JOURNAL OF MARITIME RESEARCH

Vol XX. No. II (2023) pp 141–147

ISSN: 1697-4840, www.jmr.unican.es

Evaluating the Economic Implications of the EU Emissions Trading System (EU-ETS) on the Energy Supply Chain through Maritime Transport

Carlos González[1,*]

ARTICLE INFO

Article history:
Received 9 Jun 2023;
in revised from 10 Jun 2023;
accepted 02 Jul 2023.

Keywords:
EU ETS, Shipping, GHG Emissions, Energy mix.

ABSTRACT

Climate change has emerged as a pressing global concern, prompting diverse stakeholders to actively seek ways to reduce the environmental impact of human activities on the atmosphere. Market-based measures have been recognized as key strategies for achieving emission reduction targets. In this context, the inclusion of shipping in the European Union Emissions Trading System (EU ETS) has gained considerable attention due to its potential to drive significant changes in the energy supply chain within the EU.

This paper examines the specific implications of integrating shipping into the EU ETS, with a particular focus on ships involved in the transportation of energy goods within the European Union. Given the substantial role of ships in delivering essential energy supplies to Europe, understanding the economic impact and financial exposure of energy carriers to the EU ETS is of paramount importance.

1. Introduction.

Climate change is a major topic nowadays, this phenomenon is anthropogenic and has a direct relation with the increase of population (Papadis and Tsatsaronis 2020) due to the population increase seems to be a constant trend, some actions shall be taken to tackle the climate change.

One of the instruments available for such purpose are the promulgation of environmental regulations or climate policies aim to reduce the anthropogenic footprint in a cost-effective manner (Rhodes et al. 2021). In this regard, Market Based Measurements (MBMs) is one of the existing approaches used as climate policies which is using the "polluters-pays" principle (Lagouvardou et al. 2020), having the advantage of generating funding to subsidize the investment in green technologies (Cariou et al. 2021) which in consequence should accelerate the climate change mitigation.

Some MBMs have been internationally promulgated since the International Kyoto Protocol was defined, being Emissions Trading System (ETS) one of the mechanisms introduced globally and expected to be an efficient way towards decarbonization targets (Villoria-Sáez et al. 2016; Schinas and Bergmann 2021). By coverage, the European ETS (EU ETS), which is in operation since 2005, is the second biggest cap-and-trade carbon market in the world after China's emissions trading scheme (Statista 2022). Emissions trading, also known as 'cap and trade,' is a cost-effective way of reducing greenhouse gas emissions (Guo et al. 2020).

Pushed by the European Union (EU), the International Maritime Organization (IMO) has considered the implementation of MBMs to achieve the target of reducing the carbon emissions of global shipping by at least 50% in 2050 compared with 2008 (IMO 2018; UNFCCC 2018). As a major step for the maritime transport, the European Parliament, Council of the European Union, and the European Commission have reached an agreement on including shipping in the EU ETS from 2024. Traditionally, ETS has proven to be a powerful motivator for emissions reduction; as the trading prices get higher, there is an increased reduction in carbon emissions (Chang et al. 2019). According to United Nations Conference on Trade and Development (UNCTAD), shipping is responsible for more than 80% of world trade and the total industry contribution to the world

[1]Universidad de Cantabria. Santander, España.
*Corresponding author: Carlos González. E-mail Address: carlos.gonzalezgu@alumnos.unican.es.

economy is estimated at 1-3% of world Gross Domestic Product (Ben-Hakoun et al. 2016), so its inclusion into the EU ETS scheme will have a significant impact on the sector.

The case of including shipping in the EU ETS is based on the emission allocation methodology based on transport work, more complex, given the technical and operational differences among maritime segments. Under the EU ETS each company with ships trading in the Europe and/or European Economic Area (EU/EEA) is required to surrender emission allowances corresponding to a certain amount of its GHG emissions emitted over a calendar year starting with 2024. The emissions will be reported and verified through the existing EU MRV (Monitoring, Reporting and Verification) system, which will be revised and extended to cover necessary greenhouse gases (GHG) emissions, ship types and sizes. From 2024 the EU ETS will include ships above 5000 gross tonnage (GT) transporting cargo or passengers for commercial purposes. From 2024 the EU ETS will include CO_2 emissions only, while the EU MRV will be extended the same year to include reporting of methane (CH_4) and nitrous oxide (N_2O) which are two other GHG emitted by ships. From 2026 the EU ETS will also include these two GHGs. All 100% of emissions on voyages and port calls within the EU/EEA, and 50% of emissions on voyages into or out of the EU/EEA are subject to the EU ETS. The regulation will also include measure to avoid carbon leakage or evasive behaviours.

