. This would include the third-party company's fees for providing their services which can be on a per vessel charge or per the level of complexity. Furthermore, extra costs may come from the fact that a company may not have organized and complete data, which would require additional effort from the verifier. In addition, incomplete or not accurate information identified during the verification process, would require revision and correction which would result in additional costs. Some verification companies provide a wide range of other services like for example consultation, guidance or technical support and training to optimise the collection of the information and increase the level of accuracy.

Usually, verifying companies make offers for service packages per vessel and include the monitoring plan as well as the emission report verification (annually). The prices start from around 350$ and can reach more than 650$ on a per vessel basis.

2.2 IMO strategy - DCS

In 2016, MEPC 70 (MEPC.278(70)), with amendment to MARPOL Annex VI, the IMO DCS system was adopted, consisting of requirements for ships to record and report their fuel oil consumption. Starting from January 2019, ships over 5.000 GT are required to collect consumption data for each fuel type used on board. According to IMO, the ships falling under the scope of IMO DCS produce approximately 85% of the total CO_2 emissions from international shipping which provides accurate and reliable information to the IMO in order to develop further measures to reduce GHG emissions. In addition, the Ship Energy Efficiency Management Plan (SEEMP) includes a description of the methodology and processes used to collect the data. In particular, there are three methods to monitor the fuel consumption under IMO DCS, using the BDNs, using flow meters to measure the fuel oil flows and by monitoring bunker fuel tanks on board.

The fuel oil consumption data is filed on the ships flag and following verification that the data have been reported according to the requirements of Annex VI, a Statement of Compliance is issued to the ship. The aggregated data can be submitted by the Member State Administration, or an organisation authorized by the Administration, to a dedicated module on the Global Integrated Shipping Information System (GISIS) platform. Subsequently, the IMO Secretariat produces an anonymised publicly available annual report to MEPC.

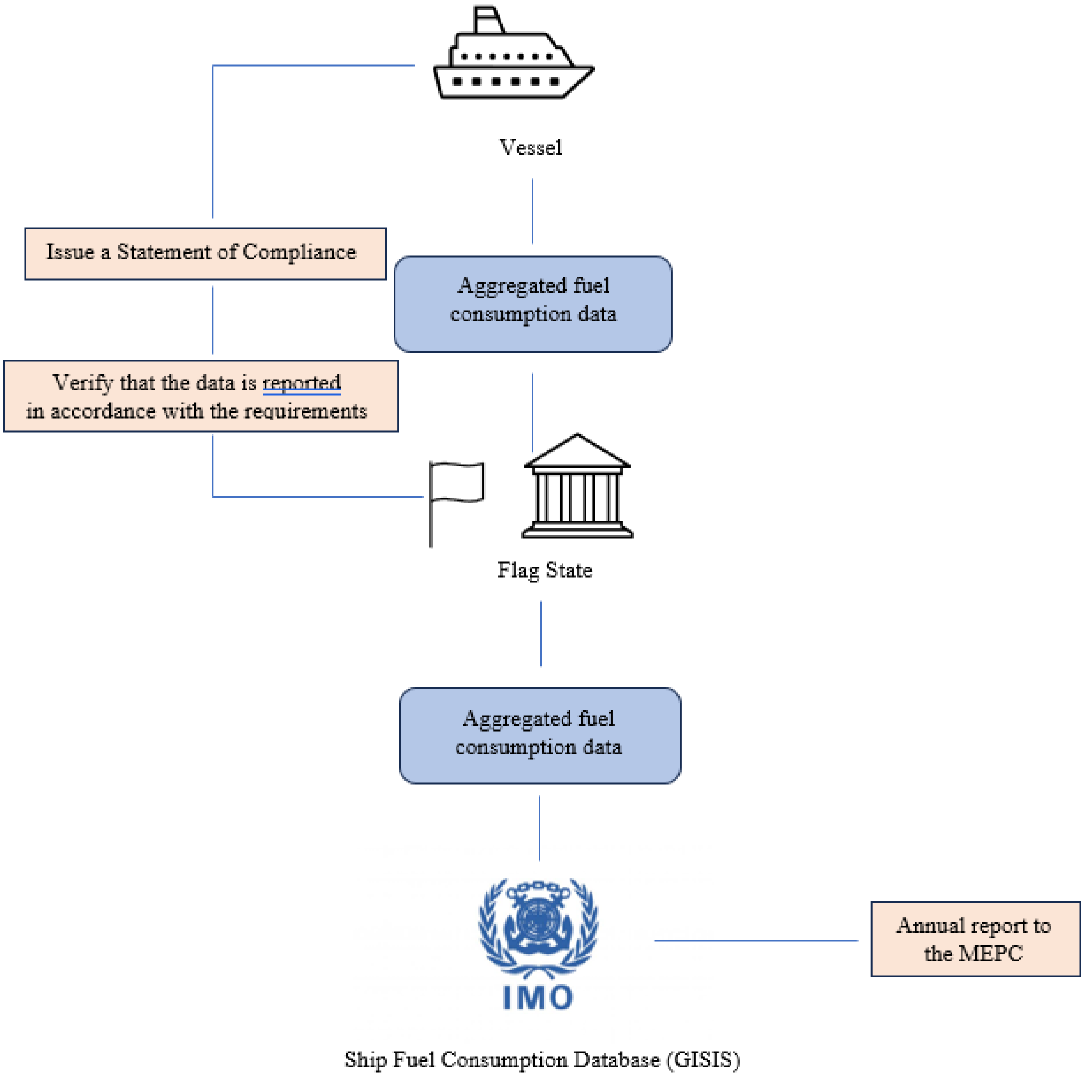


Figure 2.3: Diagrammatic representation of IMO DCS

2.3 Comparison between EU MRV and IMO DCS

EU MRV and IMO DCS are two systems developed to provide an accurate insight of the emissions from shipping, that would further support the development of policies to tackle GHG emissions. Although the two regulations may seem quite similar, there are some important differences when it comes to the scope and the requirements which are not aligned. The main argument is to achieve a harmonised approach to both systems and thus minimising the administrative burden for the shipping companies.

Table 2.2: Comparison of EU MRV and IMO DCS

	EU MRV	**IMO DCS**
Entry into force	1st July 2015	1st March 2018
Scope	Ships 5.000 GT or above Voyages to/from/within EEA ports	Ships 5.000 Gt or above International voyages
First monitoring period	2018	2019
Reported data	▪ Fuel consumption ▪ CO_2 emissions ▪ Transport work (cargo carried) ▪ Distance travelled ▪ Time at sea ▪ Average energy efficiency	▪ Total fuel consumption ▪ Distance travelled ▪ Hours underway ▪ Design deadweight (used as a proxy)
Verification	Accredited verifiers (ISO 14064)	Flag Administration or Authorised Organisation
Compliance	Document of compliance	Statement of compliance
Publication of the data	Publicly available (including individual ship's information) on an annual basis	Anonymised data (no individual ship's information)
Database	THETIS-MRV (EMSA)	GISIS (IMO)

Based on the table, there are a few key points to be highlighted:

- EU MRV regulation required the reporting of actual cargo on board, the fuel consumed, and CO_2 emitted. IMO DCS only requires the reporting of fuel consumed and the ship's deadweight.
- The geographical coverage of the two regulations. MRV covers only voyages from/to/withing EEA ports whereas DCS covers all international voyages.

- The EU makes most the information publicly available unlike the IMO that shares anonymised data. Generally, by contrast, information required by IMO DCS is less extensive and IMO gives a greater emphasis on confidentiality issues. It would be therefore fair to say that EU MRV is characterized by higher levels of transparency. The sensitivity of the data originates from the results that their publication may have to the economic and legal position of the company as well as its commercial activities. Keeping in mind that the public data can be used from various stakeholders for analysis, including the public, an issue of public interest versus economical interest arises.
- Ships have to comply with both regulations but, as shown on the table above, there are some differences that bring additional burden to the companies in terms of administrative work.

CHAPTER 3

ANALYSIS OF PUBLISHED MRV DATA (2018-2022)

In accordance with Article 21 of the MRV Regulation, the reported information is published on the THETIS-MRV website (THETIS-MRV (europa.eu)). The information is accessible through the search tool or can be exported in a spreadsheet for further analysis. A new version of the downloadable file is generated in case verified Emission Reports are amended by Companies and the version number is indicated in the file name.

For the following analysis, data extracted on 16.10.2023 were used. In particular, the analysis covers the years 2018, 2019, 2020, 2021 and 2022 and the spreadsheets' versions are 270, 217, 194, 176 and 91 respectively. The aim is to examine the trends on emissions and energy efficiency of the fleet falling under the regulation over these years.

The data used for this analysis are the original reported data without any kind of filtering by the Commission or the author and therefore any potential discrepancies or false values submitted by the companies have not been removed. As stated on the THETIS-MRV website: '*This spreadsheet is made available solely for the purpose of information in line with Article 21 of Regulation (EU) 2015/757. The European Commission and EMSA decline any responsibility or liability whatsoever for errors or deficiencies in these data. Information in the spreadsheet may not be timely, complete or accurate. Neither the European Commission, EMSA, nor any person acting on behalf of the European Commission is responsible with regard to the improper use of the spreadsheet and its content.'*

3.1 Limitations and accuracy of the EU MRV dataset

Although it has some limitations, the dataset is the most comprehensive and specifically targeted to evaluate fuel consumption and carbon intensity related to maritime trade, providing an ideal source for validating bottom-up estimates (IMO, 2020). The study compared the 2018 MRV data with IMO's data for the same year (filtering the dataset to fit MRV's criteria)[6] and

[6] Because the MRV data set only covers voyages that interact with EEA ports, the time spent at sea reported by most vessels is less than the entire year. To allow for an accurate deployment of this data for verification and quality assurance purposes, an analogous dataset was created from the bottom-up method for like-for-like

concluded that in general, parameters like distance travelled at sea and CO_2 emissions as well as, for the ship types that contribute to over than 65% of the global CO_2 emissions in 2018 and therefore are representative of the global international shipping, the parameters are well correlated. Moreover, when testing how representative of the global shipping is the MRV dataset, considering its geographical limitations, the results showed that both the operation and fleet coverage were highly representative making the dataset a valuable source of information. Finally, when comparing the operating speeds of the fleet in the two datasets, the data where very close which shows a great level of representativeness since speed is one of the strongest predictors of CO_2 emissions.

Another issue affecting the accuracy is the fact that during the measurements and reporting, there are many cases that a data error may occur. Those can be errors with the measuring device which may not be well maintained or calibrated. Lack of robust measuring procedures can also be an issue that will result in inaccurate data. One of the most common problems that affects the quality of the data directly, is human error. Usually, crew members are required to manually conduct the readings and data entry into the system that is in place. This burdening of the crew with administrative tasks can result in misreporting. Other reasons for misreporting include lack of knowledge of the correct procedures or intentionally reporting deceitful values. That would be the case for example, that some companies seem to report zero emissions or zero fuel consumption over a period or even abnormally high values (outliers) that could not possibly depict the reality, even though they have been verified by the accredited verifiers. In the reporting year 2021, only 0,7% of all emissions reports contained one or more outliers and the impact of these misstatements on the total fleet's emissions has been decreasing (4th annual report from the European Commission, 2023). To try and improve the quality of the data and as stated in the same report, 'With the aim of continuous improvement in the implementation of the EU maritime MRV Regulation, the Commission holds periodic meetings over the year with the relevant stakeholders, namely verifiers and National Accreditation Bodies, to further improve the punctuality, quality, and completeness of the reported data'.

Even though transparency is highly promoted, publishing the aggregated annual data fails to provide an insight into identifying discrepancies or false values between individual voyages.

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comparison to be made over 2018. This was possible by using the output from the voyage detection algorithm to identify voyages that interacted with EEA ports. Thus, the validation was carried out with bottom-up data that overlaps directly with the MRV data for each vessel identified. (…) The dataset accounted for around 10% of the world's fleet or more than 30% of the world's fleet over 5.000 GT, making it a highly valuable resource for the validation of the results (IMO, 2020).

However, the initial purpose of the MRV database is to serve as a data source for analysis from the stakeholders to support optimizing energy efficiency and develop regulations that tackle emissions. At some level, the errors and false entries, are to be checked by the external verifier who is responsible for verifying the accuracy of the reported information as well as the measuring procedures.