The economic impact from the inclusion of shipping in the EU ETS varies depending on the geographical scope of the system, the price of emission allowances (Christodoulou et al. 2021).

This paper aims to assess the implications of the inclusion of shipping into EU ETS, more in specific the implications of this fact in such vital sector as is the energy, analysing the financial exposure of the shipping segments involved in the European energy mix, denominated in this work energy carriers, and it is included the oil tankers, gas carriers and Liquified Natural Gas (LNG) carriers. There is another type of energy carrier, but it has been omitted due to the lack of cargo data, this type of ship are the bulk carriers transporting coal.

The data used for the assessment come from the EU MRV system (UE 2015; Bullock et al. 2020), as well as surveys launched among major brokers to obtain freight fees for the different segments and vessel's type. The assessment model used is scenario-based, and include the different coverage per year, geographical scope of the system and emission allowances allocation methods.

The rest of this paper is structured as follows: 2. EU Energy supply chain and the role of the shipping, 3. Methodology and data, 4. Results and then 5. Conclusions and 6. References.

2. EU Energy supply chain and the role of shipping.

Eurostat has different databases and analysis about the EU energy mix. The last verified data is for 2020, and it indicates that the energy mix in 2020 consists by 34.5% of oil and petroleum products, 23.7% of natural gas, 17.4% of renewables, 12.7% of nuclear energy and 10.5% of solid fossil fuels. Regarding the higher energy consumers, transport, households, and the industry accounts for 82.5% of the total energy consumed in 2020.

The shipping is having a key role for supplying the raw materials for the energy mix, transporting crude and product oils, LNG, liquified petroleum gases (LPG) and coal, which are used for electrical generation, heating, and transportation.

By looking at the MRV public data for 2021, published by EMSA, 1,854 crude/products oil carriers called into EU/EEA ports, 327 LPG carriers and 287 LNG carriers also called to EU/EEA ports in 2021. The last energy source is the coal which still is covering part of the EU energy production at quite extent (Jonek-Kowalska 2022), in 2021, EU/EEA ports receives from ships 7.5% of the total coal trade worldwide (Hellenic Shipping News Worldwide 2022), it is not possible with the existing public dataset to know the number of port calls of bulk carriers transporting coal, but what it is known is that more than 80 million tons of coal were trade in EU in 2021 (Hellenic Shipping News Worldwide 2022).

In 2021, crude oil trade was around 880 million of tons and product oil trade was 429 million of tons in Europe (UNCTAD 2022). 75.1 million of tons of LNG were received from ships in Europe in 2021 (IGU 2022). Regarding the LPG trade by ships in EU in 2021, it was moved 22 million of tons (SIGTTO 2022) in EU/EAA ports.

3. Method and data.

We investigate the inclusion of shipping in the EU ETS in the energy supply chain, assessing the economic effect and financial exposure of the ships carrying goods which are essential part in the energy supply chain in Europe. The ship types analysed are the crude/ product oil tankers, LNG carriers and LPG carriers. Due to is not possible to identify in the available MRV dataset the type of cargo carried by ships in EU ports, coal carriers have not been analysed.

The methodology used is a scenario-based approach. The three ship types that are analysed in this paper are crude oil / product tankers, LNG carriers and LPG carriers.

To assess the exposure of the ships which are transporting raw products to be used as part of the EU energy mix, the data used came from the public MRV database managed by the European Maritime Safety Agency (EMSA) for 2021. Technical data for the ships is received consulting the IHS Fairplay database. The daily charter rates have been obtained from public sources but also, from surveys across the major ship brokers.

The information available in MRV database includes, among other, the total fuel consumption and CO_2 emissions per ship. Unfortunately, the cargo type and the fuel type consumed are not register in the database. We assumed that the three types of ships under this assessment were carrying cargoes for energy production either for industry, transportation, or households.

The fuel type consumed is also relevant for our analysis due to the approach used to calculate the CO_2, CH_4 and N_2O emissions is fuel based (see Table 1), therefore, each fuel type has associated one emission factor. We have overcome this issue using the fuel mix used in the GHG reports published by IMO (Smith et al. 2014; IMO 2020) for crude/oil tankers and LPG carriers, while for LNG carriers it is used the fuel mix proposed in González Gutiérrez et al. (2020,2022).

From 2026, the CH_4 and N_2O emissions will be considered in the EU ETS, in addition of the CO_2. Most likely, the way of reporting these three GHG will be expressing them as CO_2 equivalent, multiplying each of them by their Global Warming Potential (GWP) value for 100 years (see Table 2).