3.2 Fleet composition based on the ship type

The regulation applies to all ships above 5.000 GT that carry out voyages from, to or within two ports in the EEA when transporting goods or passengers for commercial purposes. Since 2018, the composition of the fleet falling under the scope of MRV is presented in the following graphs.

Fifteen types of ships calling at EU ports report their emissions to the MRV system. For all the years, the top five ship types are: bulk carriers, oil tankers, containerships, chemical tankers and general cargo ships, which represent a little more than 80% of the total number of vessels.

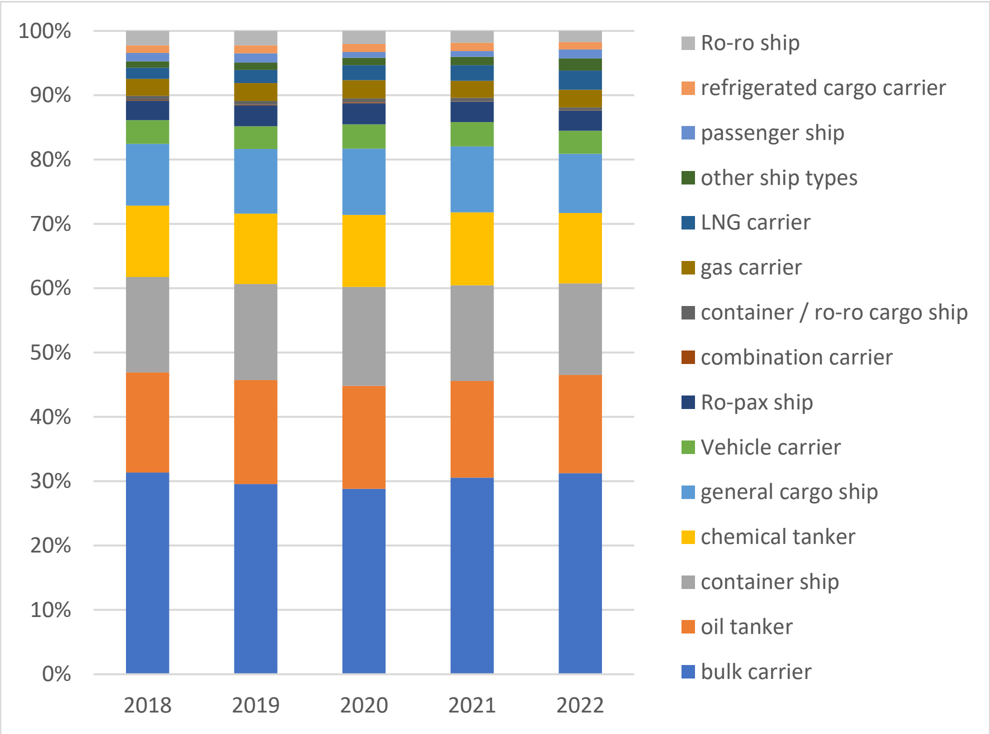


Figure 3.4: Fleet composition by ship type (in %), 2018-2022
Source: Author's calculations

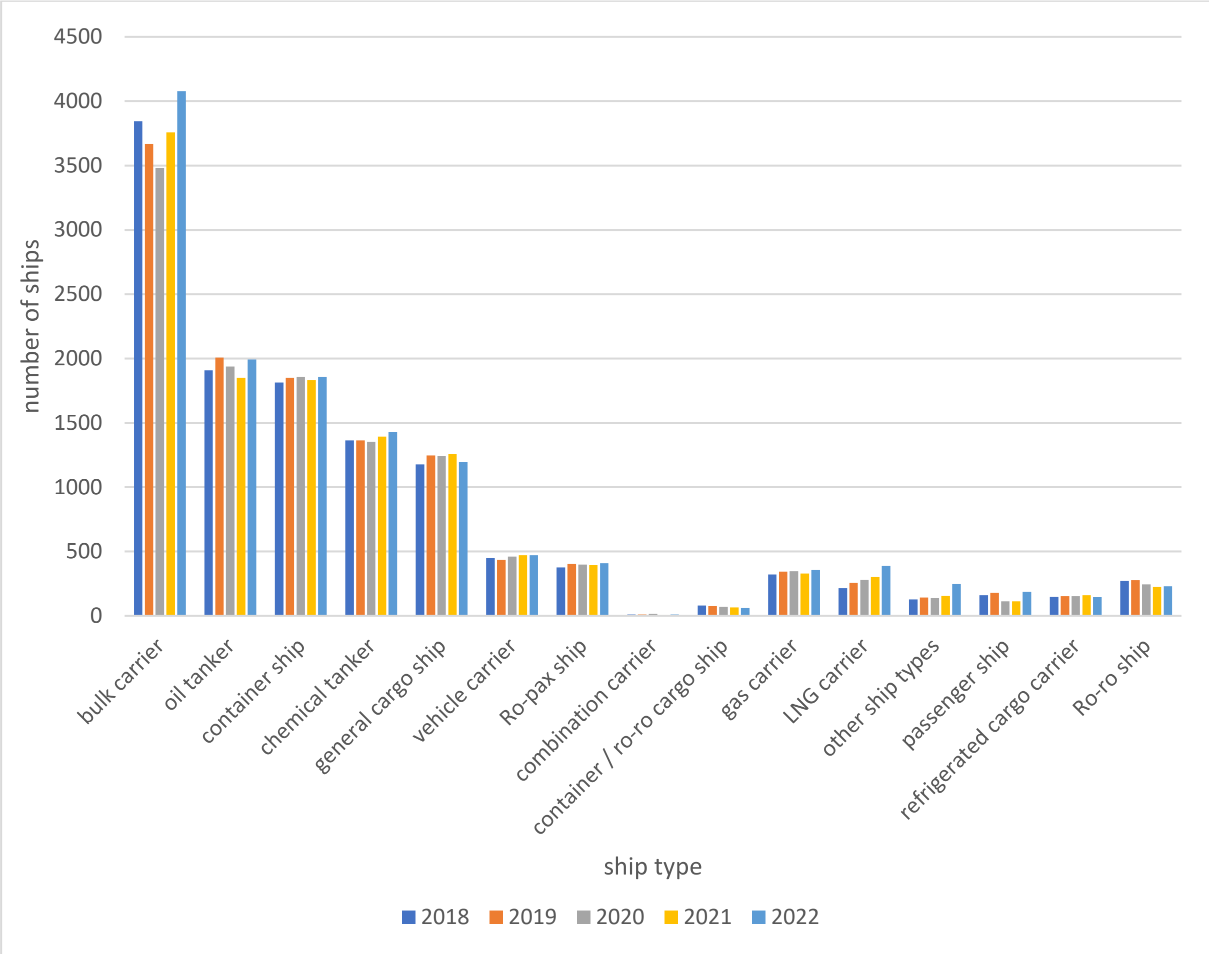


Figure 3.5: Fleet composition per ship type (by number of ships)
Source: Author's calculations

Bulk carriers seem to hold the largest share of the fleet with around 30%, followed by oil tankers that represent around 15% of the total fleet. Containerships account for around 14% which is equivalent to approximately 1.850 ships, while chemical tankers make up roughly 11% of the total fleet.

From the end of 2019 up to the beginning of 2021, COVID-19 pandemic had a large impact on the global shipping, with restrictions on passenger and crew movement transforming the operation of passenger ships. Therefore, when comparing the number of passenger ships between 2020 and 2019, a -37.98% decrease is observed. The impact on the cargo transport was not that severe, but for most ship types a decline in the number of ships between 2019 and 2020 is observed.

It should be noted that over the years that are analysed, a steady increase is observed in the number of LNG carriers operating between EEA ports. As mentioned in chapter 1, this upward trend is most likely due to the increase in the demand for LNG as it is a greener energy solution with a lower carbon factor when compared to traditional fossil fuels and is used by various industries.

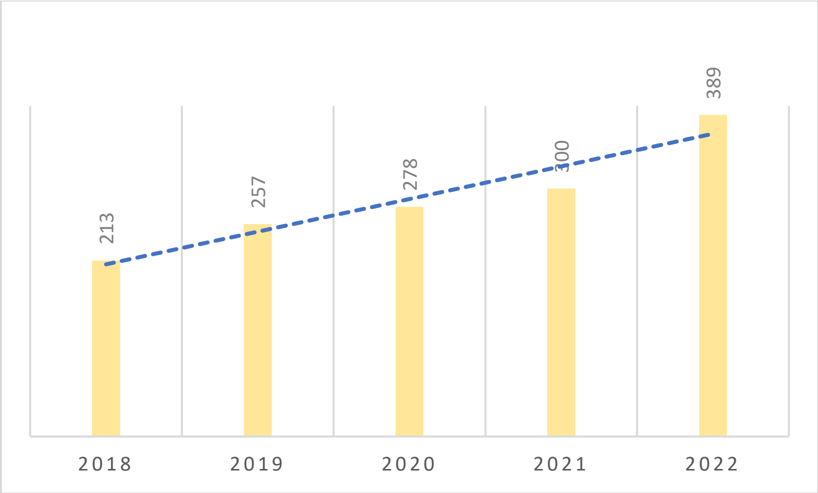


Figure 3.6: Number of LNG carriers under the scope of the regulation
Source: Author's calculations

3.3 Choice of monitoring methods

As analysed in the previous chapter, there are four methods to monitor the ship's emissions:
(a) BDN and periodic stocktakes of fuel tanks
(b) bunker fuel tank monitoring on board the vessel
(c) flow meters for applicable combustion processes and
(d) direct CO_2 emissions measurements
from which companies can choose one or a combination, if it allows for better and more accurate results. Figure 3.4 shows the monitoring methods that companies have chosen to monitor their emissions over the years 2018-2022.

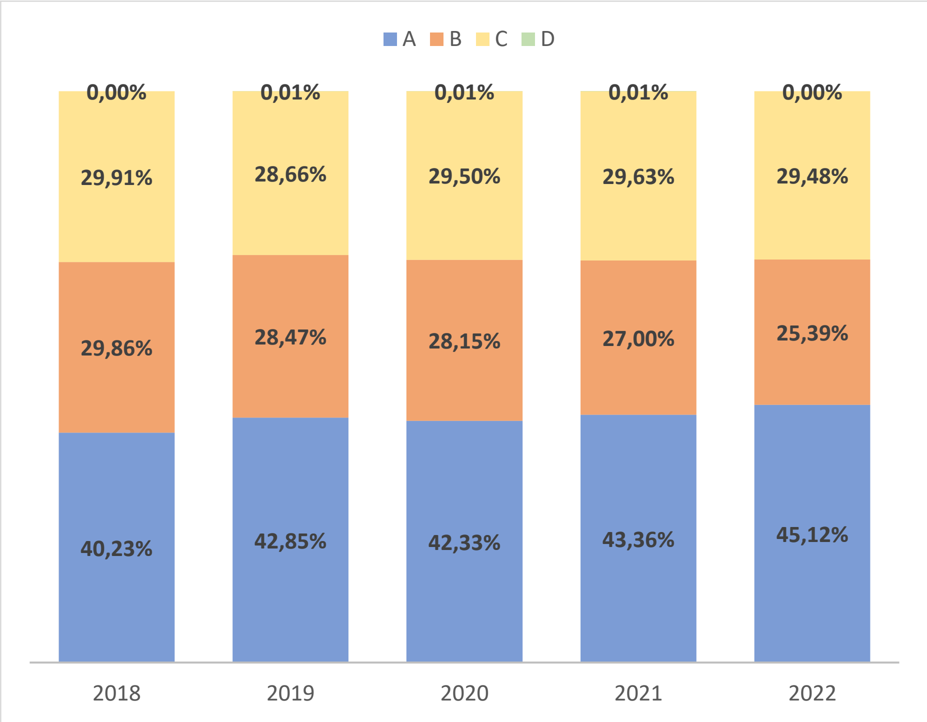


Figure 3.7: Type of monitoring methods used by the companies to monitor their emissions.
Source: Author's calculations

Over the period analysed, the choice of method A represents a percentage of above 40%. This method is widely preferred by the companies due to its simplicity and efficiency. The capital expenses (CAPEX) and operational expenses (OPEX) are the factors that form the decision making for the shipowners when it comes to choosing a monitoring method. Method A requires the minimum capital and operational expenses while it is simpler in terms of human interaction and use of equipment and therefore it can be characterised as more cost-effective. Method B and method C hold a share of around 30% over the years. These methods are in general more accurate, but they are also more expensive i.e., installation of flow meters. As expected, method D is not that popular since it requires the installation of equipment and measuring devices that come with a significant cost. For the years 2019, 2020 and 2021 only two ships used method D to monitor their emissions.

It should be noted that around 15-20% of the companies tend to use a combination of two or three methods, after a proper full assessment from a verifier, as a way to acquire more accurate measurements.

Furthermore, we can observe that bulk carriers and general cargo ships tend to prefer the use of method A, while oil tankers and chemical tankers seem to prefer slightly more method B. Most containerships use method C to monitor their emissions as well as most of the LNG carriers.

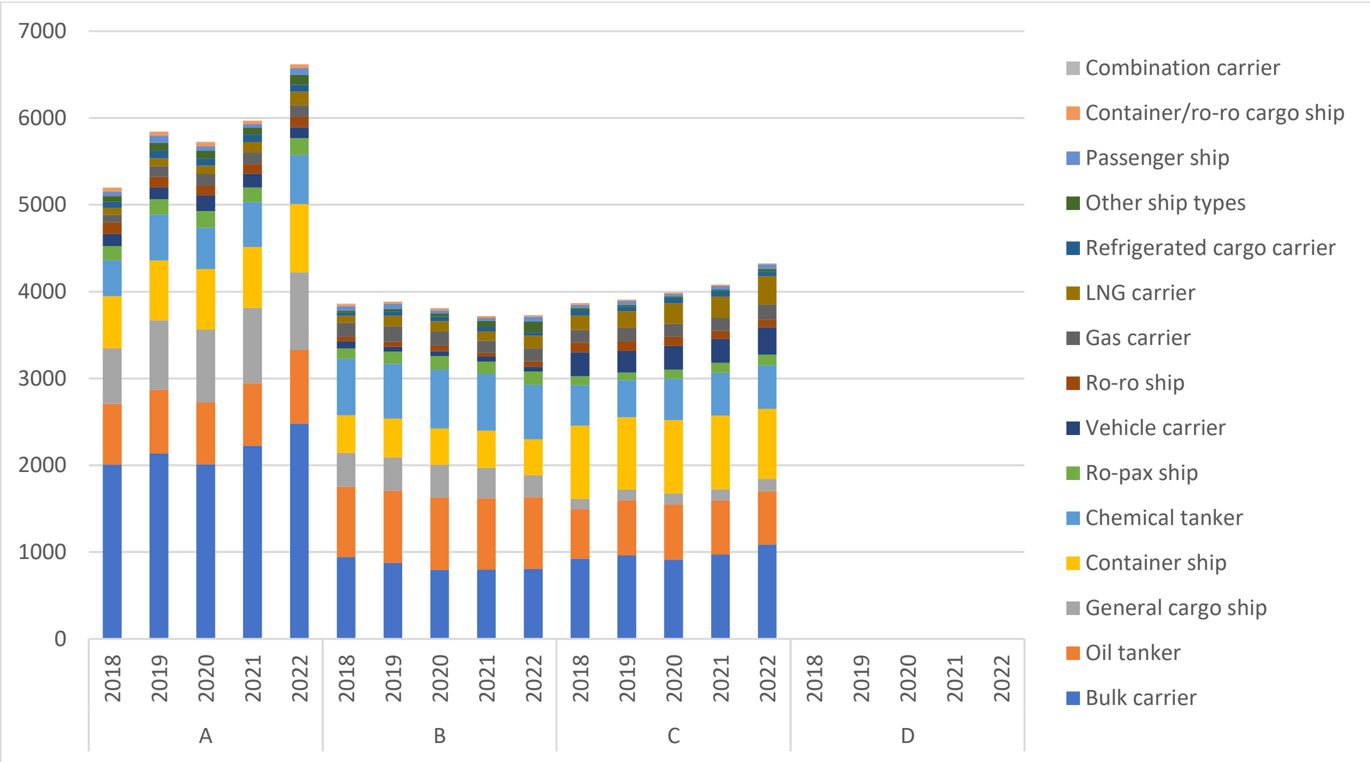


Figure 3.8: Chosen monitoring method per ship type
Source: Author's calculations

3.4 Fuel consumption

Fuel costs are a major component of the operational costs for a shipping company, as it usually varies between 30-60% of the total. Therefore, they are constantly trying to limit the fuel consumption by different measures like operational adjustments, design improvements and energy efficient measures.

Companies shall report the volumes of fuel consumed annually per ship. The following graph shows the volumes of fuel consumption for the years 2018 to 2022 as reported by the companies. In 2022, 43.9 million tonnes of fuel were consumed within the geographical area of the MRV regulation. It should be noted that, zero fuel consumption is being reported by some companies but the percentage of these deficiencies seem to keep decreasing year by year (from 5.21% in 2018 to 1.61% in 2020). The reason is usually human error when entering the data or submitting the reports. However, there appears to be another possible explanation. Zero emission reports or zero fuel consumption reports were submitted, due to the fact that a misunderstanding amongst the industry has occurred regarding the scope of the regulation and the necessity of submitting a report. Industry professionals have identified that several companies, even though they did not operate their ships in EU waters, believed that they were obliged to submit reports and therefore they reported zero consumption.

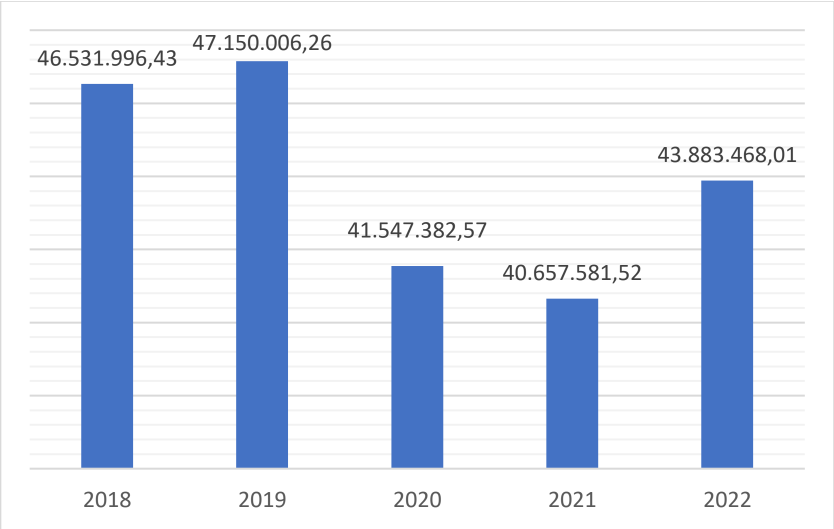
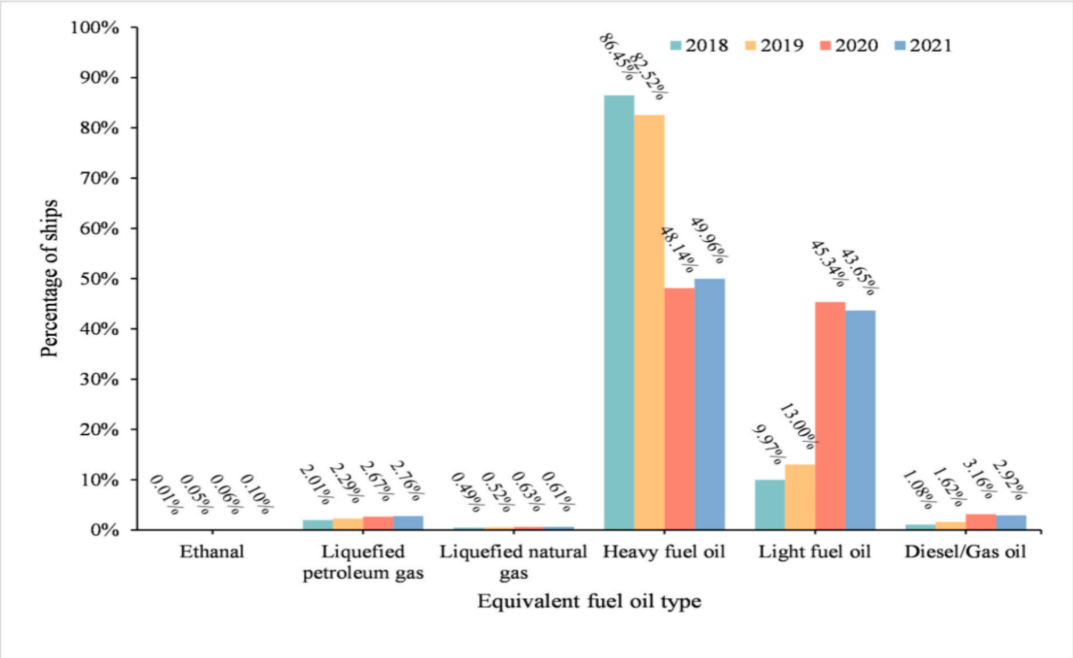


Figure 3.6: Total fleet's fuel consumption (tonnes)
Source: Author's calculations

Unfortunately, the type of fuel used by the vessels is not publicly available information. One way to try and calculate an approximate type of fuel used is to use the formula that gives the total CO_2 emissions (CO_2 emissions = total fuel consumption * emission factor) (see chapter 2.1.2.2). By calculating the emission factor, we can more or less estimate the fuel that has been used, but since ships don't use the same fuel throughout the voyage or for different activities, this would only be a not so safe estimate.

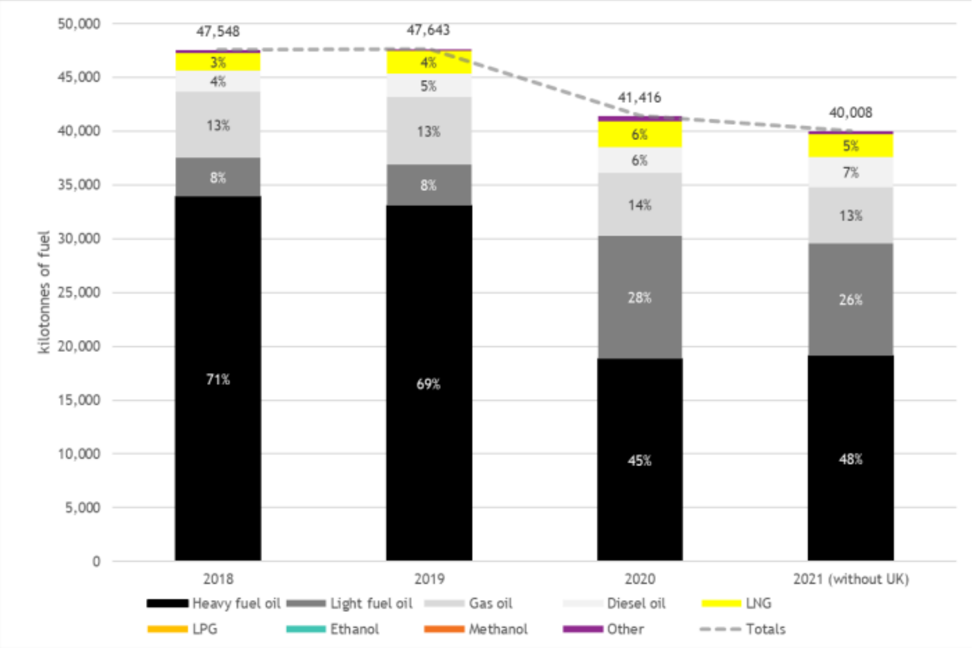
Xi Luo et al. 2024, determined the fuel type by developing ranges of carbon ratio and observing the ships that fall under each category. Graph 3.6, show the distribution of fuel oil types from 2018 to 2021 which were the years analyzed in their report. The authors concluded that over 90% of the ships use HFO and LFO due to the fact that these types are less expensive and more widely available, as for other alternative fuels, availability of infrastructure is still very limited. However, the percentage of the ships choosing alternative solutions keeps increasing over the years.



Source: Xi Luo *et al.*, 2023

Figure 3.7: The distribution of equivalent fuel type consumed by ships.

Furthermore, according to the 4th annual report from the EC, the consumption per type of fuel for 2018-2021, was as shown in figure 3.8.