Table 1: Emission factors (fuel based) for CO_2, CH_4 and N_2O.

Fuel Type	CO_2	CH_4	N_2O
RO	3.114	0.00006	0.00016
DO	3.206	0.00006	0.00015
LNG	2.750	0.05120	0.00011

Source: Smith et al. 2015.

Table 2: GWP values for 100 years for GHG considered in EU ETS (fifth assessment).

Fuel Type	GWP 100
CO_2	1
CH_4	28
N_2O	265

Source: GHG Protocol 2016.

To analyse the financial exposure, it has been considered the minimum, average and maximum price of the carbon credits for 2022 (Trading Economics 2023), the allowances or carbon credits used in this work are 60, 85 and 98 EUR per carbon credit.

The economic impact for the ships is analysed comparing the daily charter fee in 2023 versus the daily financial exposure of the EU ETS on these ships.

In general, for the energy carriers considered in this paper, the daily rates in 2023 are influenced by the war situation between Russia and Ukraine. The daily rate for oil tankers ships based on vessel size, is shown in the Table 3. Same information for LPG ships is shown in the Table 4 and for LNG carriers in Table 5.

The charter rates are expressed in US Dollar per day, to convert it to EUR per day, 0.94 has been used as exchange factor.

Table 3: Time charter rates for 1 year for oil tankers eco-tonnage with Scrubber fitted.

Size	Handy	MR	LR 1	Aframax	LR 2	Suezmax	VLCC
Deadweight (tons)	15000 - 25000	25000 - 45000	45000 - 80000	80000 - 120000	80000 - 160000	120000 - 200000	200000 - 320000
Time charter (USD/day)	24 000	27 500	36 500	40 000	40 000	42 500	45 000

Source: Alibra Shipping Limited 2023.

Table 4: Time charter rates for 1 year for LPG ships.

Category	1	2	3	4	5	6
Capacity (m^3)	< 3200	3200 - 6500	6500 - 8250	8250 -28000	28000 – 59000	>59000
Time charter (USD/day)	11 184	15 132	16 283	26 316	33 717	38 322

Source: StealthGas 2023.

Table 5: Time charter rates for 1 year for LNG ships.

	Prop. Systems				Size (1		
	Steam	TFDE	MGI	MSD	145k m^3	160k m^3	174k m^3
Time charter (USD/day)	54 000	106 000	171 000	80 000*	70 000	157 000	229 000

MSD: Slow diesel engines, **MGI**: 2-stroke gas engines**, TFDE**: 4-stroke gas engines part of diesel electric propulsion system

*These ships are the LNG carriers known as Q-Flex and Q-max, it has not been possible to find the charter rates as open access, therefore, it has been decided to set a daily rate intermediate between steam ships and TFDE. (1 these values come from surveys among ship brokers and charters.
Source: Splash 24/7, 2023.

4. Results.

In this section, it is shown the results of the economic impact and financial exposure of energy carriers as consequence of the inclusion of the shipping in the EU ETS.

Using the latest data verified and available in EMSA, which is for year 2021, the total amount of CO_2 emissions is shown in the Table 6.

Table 6: Total CO_2 emissions in EU in 2021.

Vessel type	CO_2 emissions (million tons)				
	Between EU/EEA Ports	From EU/EEA port to non-EU/EEA ports	From non-U/EEA port to EU/EEA ports	At EU/EEA Port	Total
Gas Carrier	0.457	0.898	0.869	0.178	**2.402**
LNG Carrier	0.135	2.949	3.076	0.168	**6.328**
Oil Tanker	2.096	5.991	6.443	1.726	**16.256**
Total	**2.688**	**9.838**	**10.388**	**2.072**	**24.986**

Most of the CO_2 emissions are allocated in voyages from EU/EEA ports to non-EU/EEA ports with around 42% of the total CO_2 emissions. Around 11% of the total CO_2 emissions are produced for voyages between EU/EAA ports, while approximate 8% of the total CO_2 are emitted at berth.

In 2021, 583 Aframax tankers sailed from/to or within EU/EEA ports, being the most represented energy carrier operation in Europe with the 23.6% of the total energy carriers under analysis. The gas carriers between 3200 and 6500 m^3 of cargo capacity and the LNG carriers with MSD propulsion system onboard are the ones accounting lowest number of voyages within the EU ETS framework.