Source: 4th annual report from the European Commission, 2023

Figure 3.8: Total fuel consumption and shares per fuel type

A significant reduction in consumption of heavy fuel oil (HFO) from 2019 to 2020 is a result of the limits in sulphur content of the fuels used internationally and in specific areas (SECAs). As of 2020, outside of SECAs, the sulphur content of the fuel must be less than 0,5% m/m which has led the operators to the use of fuels with lower sulphur content, for example low sulphur marine gas oil, very low sulphur fuel oil, LNG, etc. The same report explains that for most ship types HFO is the fuel with the highest use rate, while LNG carriers use LNG for propulsion purposes along with carrying it (around 75%). As per the same analysis, LNG consumption by vessels that are not LNG carriers (containerships, Ro-pax, gas carriers, oil tankers), has almost doubled between 2018 and 2019 which shows a shift to LNG use as fuel. The share of other alternative fuel types, like methanol or ethanol, remains at extremely low levels but the share keeps increasing over time.

3.5 Total emissions and number of emissions reports

Figure 3.9 shows the total CO_2 emissions that were reported in the emission reports. As previously explained, in some reports companies seem to have reported zero fuel consumption and/or zero emissions. The percentage of such invalid reports during the years is also shown in the graph below (red bars), where one can see the decrease of those reports through the years. This serves as a sign of the constant improvement of the quality of the MRV data. In a very few cases (three through the whole data), companies reported the fuel consumption but zero CO_2 emissions.

Furthermore, it should be noted that after 2021, the data from the UK is no longer included, as it now falls out of the scope of the Regulation. Unfortunately, the information included in the database does not allow for the port calls in the UK to be identified and therefore a comparative analysis between the years before and after BREXIT to determine the impact, cannot be made. The country continues to use the system but is now named UK MRV.

For the shake of this analysis and in order to identify trends in the emissions at EU level, the reports that include zero emissions are hereafter excluded from the dataset.

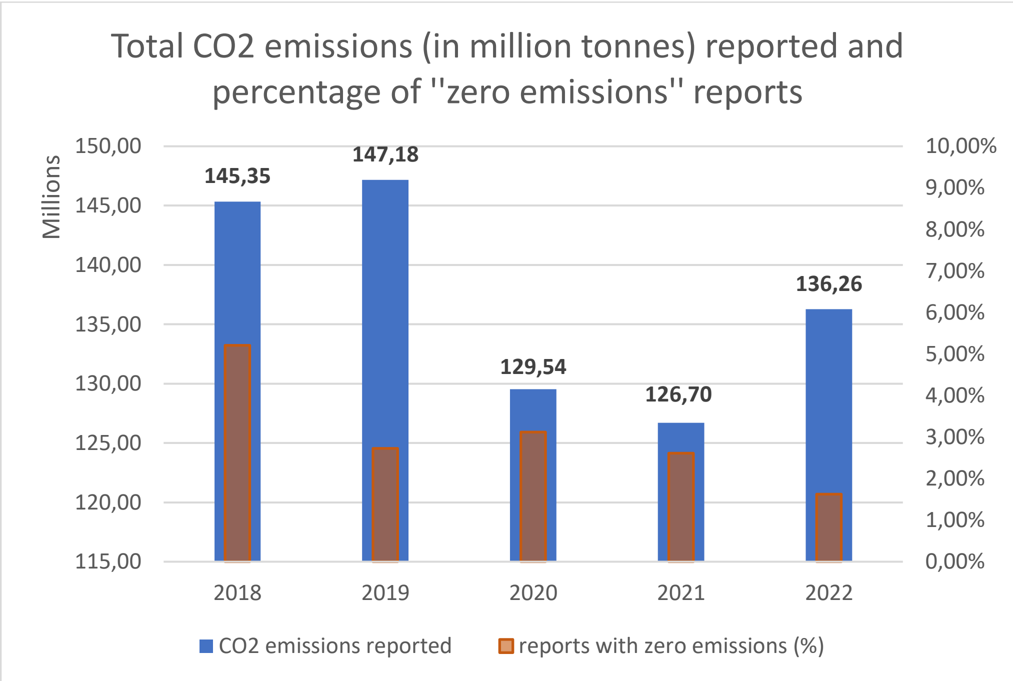


Figure 3.9: Total CO2 emissions in million tonnes, as reported in the emission reports that were submitted for the years 2018-2022 and percentage of reports that include zero emissions.

Source: Author's calculations

In addition, the impact of the global pandemic on maritime voyages that were performed depicted in the emissions. In 2020 and 2021 the emissions decreased significantly. In 2022, the emissions from the fleet reached 136,26 million tonnes which is higher than the two previous years as expected due to the gradual recovery of the sector and the return to its normal state.

With the exclusion of the ''deficient'' reports, graph 3.7 represents the emission reports that were submitted through the years and the CO_2 emissions reported. What is particularly noteworthy is the significant increase in the number of emission reports that were actually submitted, which is an indicator of the wider implementation of the Regulation. Furthermore, even though the number of emissions reports submitted is increasing, with no great fluctuations regarding the number of vessels, the total emissions of the fleet are declining over time. Therefore, this shows that a positive trend is created in reducing CO_2 emissions in the EU.

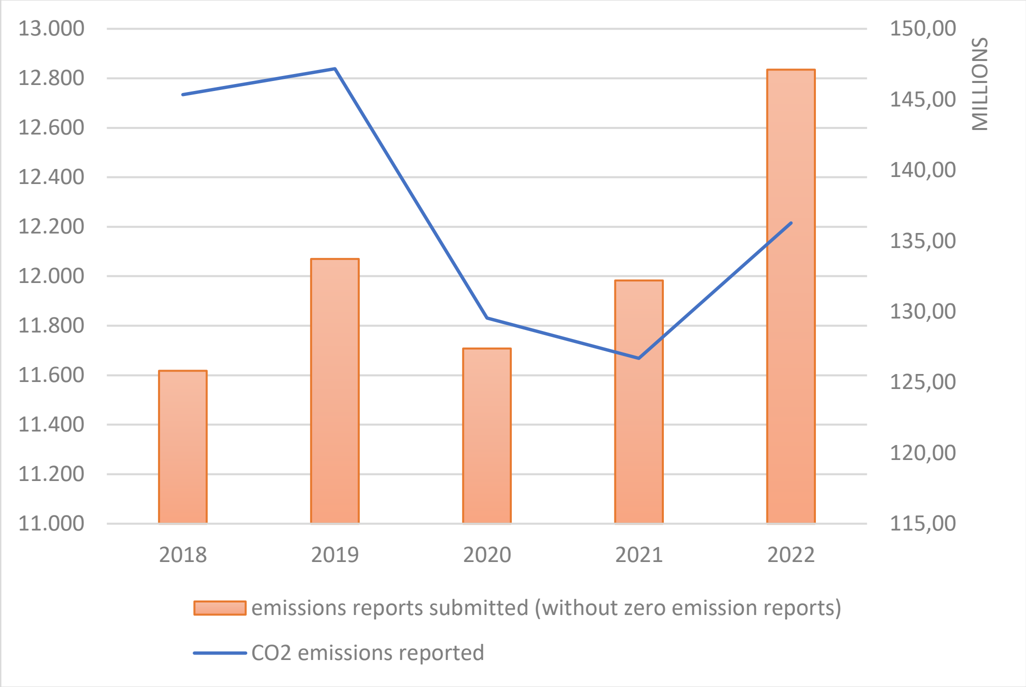


Figure 3.10: Total CO_2 emissions (in million tonnes) that were reported in the emission reports and total number of emission reports that were submitted (2018-2022)
Source: Author's calculations

3.6 Analysis of the emissions per type of voyage

As per the Regulation, the company must report not only the total CO_2 emissions but also to provide a distinction between the different types of voyages, meaning where the emissions in question where emitted, i.e. intra EU voyages (from an EU port to another EU port), extra EU voyages (departing from an EU port), extra EU voyages (arriving at an EU port) and emissions inside the area of a port while at berth. Graph 3.8 shows how the emissions were distributed between these categories for the years 2018 to 2022.

Of the total emissions, around 30% arise from voyages between ports of EU Member States and around 6-7% while the ships are at berth. A total of 60% of the emissions are produced during voyages departing from or arriving to EU ports. No significant changes are observed in general during the years, but the impact of UK's withdrawal from the EU is clearly shown in 2021 affecting the intra EU voyages since UK's ports are not considered EU ports.

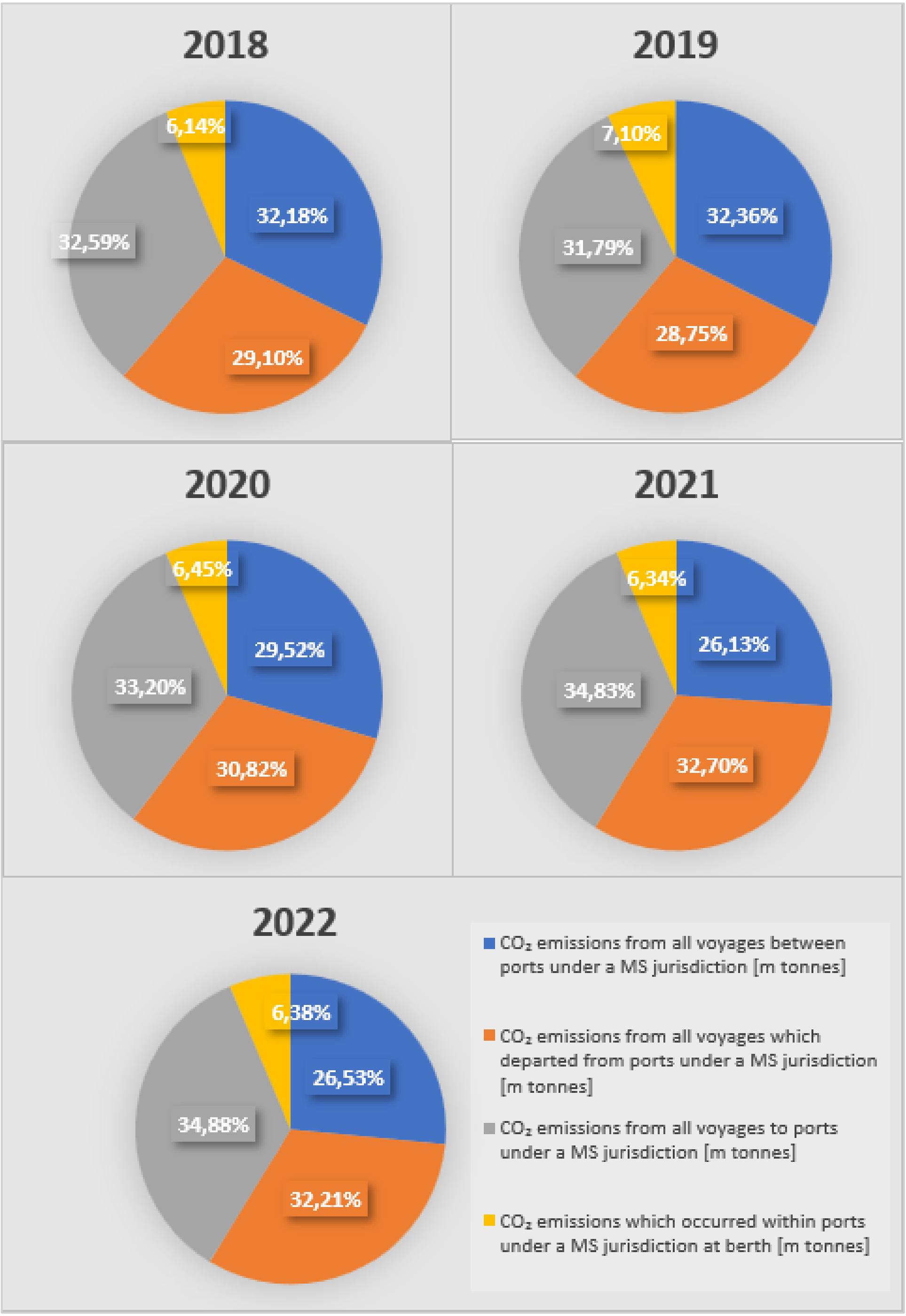


Figure 3.11: Distribution of CO_2 emitted under the Regulation per type of voyage.
Source: Author's calculations

3.7 Analysis of the emissions per type of ship

Looking closely at the total emissions by ship type, containerships seem to hold the largest share over the years that are analysed. This is due to the fact that containerships travel with very high speeds, almost double than other ship types, since the market is subject to high demand. Containership emissions peaked in 2018 and since then they have gradually decreased. Oil tankers peaked in 2019, and their emissions are decreasing ever since. For bulk carriers, the years 2019-2021 show a great reduction in the carbon emissions but in 2022 they seem to have fully recovered from the events of the past years as their emissions have reached 2018 levels in 2022. Furthermore, passenger ships, which were affected the most by the pandemic, which can also be observed when analysing their emissions, reached their 2019 levels in 2022 which shows that the passenger transport market is back to normal. LNG carriers reported significantly more emissions in 2022 (10.783.156,27 tonnes) compared to the previous years.

For the most types of ships, their emissions peaked in 2018 or 2019 and since then they are gradually decreasing. This could be an indicator of the steadily decarbonisation of the sector but definitely the years 2019 and 2020 cannot be considered indicative as major events took place on a global scale (pandemic, BREXIT and Global Sulphur Cap). A more proper analysis could be made when the data for 2023 will be available as they would give a more accurate insight into the emissions reductions as well as the impact of the new regulations.

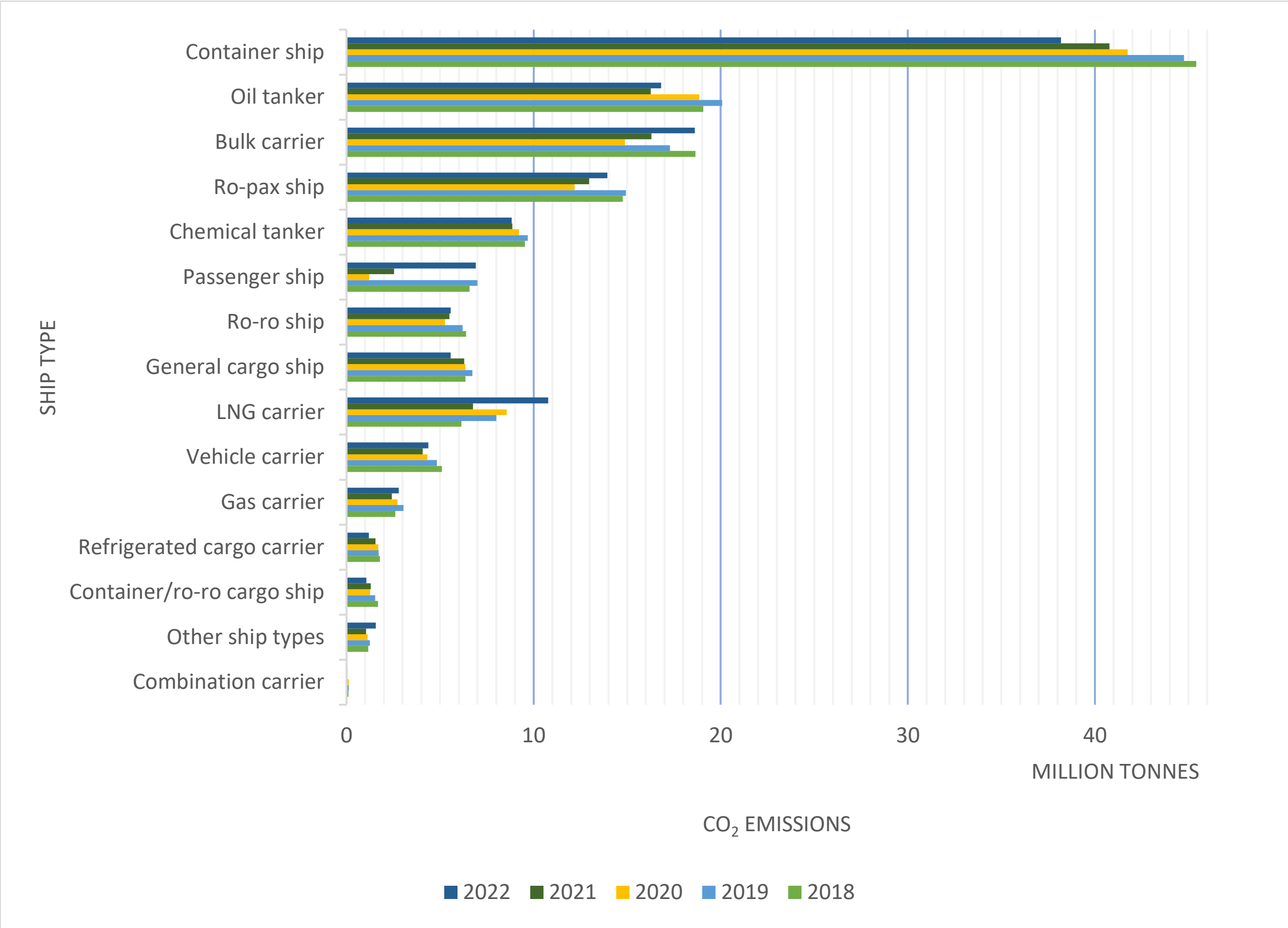


Figure 3.12: CO_2 emissions by type of ship.
Source: Author's calculations

Furthermore, to have a better insight into the changes in CO_2 emissions for each type of ship from the first year the Regulation came into effect up to the last year for which we have available data, namely 2018 and 2022, a comparison was made between the two years.

It should be noted though that since 2018 was the first year that the regulation was implemented, fewer emission reports were submitted, 11.618 in 2018 versus 12.835 in 2022 (excluding zero emissions reports). This could be also explained by various fluctuations in trade patterns between the EU and the world, although, major changes in the number of port calls or the number of the fleet operating in this geographical area, are highly unlike to have taken place over a five-year timeline.

As displayed on figure 3.13, there was an overall positive reduction in the emissions of around 9 million tonnes from 2018 to 2022. This is an indicator of how the industry is changing and moving towards more energy efficient technologies as well as of the impact international and regional regulations have had. For most ship types, reductions are observed between the two years. Containerships have shown the greatest change with a reduction of around 7,2 million tonnes which accounts for 80% of the total reduction.

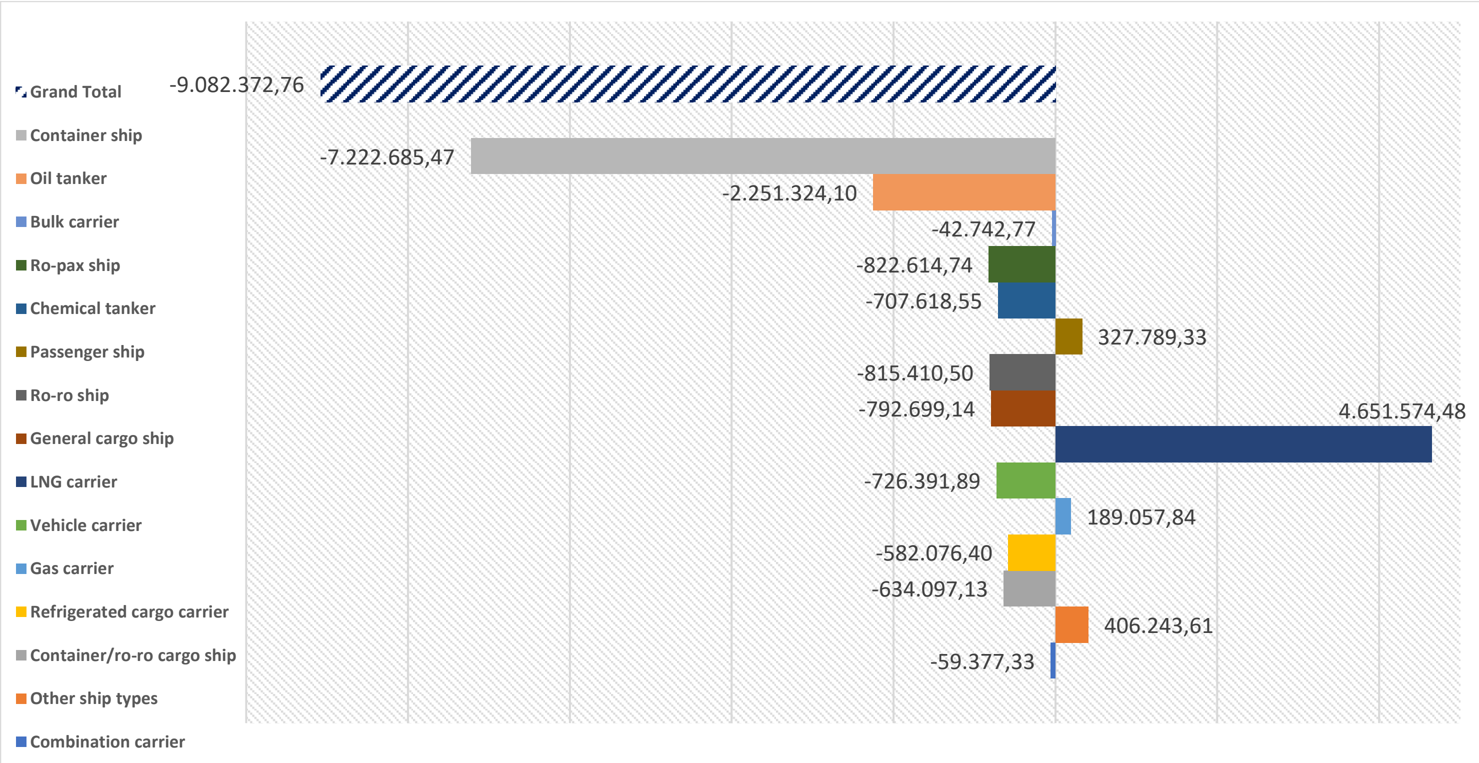


Figure 3.13: Change of tonnes of emissions for each ship type between the years 2022 and 2018.
Source: Author's calculations

Perhaps, a fairer comparative analysis could be made between the years 2021 and 2022 since for both of these years UK's withdrawal from the EU (in 2020) and the global sulphur cap (2020) were both in place as well as even though there were still a few COVID related restrictions' impacts, overall, 2021 is considered a year that the international trade and the global economy had mostly recovered. Therefore, figure 3.14 shows the differences observed in the tonnes of CO_2 emissions between the two years for all ship types.

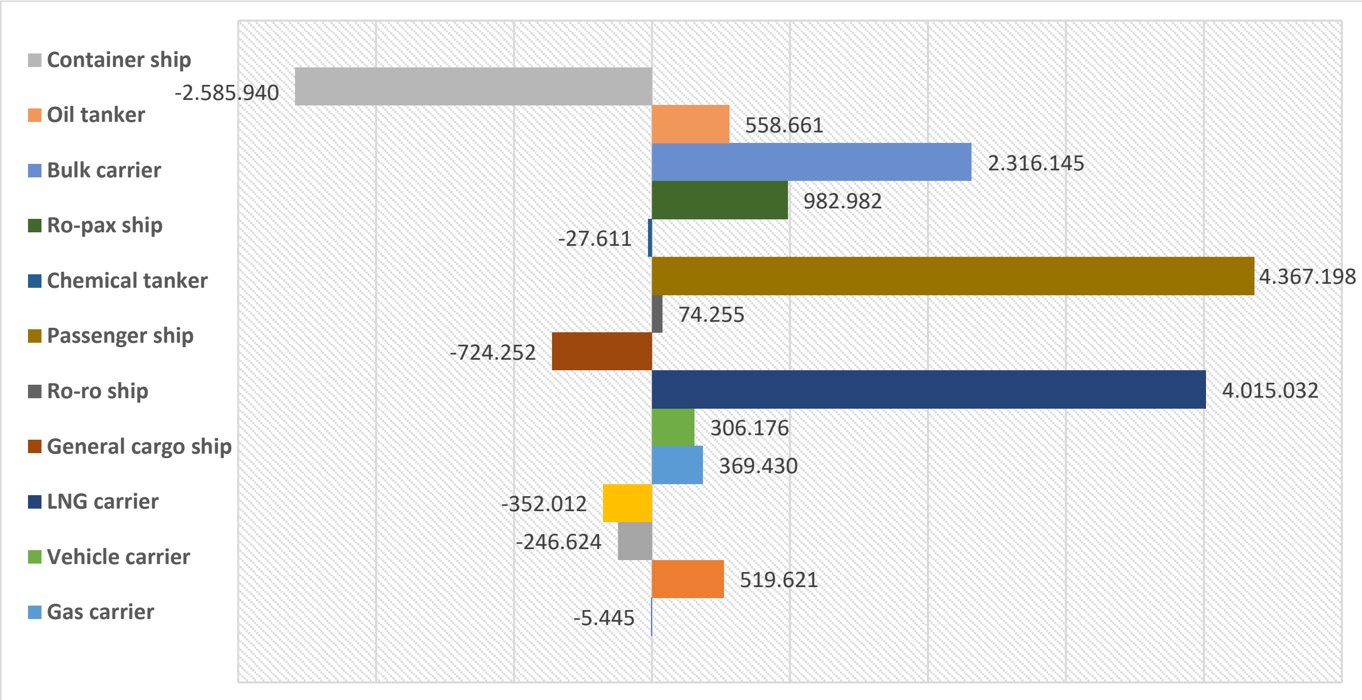


Figure 3.14: Change of tonnes of emissions for each ship type between the years 2022 and 2021.