Analysing the atmospheric impact of each ship type (Table 7), in the Gas Carrier fleet operation under the EU ETS framework, the gas carrier with cargo capacity between 8250 and 28000 m^3 are emitting the highest total CO_2 emissions for this fleet. For the LNG carriers, the ships with TFDE are responsible of the highest total amount of CO_2 emission for this fleet, while for oil tankers, the Aframax tankers are the highest contributor to the total CO_2 emissions for the oil tankers fleet in 2021.

Table 7: Total CO_2 emissions in EU in 2021 per vessel category.

		CO_2 emissions (million tons)			
Vessel Type	Ship Category	Between EU/EEA Ports	From EU/EEA port to non-EU/EEA ports	From non-EU/EEA port to EU/EEA ports	At EU/EEA Port
Gas Carrier	1	0	0	0	0
	2	0.100	0.022	0.020	0.021
	3	0.116	0.144	0.135	0.044
	4	0.149	0.417	0.393	0.055
	5	0.086	0.154	0.160	0.035
	6	0.006	0.161	0.161	0.023
LNG Carrier	MGI	0.039	0.617	0.668	0.036
	MSD	0.009	0.343	0.413	0.018
	Steam	0.027	0.909	0.888	0.044
	TFDE	0.060	1.079	1.107	0.071
Oil Tanker	Aframax	0.502	2.189	2.647	0.763
	Handy	0.375	0.240	0.242	0.124
	LR1	0.445	1.160	1.136	0.279
	LR2	0.319	1.243	1.493	0.326
	MR	0.414	0.360	0.399	0.157
	Suezmax	0.022	0.177	0.191	0.049
	VLCC	0.020	0.621	0.335	0.027

40% of the total population is living near to the coastal areas (UN 2017), therefore the impact of the energy carriers at port is also relevant due to its impacts on humans and animals. As a briefly assessment, from the available data, focusing on SO_x and Particulate Matter (PM) as two pollutants very harmful for the health of the persons and animals, it can be seen that the oil tankers are responsible of 42% of the SO_x and PM emissions at port of the total energy carriers emissions, and per ship´s category, the Aframax tankers are the higher individual contributor with 18% of the SO_x and PM emissions at EU/EEA ports.

4.1. Economic impact of EU ETS for energy carriers.

In this section we analyse the economic impact of the energy carriers using a scenario-based approach with three different prices for the emissions allowance (60, 85 and 98 EUR) as it is shown in Table 8.

In 2024, the economic impact for the energy carriers could be from 600 to 1,075 million of EUR depending on the emissions allowance used.

Oil tankers is the type of energy carrier more influenced for the inclusion of the shipping in the EU ETS. Guessing the cost of the allowance of 85 EU per ton of CO_2, the oil tankers would need to pay in the first year of implementation of shipping into the EU ETS, 553 million EUR, also influenced for being the type of energy carrier which was calling the most in European ports in 2021, being the 75% of the total energy carriers.

As it has been mentioned in previous sections, in 2026 the EU ETS will also consider the CH_4 and N_2O emissions in addition to the CO_2 emissions. All these three pollutants are GHG, so they are going to be expressed as CO_2 equivalent to get a representative figure for GHG. This fact is going to impact on ships using LNG as fuel due to the methane slip (Ushakov et al. 2019; Jensen et al. 2021; Wu et al. 2022; Taghi Zarrinkolah and Hosseini 2023). As an estimation, the inclusion of CH_4 and N_2O on the EU ETS in 2026 would increase around 1.4% the economic impact, while on LNG carriers that are using LNG as their primary fuel, the economic impact might go up to 34%.

4.2. Financial exposure of the energy carriers due to its inclusion in EU ETS.

In this subsection we try to contextualize the economic impact comparing the EUA daily exposure versus the daily time charter fee for each vessel type and category. In addition, it is going to show a voyage simulation for different energy carriers.

Table 8: Exposure of energy carriers in EU ETS framework.

	Million Euros (million EUR)				
Year	Scenario	Gas Carrier	LNG Carrier	Oil Tanker	Total
2024	EUA 60 EUR	57.669	151.843	390.473	599.985
	EUA 85 EUR	81.698	215.111	553.171	849.979
	EUA 98 EUR	95.502	322.439	646.584	1,064.525
2025	EUA 60 EUR	100.921	265.725	683.328	1,049.974
	EUA 85 EUR	142.971	376.443	968.049	1,487.463
	EUA 98 EUR	167.128	564.269	1,131.521	1,862.918
2026	EUA 60 EUR	146.176	508.857	989.669	1,629.375
	EUA 85 EUR	207.083	720.881	1,402.031	2,308.281
	EUA 98 EUR	238.755	831.755	1,616.459	2,661.312

Source: EUA - European emission allowances.