Source: Author's calculations

Diving deeper into 2022 being the year with the most recent data that we have available, a comparison was made between the emissions for the different ship types. To be able to compare more accurately and to identify the most polluting ship type, a division with the number of the vessels was made for all ship types (to find an average value). What is avoided here is, for example: according to figure 3.9, containerships seem to have the largest share of emissions for 2022. It wouldn't be accurate to come to the conclusion that high emissions make containerships the most polluting type, since, according to figure 3.12, containerships hold the third place when it comes to the number of individual vessels calling in EU ports.

Another example is bulk carriers. For 2022, bulk carriers accounted for 18,6 million tonnes (excluding the zero emissions reports), being the second biggest contributor of CO_2 after containerships. However, the number of bulk carriers in 2022 was 3.968 which means that they represented more than 30% of the fleet falling under the MRV Regulation.

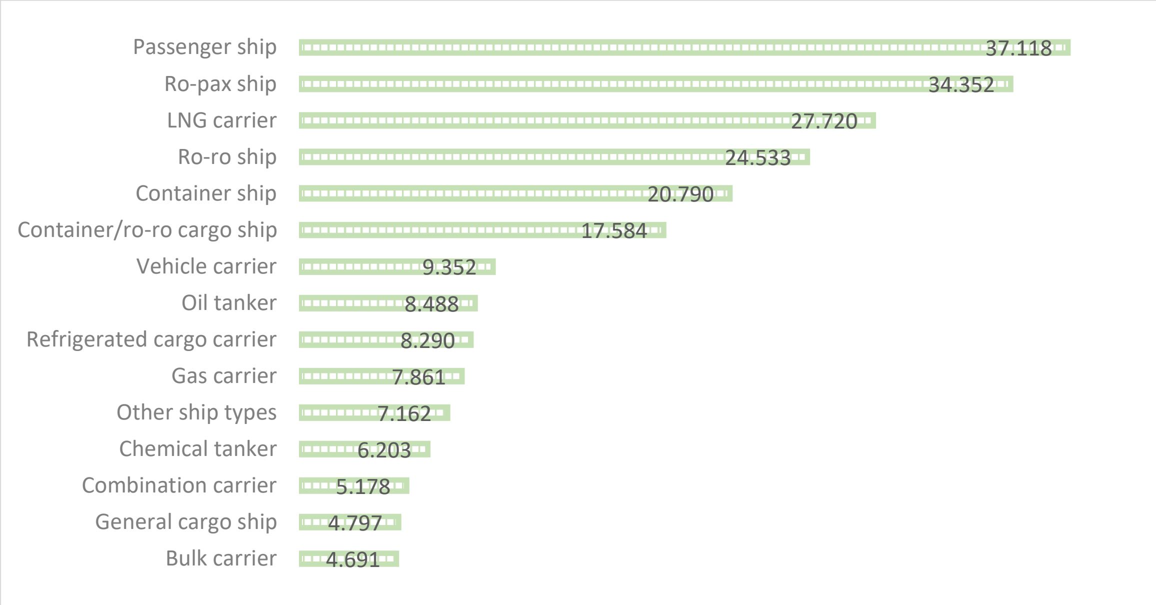


Figure 3.15: Average CO_2 emissions (in tonnes) for each ship type, for the year 2022.
Source: Author's calculations

Figure 3.12 and 3.15 shows that passenger ships could be considered as the most polluting ship type, whereas bulk carriers have the lowest average. In general, passenger ships as well as Ro-pax ships, due to the fact that they transport passengers and a priority in travel time and comfort are required, tend to sail with higher speeds. Higher speeds mean higher fuel consumption and thus more CO_2 emissions. On the other hand, bulk carriers transport large quantities of non-packed commodities like grains, coal and iron ore, and they have lower operating speeds.

Figure 3.16 shows the percentage of emissions attributed to transportation of passengers versus transportation of freight. Overall, as expected, emissions attributed to freight transport represent the biggest share of the total emissions, while passenger transport represents only 10%. The fluctuation during the years 2020 and 2021 is due to the impact of the pandemic on international transport that disturbed the relationship between the two.

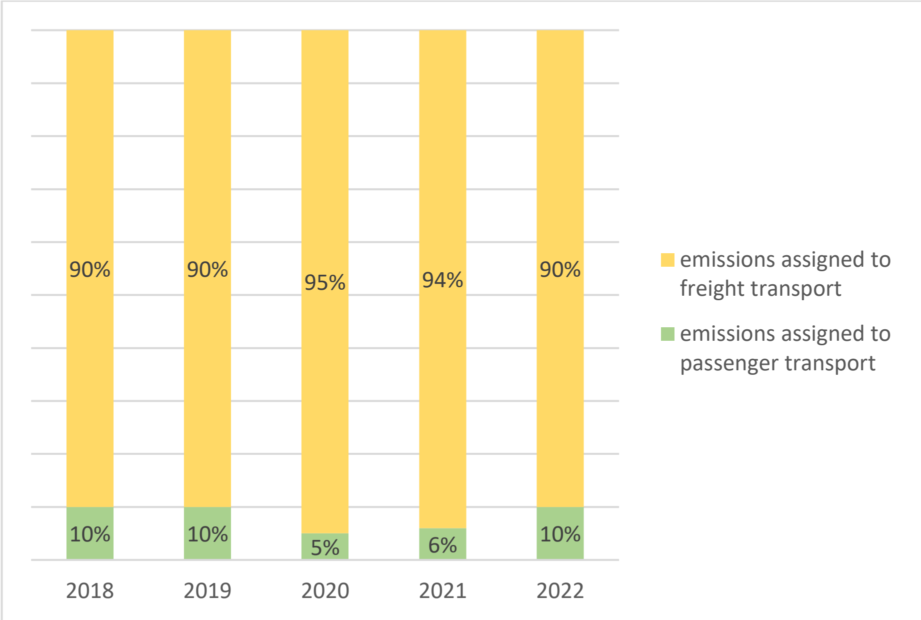


Figure 3.16: Percentage of emissions assigned to freight and passenger transport.

Source: Author's calculations

Moreover, it is very important to consider the benefits for the society. Passenger ships contribute to high emission rates while contributing to passenger mobility and tourism. Bulk carriers or containerships, despite having lower average emissions, they play a critical role for industries and food supply chains on a global scale. It is clear that there is a level of complexity when it comes to the evaluation of the environmental impact, as both the emissions and the benefits to the economy and society should be considered.

To try and overcome this very complex issue in order to gain a more realistic insight on the performance of the fleet, the European Commission included in this Regulation, the requirement for all ships to report their transport work[7]. CO_2 emissions per transport work is also referred to as EEOI (Energy Efficiency Operational Indicator) and it reflects the carbon intensity of the transport service. Operational efficiency depends on various factors like speed,

[7] Companies need to report the annual average of CO_2 per transport work in different metric depending on the cargo and the type of ship: in mass (gCO_2 / m tonnes * n miles), volume (gCO_2 / m^3 * n miles) and deadweight (gCO_2 / dwt carried * n miles). Ro-pax vessels, due to their uniqueness of transporting cargo (vehicles) and passengers, need to distinguish between transport work attributed to passenger and freight transportation, so, where applicable, they must report annual average of CO_2 per transport work for passengers (gCO_2 / pax * n miles) and for freight (gCO_2 / m tonnes * n miles).

and voyage/weather conditions. Including transport work into the analysis of the environmental impact, is a way to assess the efficiency, meaning the emissions in relation to the amount transported. For example, if passenger ships have higher average emissions and perform less transport work than bulk carriers, they may be less efficient in terms of emissions per tonne-kilometre.

Due to limitations in the availability of data in the database as well as lack of technical expertise, an analysis on the efficiency of each ship type could not be done. However, to provide some insight into this subject, the 4th annual report by the EC on CO_2 emissions from maritime transport for the years 2018 to 2021 can serve as a reference. A detailed analysis was conducted on the EEOI values of the fleet over the years in question. As explained, EEOI values can serve as an indicator of the operational efficiency of the ships. When analysing the oil tankers' EEOI, the report concludes that there have not been significant changes over the years, since the trendlines overlap, which indicates a relative stability in the technological and commercial trends of the maritime sector. That could imply that the industry has reached the peak in terms of achievable efficiency using the current technology widely available. However, we could argue that this shows a lack of investments in new and more efficient technologies mostly due to economic constraints as it would imply significant costs. In addition, the current uncertainty around the future regulations, the fuel mix and the shape of the market doesn't allow for significant investments on ship design and efficiency.

Conclusions

Maritime transport is essential for international trade and the global economy with over 80% of the world's goods in terms of volume being transported by sea. It is a cornerstone of global energy, food and supply chain security. The sector has significant environmental, economic and social impacts on a global scale. Even though it is considered the most efficient mode of transport, maritime sector is responsible for high levels of water and air pollution. Shipping contributes to water pollution, meaning substances that end up in the ocean from the operation of ships (discharges and sewage), underwater radiated noise emitted from the operation of ships which affects large mammals, and antifouling compounds that affects marine resources and adds up to the depletion of our oceans.

Furthermore, the sector contributes to air pollution, with millions of tonnes of GHGs and other air pollutants emitted in the atmosphere annually, having a direct impact on human health, climate change, acidification and eutrophication. In this thesis, a thorough analysis of the most important air polluting substances was made, using data from EU and international sources. Carbon dioxide holds the lion's share with around 90% of total international GHG emissions from shipping followed by black carbon, nitrous oxide and methane. All the substances analysed followed more or less the same trendlines from 1990 until today. The analysis showed that from 1990 and for the next eighteen years, emissions have increased gradually due to the growth of international shipping, up until 2008 where the peak was reached. After that, economic crisis led to decrease in the demand for maritime transport as well as forced the operators to reduce their ships' speeds which resulted in lowering the emission levels worldwide. Finally, from 2015, a recovery was observed with emissions gradually increasing but in lower levels than 2008. It is worth mentioning that the impact of major on the global economy, the demand for maritime transport and therefore the emissions from ships can be observed throughout the years, like for example the global pandemic or the establishment of the Global Sulphur Cap.

Overall, emissions levels tend to depict the international efforts to regulate and minimise the environmental impact which allows us to conclude that the measures taken are quite efficient, but still far from the upcoming agreed targets. Actions taken from governments and international organizations aim to limit the emitted substances by enforcing mandatory energy efficiency measures for the sector, while setting ambitious goals for the following years. In particular, the international shipping industry targets on achieving net zero emissions by 2050 and up to 10% uptake of alternative fuels by 2030. This requires the development of design-based measures, which refers to hull optimisation, use of lower carbon fuels or propulsion systems' optimisation, as well as operational measures, which refers to lower speeds, voyage planning, weather routing, etc. IMO has developed measures that apply to the global fleet (EEDI, SEEMP, EEOI, EEX, CII) in order to establish international minimum levels of energy efficiency and to ensure a continuous improvement of the ship's operational carbon intensity while ensuring that this improvement comes in a cost-effective way. In addition, the EU has worked on a basket of measures to support the transition to a more energy efficient maritime transport by developing regulations that aim to encourage alternative fuels uptake, to support the development and availability of the necessary infrastructure, to provide a system of standardisation of the new fuels and to create an environment that can foster this change by applying market-based measures.