Table 9: Percentage of the Time Charter daily rate consumed by daily EUA.

		2024			2025			2026		
	Ship Category	EUA60	EUA85	EUA98	EUA60	EUA85	EUA98	EUA60	EUA85	EUA98
Gas Carrier	2	3.4%	4.8%	5.6%	6.0%	8.5%	9.8%	19.8%	28.0%	32.3%
	3	5.1%	7.2%	8.3%	8.9%	12.7%	14.6%	32.4%	45.9%	52.9%
	4	2.9%	4.2%	4.8%	5.1%	7.3%	8.4%	18.6%	26.3%	30.3%
	5	3.1%	4.4%	5.1%	5.4%	7.7%	8.9%	19.7%	27.9%	32.2%
	6	3.6%	5.1%	5.9%	6.3%	8.9%	10.3%	22.8%	32.4%	37.3%
LNG Carrier	MGI	1.2%	1.8%	2.0%	2.2%	3.1%	3.5%	10.4%	14.7%	17.0%
	MSD	5.0%	7.0%	8.1%	8.7%	12.3%	14.2%	31.4%	44.4%	51.2%
	Steam	5.9%	8.4%	9.7%	10.4%	14.7%	17.0%	49.8%	70.6%	81.4%
	TFDE	2.4%	3.4%	3.9%	4.2%	5.9%	6.8%	20.0%	28.3%	32.6%
Oil Tanker	Aframax	2.8%	4.0%	4.7%	5.0%	7.1%	8.1%	18.1%	25.6%	29.5%
	Handy	2.8%	3.9%	4.5%	4.8%	6.8%	7.9%	17.4%	24.7%	28.5%
	LR1	2.3%	3.2%	3.7%	4.0%	5.7%	6.5%	14.5%	20.6%	23.7%
	LR2	3.3%	4.7%	5.4%	5.8%	8.2%	9.5%	21.0%	29.7%	34.2%
	MR	2.8%	4.0%	4.6%	4.9%	7.0%	8.0%	17.8%	25.2%	29.1%
	Suezmax	3.6%	5.2%	5.9%	6.4%	9.0%	10.4%	23.1%	32.7%	37.7%
	VLCC	4.2%	6.0%	6.9%	7.4%	10.5%	12.1%	26.7%	37.9%	43.7%

Source: EUA - European emission allowances.

The Table 9 shows the amount of the daily time charter fee which would be used to buy emissions allowances in 2024, 2025 and 2026, for each vessel type.

With the time charter rates found in March 2023, the data shows that in general, the Steam LNG carriers and the gas carriers with a cargo capacity between 6500 and 8250 m3 are the ships which would be more exposed by the EU ETS. These two ship types in 2024, would need to allocate between 5 and 10% of the daily time charter rate to surrender the daily CO_2 emissions depending on the best- and worst-case scenario analysed. These percentages, keeping the same time charter rate, would go between 32 to 80% of the total time charter daily rate to pay the EAUs in 2026. For oil tanker, the VLCC tankers would be the type of oil tanker which would be more financially exposed to EU ETS as shown in Table 9.

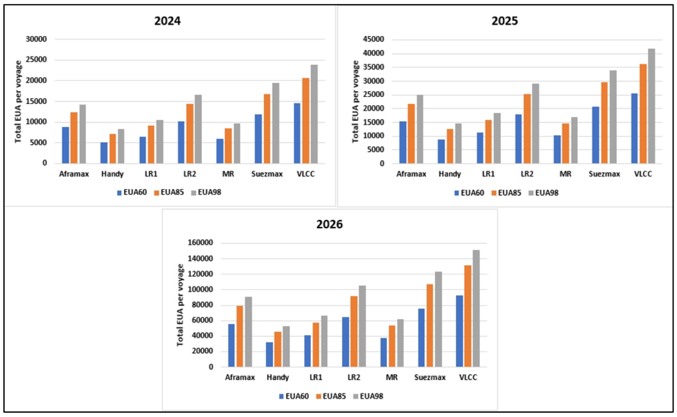
4.2.1. Voyage simulation for Energy carriers.

It has been done a simulation from a voyage from/to non-EU/EEA to/from an EU/EEA port, having a distance between the ports of 4800 nautical miles. We simulate a voyage as well between EU/EEA ports, where distance sailed assumed 3600 nautical miles. The average speed used for gas carriers were 14.5 knots, 17.2 knots for LNG carriers and 13 knots for oil tankers.

The voyage definition on the MRV regulation, used as based for EU ETS, is "berth to berth." Hence, a voyage starts at berth of one port of call and ends at berth of the next port of call. The days at berth used for gas carriers is 1.03, 1.13 for LNG carriers and 0.98 days for oil tankers.

The simulations have been done for the three categories of

Figure 1: EU ETS voyage exposure simulation from/to non-EU/EEA port to/from EU/EEA port for oil tankers.

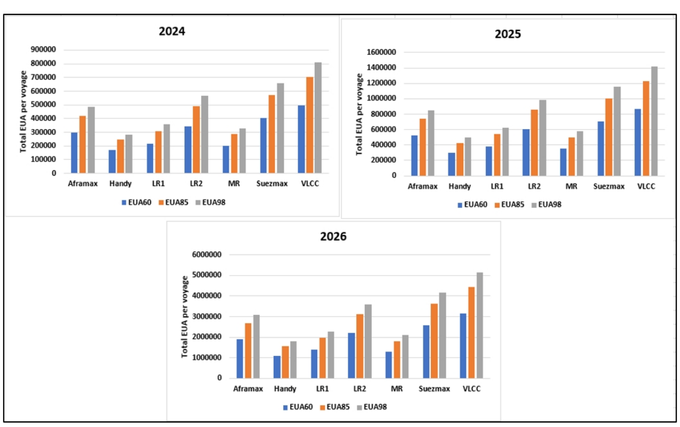


Source: Author.

ships separately. For oil tankers, simulating a voyage from/to non-EU/EEA port to/from a EU/EEA port (Figure 1), VLCC is the ship with highest exposure with EUA costs from 14k to 23k EUR per voyage in 2024, from 25k to 41k EUR for the same voyage in 2025 and from 92k to 151k EUR for same voyage in 2026.

For oil tankers, simulating a voyage between-EU/EEA ports (Figure 2), VLCC is again the ship with highest exposure with EUA costs from 49k to 81k EUR per voyage in 2024, from 86k to 141k EUR for the same voyage in 2025 and from 314k to 513k EUR for same voyage in 2026.

Figure 2: EU ETS voyage exposure simulation within EU/EEA ports for oil tankers.

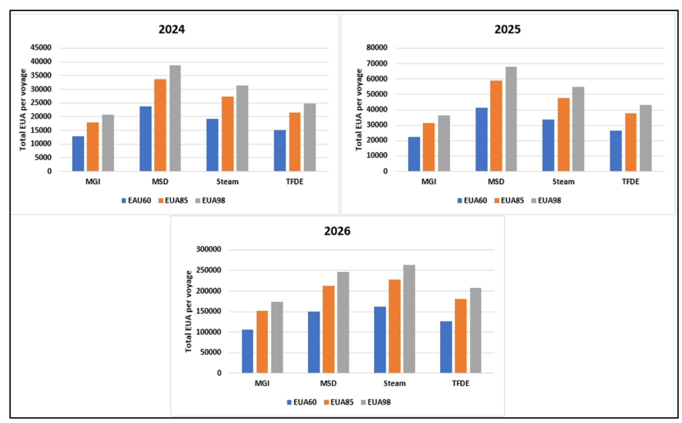


Source: Author.

In regards LNG carriers, simulating a voyage from/to non-EU/EEA port to/from a EU/EEA port (Figure 3), LNG carriers with MSD and Steam turbines are the ships with highest exposure with EUA costs from per voyage. MSD ships would be the highest exposure until 2026 when the steam ships become the LNG carrier type more financially exposed, having the highest exposure due to the EU ETS between 63k to 67k EUR extra per voyage until 2025, and from 2026 the exposure goes from 150k to 263k EUR extra per voyage. Simulating a voyage between-EU/EEA ports (Figure 4), it is observed the same trend, the ships with highest exposure would have an additional costs due to the EU ETS from 63k to 223k EUR extra per voyage until 2025, and from 2026 the exposure goes from 496k to 869k EUR extra per voyage.