The first step for the IMO and the EU was to develop systems to monitor the carbon emissions of the fleet in order to assess the state of the sector's environmental footprint and to observe the trendlines through the years. IMO's DCS and EU's MRV are two monitoring and reporting regimes mandatory for the shipping companies, that play a pivotal role in understanding the shipping emissions and address them effectively. A comparison made in chapter two revealed that there are a few key differences between the two systems that do not allow for a direct comparison of the two datasets and therefore the need for the development of an international combined catholic system was identified. An alignment of the EU legislation with the IMO measures in required to ensure faster results. In addition, when looking into the implementation costs for the shipping companies, an additional administrative burden was associated but of a small significance, since most of the data required from the regulations are already being collected by the shipping companies on a daily basis. Other implementation costs include the operation of systems for data collection and handling, the need to provide training to the personnel, the possible cost of penalties in case of non-compliance and of course the costs deriving from hiring a third-party verifier. Overall, we could say that these costs do not represent a significant amount for the company and also, they are considered one-time expenses (training or installation of systems) and fixed expenses (third-party verifier).

The analysis of the MRV dataset showed how comprehensive it is to evaluate the state of the fleet, despite its geographical limitations, while providing a great source for validating bottom-up estimates. However, a few essential weaknesses were highlighted when it comes to the quality of the data that are reported. In particular, the accuracy was questioned, leading to the identification of a few parameters that affect it, like for example mistakes during the measurement procedures on board due to lack of calibration or poor maintenance of the equipment. The most common issue that affects the quality of the data though is human error or intentionally reporting deceitful values, something that in many cases cannot be checked by an authority or verifier. In addition, some unrealistic values (outliers) are often spotted in the dataset when it comes to fuel consumption or volume of emissions. But some false values that may not be far from reality and therefore not easy to be identified are also spotted and thus they may affect the statistical analysis since they are not being excluded. Furthermore, the issue of the ‘’invalid’’ zero emissions reports was analysed, concluding that even though there is still a small percentage of such reports submitted, the amount has significantly decreased over the years of the regulation.

During the analysis conducted in chapter 3, a few conclusions were drawn regarding the trendlines formed over the years analysed. Firstly, there were no major changes through the years when it comes to fleet composition and fuel consumption. Of course, COVID-19 pandemic impacts are clear for the years 2020 and beginning of 2021, since the number of voyages and ships operating was limited, as well as the impact of UK’s exit from the European Union that caused many voyages to not fall under the scope of MRV. Secondly, an increase in the number of LNG carriers was observed which is most likely due to the increase in the demand for LNG worldwide, a fact that is supported also when looking at the orders for new vessels. LNG use as a fuel is also gradually increasing, while the two observations are closely correlated since LNG carriers also use LNG for propulsion purposes. Moreover, total fleet’s fuel consumption has decreased from 2019 to 2022 and such have the emissions. It is indeed very interesting to see how these numbers will be formed in 2023 as we are coming closer to 2030 targets.

Regarding the type of fuels used by the fleet, HFO remains the most popular choice from the shipping companies while it is the cheapest and most cost-efficient option, but the percentage keeps dropping more and more after 2020, when the Global Sulphur Cap establishment forced ships to burn LSFO in an effort to reduce sulphur emissions. Reaching the ambitious international and EU decarbonisation goals by 2030 and 2050 means that alternative fuels should already represent a substantial percentage of the maritime fuel mix. The issue lies in the fact that the future is uncertain for the shipowners but also for the policy makers, especially in this evolving maritime landscape. On one hand, policy makers try to create an environment to foster decarbonisation while not being able to directly shape and influence the market. They aim to balance the adoption of greener fuels while at the same time maintaining the competitiveness of the industry. On the other hand, shipowners are forced to make long-term investments in an environment, with environmental, technological and regulatory uncertainty.

The bigger arguments from the industry are concerns about the gaps in prices between traditional and alternative fuels, the infrastructure readiness and availability in the world's major ports as well as the compatibility of these new fuels with the vessels' engines. A report published by Maersk Mc-Kinney Moller Centre for Zero Carbon Shipping (2024), assesses the impact of EU and US policy framework on the deployment of alternative fuels. One of the issues the report mentions lies on the unpredictable market dynamics of the shipping industry which results in great uncertainty. The authors suggest that this would create a motivation for companies to pursue long-term offtake agreements as a strategic move against price fluctuations and secure the price of alternative fuels, while this would lead to companies postponing investments in alternative fuels. The authors also support that it is very likely to create a future market where dual-fuel vessels would opt to use a combination of alternative and fossil fuels, which would depend on the customers' willingness to pay, the availability of alternatives and the regional regulatory standards.

Another important concern is regarding safety and handling procedures of the new fuels, as well as the impact to human lives and the environment in case of an accident or spill. Seafarers would need to acquire new skills, education and operational training, as 800.000 seafarers will have to be upskilled/reskilled by mid-2030 in order to support this transition (DNV, 2022). To this regard, many organisations, private institutions, NGO's, universities and members from the industry, are continuously conducting studies and experiments on the behaviour of the fuels in question (ammonia, hydrogen, LNG, biofuels), but only a few of them are based on practical experience.

With the new EU regulations reshaping the maritime landscape, the industry anticipates the results of the implementation in the following years. EU ETS is expected to redefine market dynamics, with companies that are early adopters of green technologies gaining a significant competitive advantage, by leveraging the cap-and-trade system and trading of allowances. Even though most EU shipping or management companies find the new regulations cumbersome and complex, those who will manage to promptly comply, will not only reduce their carbon footprint, but also generate revenue and thus financially benefit (Zhang and Xiao, 2024).

Achieving a sustainable maritime industry is a challenging complex matter which policy makers are trying to address in a holistic way. The transition must be just and must make sense for the industry and the society in economic terms. Transition to greener energy and operational solutions must be achieved in parallel to economic stability and growth. Fuel efficiency and operating costs play a crucial role for the industry as it represents a substantial cost for the ship owners and operators, and therefore these factors must be carefully considered when taking action to limit the environmental impact. Furthermore, the regulatory framework should be able to take care of the price gaps that will be formed between traditional and alternative fuels, in order to protect the industry and the global economy. Setting realistic targets while consulting with the industry in order to secure alignment of the interests of all stakeholders is the only way towards a sustainable, carbon neutral maritime sector. The future holds great promise, and the maritime sector eagerly awaits to see what comes next.

ANNEX I - List of Abbreviations

AFID	Alternative Fuel Infrastructure Directive
BC	Black carbon
BDN	Bunker Delivery Note
CAPEX	Capital Expenses
CCS	Carbon Capture Systems
CH_4	Methane
CII	Carbon Intensity Indicator
CO_2	Carbon Dioxide
CO_2 eq	Carbon Dioxide Equivalent
CSRD	Corporate Sustainability Reporting Directive
EC	European Commission
ECSA	European Community Shipowners' Associations
EEA	European Environment Agency
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Index
EEXI	Energy Efficiency Existing Ship Index
EFTA	European Free Trade Association
EIV	Estimated Index Value
EMSA	European Maritime Safety Agency
EMTER	European Maritime Transport Environmental Report
ESG	Environmental, Social, Governance
ETD	Energy Taxation Directive
EU	European Union
EU ETS	European Union Emissions Trading System
FTE	Full-Time Equivalent
GHG	Greenhouse Gases
GISIS	Global Integrated Shipping Information System
GT	Gross Tonnage
GVA	Gross Added Value
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
HFO	Heavy Fuel Oil
HSFO	High Sulphur Fuel Oil
IEA	International Energy Agency
IMO	International Maritime Organization
IMO DCS	International Maritime Organization Data Collection System
IPCC	Intergovernmental Panel for Climate Change
ISO	International Organization for Standardization
LFO	Light Fuel Oil
LNG	Liquified Natural Gas
LPG	Liquified Petrol Gas
MARPOL	Marine Pollution
MDO	Marine Diesel Oil
MEPC	Marine Environment Pollution Committee
MGO	Marine Gas Oil
MRV	Monitoring, Reporting and Verification
N_2O	Nitrous Oxide
NMVOC	Non-methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
ODS	Ozone Depleting Substances
OPEX	Operational Expenses
PFCs	Perfluorinated Compounds
PM	Particulate matter
RED	Renewable Energy Directive
RO-PAX	Roll-on/Roll-off passenger ship
RO-RO	Roll-on/Roll-off (cargo) ship
SECA	Sulphur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SF_6	Sulphur Hexafluoride

SO_x	Sulphur Oxides
STEAM	Ship Traffic Emissions Assessment Model
TEU	Twenty-foot Equivalent Unit
UK	United Kingdom
UK MRV	United Kingdom's Monitoring, Reporting and Verification System
ULSFO	Ultra Low Sulphur Fuel Oil
UNCTAD	United Nations' Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds

ANNEX II - List of pollutants derived from a ship's operation, associated risks and opportunities and ccompliance obligations

<table>
<tr><th>Activity</th><th>Environmental Aspect</th><th>Environmental Impact</th><th>Associated Risks</th><th>Associated Opportunities</th><th colspan="4">Compliance Obligations
-
Limit</th><th>Process to control the aspect</th></tr>
<tr><td rowspan="5">Main & Auxiliary Engines Operation

Boilers' Operation

- Aerial Emissions</td><td>CO_2

Carbon Dioxide</td><td rowspan="5">Greenhouse effect

Ozone depletion

Global warming

Smog

Respiratory diseases

Acid rain

Photochemical Pollution</td><td>Non-Compliance to applicable legal requirements</td><td>As global temperature increases, new naval routes are to be developed in the arctic, resulting in significant reduction in distances between certain port destinations

New Fuels (Hydrogen, Ammonia, Biofuels, etc.)</td><td colspan="4">Ø</td><td rowspan="5">Rational use of marine fuels

New vessels are designed with low waste levels & highly efficient plant & equipment to support low-energy operation

Use of high quality (high thermogenetic power, low sulphur content, low water content) fuels

Reduce consumption

Strict implementation of engines' maintenance procedure as per instructions of manufacturer

Maintenance of cooling and lubrication systems as per instructions of manufacturer

Increase awareness

Active dialogue with customers

Active dialogue with manufacturers</td></tr>
<tr><td>SO_X

Sulphur oxides</td><td>Failing to change over to low sulphur fuel when required due to poor familiarization and training of the crew or to shortage of low sulphur fuel oil</td><td>New equipment (EGCS)</td><td colspan="4">Max 0.5 m/m S for all grades (global limit)

Max 0.1 % m/m S for all grades</td></tr>
<tr><td rowspan="3">NO_X

Nitrogen oxides</td><td rowspan="3">Non-Compliance to applicable legal requirements</td><td rowspan="3">Not identified</td><td>Tier</td><td>n[8] < 130</td><td>n < 130</td><td>n < 130</td></tr>
<tr><td>I</td><td>17</td><td>$45 \times n^{(-0.2)}$</td><td>9.8</td></tr>
<tr><td>II</td><td>14.4</td><td>$44 \times n^{(-0.23)}$</td><td>7.7</td></tr>
</table>

[8] n = engine's rated speed (rpm), Total weighed cycle emission limit (g/kWh)

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit				Process to control the aspect
					III[9]	3.4	$9 \times n^{(-0.2)}$	2	
	H_XC_X Unburned hydrocarbons	Photochemical Pollution		Not identified	Ø				
	Particulate Matter Emissions	Serious health issues Premature death	Non-Compliance to Company's Energy Efficiency Policy and to applicable legal requirements	Not identified	Ø				Rational use of marine fuels Use of high quality (high thermogenetic power, low sulphur content, low water content) fuels
Maintenance and operation	**Emissions from the use of incinerators**	Air pollution	Damage to Company's reputation due to poor familiarization and training	Not identified	Annex I, II and III Cargo residues PCBs, PVCs Halogen Compounds Heavy metals				Strict implementation of procedures regarding the use of incinerators
	Use of spare parts and consumables, packed in environmental harmful packaging	Downgrading of landscape and seascape Toxic impact to marine life	Improper storage, lack of timely disposal, risk of pollution Lack of recycling of packing material and other items Lack of social responsibility	Challenge to continual improvement Assign priority to suppliers with ability to collect packing material after supply	Cumulative concentrations Pb (lead) + Cd (cadmium) + Hg (mercury) + Cr Hexavalent <100 ppm				Strict observance of 94/62/EEC (as amended by Dir.2004/12/EC) by suppliers of packaged goods Encourage suppliers and subcontractors to have ISO 14001 certification Reduce garbage generated by excessive packing