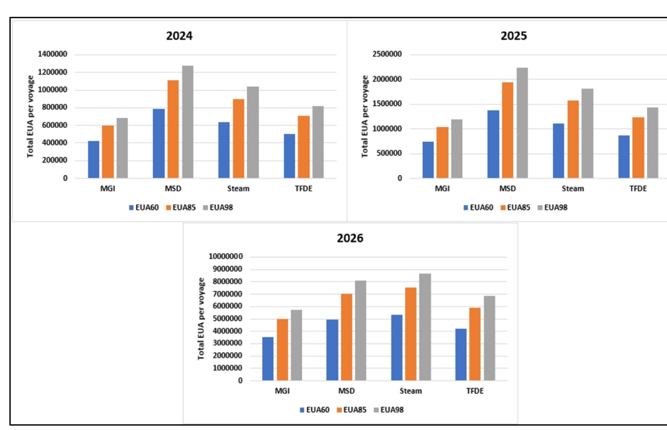
For gas carriers, simulating a voyage from/to non-EU/EEA port to/from a EU/EEA port (Figure 5), Very Large Gas Carriers (VLGC) is the gas carrier type with highest exposure with EUA costs from 9k to 15k EUR per voyage in 2024, from 16k to 27k EUR for the same voyage in 2025 and from 60k to 99k EUR for same voyage in 2026. The gas carriers, simulating a voyage between-EU/EEA ports (Figure 6), again the VLGC is again the ship with highest exposure with EUA costs from 32k to 52k EUR per voyage in 2024, from 56k to 92k EUR for the same voyage in 2025 and from 205k to 334k EUR for same voyage in 2026.

Figure 3: EU ETS voyage exposure simulation from/to non-EU/EEA port to/from EU/EEA port for LNG Carriers.



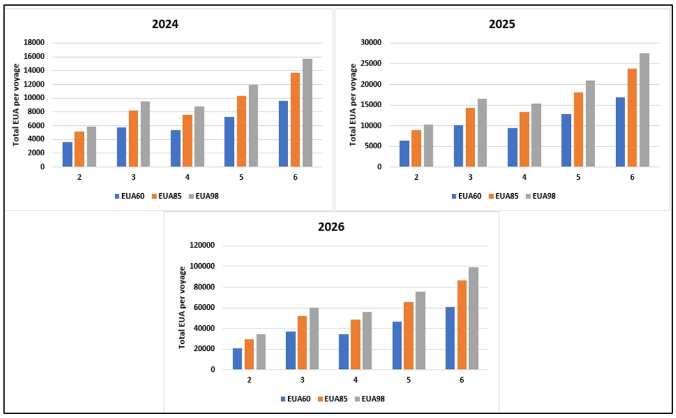
Source: Author.

Figure 4: EU ETS voyage exposure simulation within EU/EEA ports for LNG carrier.



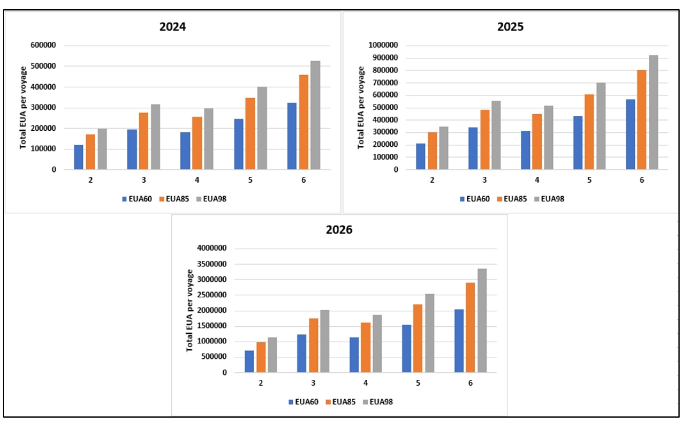
Source: Author.

Figure 5: EU ETS voyage exposure simulation from/to non-EU/EEA port to/from EU/EEA port for Gas Carriers.



Source: Author.

Figure 6: EU ETS voyage exposure simulation within EU/EEA ports for Gas carrier.



Source: Author.

Conclusions.

The inclusion of shipping in the European Union Emissions Trading System (EU ETS) holds significant economic implications for the shipping industry and contributes to the reduction of atmospheric emissions. The surrendering of emission allowances (EUAs) based on MRV-reported data will require ships, particularly oil tankers, gas carriers, and LNG carriers, which emitted 25 million tons of CO2 in 2021, to navigate an estimated economic exposure of around 2000 million euros, with each EUA valued at an average of 80 EUR.

The potential future inclusion of additional greenhouse gases such as methane and nitrous oxide in the EU ETS from 2026 may pose economic challenges for LNG carriers heavily reliant on LNG as their primary fuel source, potentially leading to a negative economic impact of around 34%.

Analysing the case scenarios, we found that energy carriers operating under the EU ETS regulation would need to allocate approximately 10% of their daily time charter rate for the purchase of EUAs in 2024. However, by 2026, this percentage could increase to 80% for LNG carriers with steam ships and up to a maximum of 50% for other carriers, significantly impacting their voyage economics.