[9] Tier III controls apply only to specified ships while operating in NECAs. Outside the NECAs, the Tier II controls apply (IMO, https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx)

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit	Process to control the aspect
	Ships recycling	Damage to sea and land Toxic impact to marine life Contamination of subterranean water	Health and Safety impacts	Financial profit from recycling Sustainable development Economic activity from associated industries Large scale direct/indirect employment	Ø	Recycling of scrap during hull repairs and maintenance Address environmentally sound ship recycling contracts Participation to industry initiatives Inventory of Hazardous Materials (IHM)
	Discharge of sludges at sea	Toxic impact to marine life Downgrading of seascape and coasts Ecological and navigational safety consequences Loss of biodiversity	Damage to Company's reputation due to poor familiarization and training Accidental release disposal of garbage/waste into environment Storage in unauthorized tanks, illegal means to reduce volume Regulatory violation, Financial Loss Health and respiratory problems from sandblasting Poor record keeping Lack of documentation	Not identified	prohibited	Strict implementation of sludge monitoring procedures
	Discharge of oily bilge water at sea			Not identified	Oil content in the effluent ≤ 15ppm	Strict implementation of bilge monitoring procedures
	Oil spill from Bunkering/ Collision / Stern tube lube oil/ / IGS effluent discharge/ Drydocking repairs, Propeller shaft leakages, Hull cleaning, Propeller polishing			Not identified	prohibited	Strict implementation of bunkering procedures Maintenance in good order to minimize leakages Materials removed during hull cleaning and/or propeller polishing must be collected and disposed ashore Use hull coatings with the lowest effective biocide release rates Monitoring of leakages from propeller shaft and stern tube
	Uncontrolled disposal of Solid Waste/Garbage at sea and on land/ Garbage production			Not identified	As per Revised MARPOL Annex V Garbage Management Plan	Strict implementation of Garbage Management Plan Reduce quantity of garbage

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit	Process to control the aspect
	Use of TBT, cybutryne or other tri-organotin antifouling	Serious toxic impacts to marine life	Non-Compliance to Company's relevant procedures and to applicable legal requirements	Not identified	prohibited	Exclusive use of TBT-free antifouling systems
Maintenance and operation	**Noise (including underwater radiated noise)**	Temporary or Permanent damages to hearing Long-term negative consequences on marine life	May influence communication and understanding efficiency of involved personnel Cetaceans' disorientation and implications for reproduction and survival	Not identified	Use of ear protectors over the noise regulated limits Provide acceptable noise environment for seafarers & maintain as low as practicable ambient noise levels Reduce any disturbance to marine life	Strict observation of employees' ear protection measures Reduce of speed during passage through sensitive areas
Crew Accommodation	**Uncontrolled discharge of untreated Sewage - Grey water**	Algal bloom Downgrading of landscape and seascape	Ports and Terminal without waste reception facilities	Not identified	Discharge of effluents through sewage treatment plant	Strict implementation of procedures regarding handling of sewage and maintenance of sewage treatment plant
Crew Accommodation	**Emissions of Chlorofluoro-carbons CFCs & Ozone Depleting Substances**	Depletion of ozone layers	Degraded environment	Not identified	Prohibition of CFCs /HCFC production (HCFC-22 from 2020 and HCFC-123 from 2030) From 1/1/2015, the use of R22 is illegal	Strict implementation of procedures regarding maintenance of air condition systems
Office/ Ship Operation	**Fuel consumption in ships**	Lack of natural resources Global warming and GHE	Poor quality of fuels Excessive sludge production	Fuel saving results in financial profit	Ø	Reduce consumption Implementation of engines' maintenance as per maker's instructions Use of Antifouling Paints/Hull and propeller cleaning

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit	Process to control the aspect
	Fresh water purchased in ships	Lack of resources	Contamination and Infectious disease transmission through hazardous water	Improve awareness on methods to conserve FW/ Minimization of plastic bottles use		Rational use of fresh water Increase awareness
Office/ Ship Operation	**Electric energy consumption in offices**	Lack of resources Global warming and GHE	Short-circuit	Improve awareness on methods to conserve electricity	Ø	Rational use of electric energy Increase awareness
	Fresh water consumption in offices	Lack of resources	Damage to the hydraulic installation	Improve awareness on methods to conserve FW/ Minimization of plastic bottles use		Rational use of fresh water in offices Increase awareness
	Paper consumption in offices	Lack of resources	Lack of free space in office area Lack of recycling facilities Global warming, deforestation Loss of printed documents & records	Use of recycled paper	Ø	Rational use of photo copy paper and printouts. Double side printing. Use of electronic correspondence and filling to the max. extent. Use/recycle paper. Promote recycling.

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit	Process to control the aspect
Crew Accommodation	**Illegal disposal of hazardous waste (i.e., batteries, medical waste, fluorescent lamps, aerosol cans, chemical products, pyrotechnics, detergents, plastic, empty antifouling paint, lubricating, hydraulic oil & empty chemical drums)**	Toxic impact to marine life & damage to human health	Ports and Terminal without waste reception facilities Lack of initiative to find alternate product	Not identified	Prohibition of incineration and controlled discharge	Strict implementation of procedures regarding disposal of hazardous waste
Cargo Operations	**Ballast Operations**	Contaminating the marine environment with foreign microorganisms and/or bacteria	Failing to comply with requirements/ Damage to company’s reputation due to poor familiarization and training Poor record keeping Lack of documentation	Not identified	Ballast Water Management plan Ballast Water record book	Strict implementation of Water Ballast Management Plan Increase awareness and knowledge
	Accidental oil discharges (crude oil / /chemical/ oil product cargoes)	Downgrading of landscape and seascape Toxic impact to marine life Loss of fisheries	Non-Compliance with applicable legal requirements Severe damage to company’s reputation due to poor familiarization and training	Not identified	Limit of discharge as per Annex I-Reg. 34 & Annex II-Reg. 13	Strict implementation of procedures regarding discharge of cargo

Activity	Environmental Aspect	Environmental Impact	Associated Risks	Associated Opportunities	Compliance Obligations - Limit	Process to control the aspect
	Accidental discharge of slops & cargo residues into the sea	Downgrading of landscape and seascape Toxic impact to marine life Loss of fisheries	Severe damage to company's reputation due to poor familiarization and training	Not identified	Limit of discharge as per Annex I-Reg. 34 & Annex II-Reg. 13	Strict implementation of procedures regarding handling of slops
	Emission of Volatile Organic Compounds (VOCs) **(applicable only for crude oil tankers)**	Green-house effect Acid rain Photochemical Pollution	Non-Compliance to applicable legal requirements	Not identified	VOC emissions to be monitored and minimized to the extent possible	Strict implementation of procedures regarding monitoring and control of VOC. VEC implementation when possible
Maintenance and operation	**Open Loop Exhaust Gas Scrubber Wash Water Effluent (if applicable)[10]**	Marine Pollution in ≤ 4 meters from the vessel	Regulatory violation, Financial Loss	Not identified	As per local restrictions (State or Port)	Strict implementation of Company's procedures, monitoring of forthcoming regulations and manufacturer's manual for EGCS

Source: Alpha Marine Consulting P.C., 2025

[10]Wash Water is neutralized in distance > 4 meter

ANNEX III - Key regulations and Conventions addressing air emissions from shipping

Regulation / Convention	Issued by	Scope	Key Provisions	Date of Enforcement
MARPOL Annex VI	IMO	Prevention of air pollution from ships	Sets limits on SOx, NOx, and PM emissions. Establishes Emission Control Areas (ECAs).	19 May 2005
Global Sulphur Cap	IMO	Reduction of sulphur content in fuel oil to 0.50% (from 3.50%)	Requires use of low-sulphur fuels or alternative technologies (e.g., scrubbers)	1 January 2020
Energy Efficiency Design Index (EEDI)	IMO	Technical measure to reduce GHG emissions	Mandates energy-efficient ship design for newbuilds.	1 January 2013
Energy Efficiency Operational Indicator (EEOI)	IMO	Voluntary operational measure to improve energy efficiency	Provides a performance indicator to monitor CO_2 emissions per transport work.	Introduced 2009
Energy Efficiency Existing Ship Index (EEXI)	IMO	Technical measure for existing ships to meet energy efficiency standards	Requires existing ships to calculate and meet energy efficiency standards similar to EEDI.	1 January 2023
Estimated Index Value (EIV)	IMO	Ship design performance indicator for CO_2 emissions	Early-stage calculation for CO_2 emissions based on design parameters for energy-efficient ships.	Introduced 2011
Ship Energy Efficiency Management Plan (SEEMP)	IMO	Operational measure to improve energy efficiency	Encourages onboard practices and ship routing to reduce fuel consumption.	1 January 2013
Carbon Intensity Indicator (CII)	IMO	Framework for operational carbon intensity performance	Requires ships to calculate and report their annual CII and maintain specified rating thresholds.	1 January 2023
IMO Data Collection System (DCS)	IMO	Collection of fuel oil consumption data from ships	Ships >5,000 GT must collect and report annual fuel oil consumption data to their flag state.	1 March 2018
EU Monitoring, Reporting, and Verification (MRV) Regulation	European Union	CO_2 emissions from ships calling at EU ports	Requires Ships >5,000 GT to monitor, report, and verify CO_2 emissions, fuel consumption, and cargo carried.	1 July 2015
EU Emissions Trading System (ETS Maritime)	European Union	Cap-and-trade system for GHG emissions	Expands to cover shipping emissions requiring operators to purchase allowances for CO_2 emissions.	1 January 2024
Fit for 55 Package	European Union	Legislative package to reduce EU GHG emissions by 55% by 2030	Includes a basket of measures like maritime ETS, FuelEU Maritime, AFID updates, and taxation reforms under ETD.	Proposed July 2021 (Phased from 2024)
European Green Deal	European Union	Broad framework for EU climate neutrality by 2050	Targets 55% GHG emissions reduction by 2030, promotes sustainable transport, alternative fuels, and energy efficiency.	Announced 11 December 2019 (Phased)

Alternative Fuels Infrastructure Directive (AFID)	European Union	Infrastructure for alternative fuels in transport	Sets requirements for LNG bunkering, shore-side power (OPS), and infrastructure for alternative fuels.	18 November 2014 (Directive 2014/94/EU)
Renewable Energy Directive (RED)	European Union	Promotion of renewable energy, including in shipping	Requires renewable fuels in transport and sets targets for advanced biofuels and renewable energy use.	RED II: 1 July 2021
Energy Taxation Directive (ETD)	European Union	Taxation of energy products and electricity	Includes plans for taxing marine fuels to align with EU climate goals.	Under revision (initial 2003)
FuelEU Maritime Regulation	European Union	Aims to increase uptake of renewable and low-carbon fuels	Sets GHG intensity limits for ship energy use and incentivizes alternative fuels and technologies.	1 January 2025
Sulphur Directive	European Union	Reduction of sulphur content in fuel oil (maximum of 0.10% for ships in EU ports)	Requires use of low-sulphur fuels or alternative compliance technologies (e.g., scrubbers)	1 January 2010
Clean Shipping Act	United States (State Level)	Air quality and pollution in coastal and port areas	Establishes stringent state-level emission requirements (e.g., California).	Varies (e.g., CA 2006)
Port State Control (PSC)	Regional Cooperation	Compliance with international emission rules	Inspects ships for compliance with MARPOL Annex VI and other emission standards.	Continuous (Region-Specific)
NOx Technical Code	IMO	Technical requirements for NOx emission control	Sets standards for marine diesel engines regarding NOx emissions.	19 May 2005
Hong Kong Convention (2009)	IMO	Safe and environmentally sound ship recycling	Limits environmental harm, including emissions during dismantling.	26 June 2025
Greenhouse Gas Strategy	IMO	GHG reduction in international shipping	Targets a 50% reduction in GHG emissions by 2050, aiming for zero emissions later.	Adopted 2018 (Ongoing)

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