To mitigate the economic effects of the EU ETS, alternative strategies such as Ship-to-Ship operations and changes in voyage routes have been identified as potential options for reducing emissions exposures. These strategies, known as carbon leakage or evasive ports, have been successfully employed in other vessel segments and warrant consideration for energy carriers as well.

Moving forward, the implementation of energy-saving devices, optimization of ship designs, and the development of alternative fuel capabilities onboard and onshore will play crucial roles in reducing emissions and adapting to the EU ETS requirements.

Given the complexity of the shipping industry and the EU ETS's goal of accelerating industry decarbonization, it is imperative for all stakeholders to align their interests, acknowledge the challenges ahead, and work together to share and reduce the financial exposure of their assets. This calls for increased transparency and data sharing among different stakeholders.

In conclusion, the integration of shipping into the EU ETS represents a significant step towards mitigating climate change impacts in the industry. Continued collaboration and a collective effort to adopt sustainable practices will pave the way for a greener and more resilient future for the shipping sector.

References.

Alibra Shipping Limited 2023. Wet Time Charter Estimates. Available at: https://alibrashipping.com/data/ [Accessed: 11th March 2023].

Ben-Hakoun, E., Shechter, M. and Hayuth, Y. 2016. Economic evaluation of the environmental impact of shipping from the perspective of CO2 emissions. *Journal of Shipping and Trade* 1(1). doi: 10.1186/s41072-016-0011-5.

Bullock, S., Mason, J., Broderick, J. and Larkin, A. 2020. Shipping and the Paris climate agreement: a focus on committed emissions. *BMC Energy* 2(1). doi: 10.1186/s42500-020-00015-2.

Cariou, P., Lindstad, E. and Jia, H. 2021. The impact of an EU maritime emissions trading system on oil trades. *Transportation Research Part D: Transport and Environment* 99. doi: 10.1016/j.trd.2021.102992.

Chang, C.C., Huang, P.C. and Hsieh, C.C. 2019. Carbon allowance allocation in the shipping industry under different economic activities. In: *Procedia Manufacturing*. Elsevier B.V., pp. 112–119. doi: 10.1016/j.promfg.2019.02.017.

Christodoulou, A., Dalaklis, D., Ölçer, A.I. and Ghaforian Masodzadeh, P. 2021. Inclusion of shipping in the eu-ets: Assessing the direct costs for the maritime sector using the mrv data. *Energies* 14(13). doi: 10.3390/en14133915.

GHG Protocol 2016. *Global Warming Potential Values*. Available at: www.ipcc.ch.

González Gutiérrez, C. 2022. Análisis de la sostenibilidad socioeconómica y medioambiental del sector transporte marítimo mundial en buques gaseros. Available at: https://repositorio.unican.es/xmlui/handle/10902/28059 [Accessed: 12 March 2023].

González Gutiérrez, C., Suárez De La Fuente, S., Bonello, J.-M. and Bucknall, R. 2020. An empirical analysis on the operational profile of liquefied natural gas carriers with steam propulsion plants. *Journal of Navigation*. doi: 10.1017/S0373463320000612.

Guo, J., Gu, F., Liu, Y., Liang, X., Mo, J. and Fan, Y. 2020. Assessing the impact of ETS trading profit on emission abatements based on firm-level transactions. *Nature Communications* 11(1). doi: 10.1038/s41467-020-15996-1.

Hellenic Shipping News Worldwide 2022. EU: 40 million Tons of Coal Will Need to Be Sourced from Elsewhere After Ban on Russian Coal. Available at: https://www.hellenicshippingnews.com/eu-40-million-tons-of-coal-will-need-to-be-sourced-from-elsewhere-after-ban-on-russian-coal/ [Accessed: 10 March 2023].

IGU 2022. *2022 WORLD LNG REPORT*.

IMO 2018. *RESOLUTION MEPC.304(72) (adopted on 13 April 2018) INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS*.

IMO 2020. Fourth IMO GHG Study 2020 Full Report. *Angewandte Chemie International Edition* 6(11), pp. 951–952.

Jensen, M.V., Cordtz, R.F. and Schramm, J. 2021. Numerical analysis of methane slip source distribution in a four-stroke dual-fuel marine engine. *Journal of Marine Science and Technology (Japan)* 26(2), pp. 606–617. Available at: https://link.springer.com/article/10.1007/s00773-020-00760-3 [Accessed: 17 March 2023].

Jonek-Kowalska, I. 2022. Towards the reduction of CO2 emissions. Paths of pro-ecological transformation of energy mixes in European countries with an above-average share of coal in energy consumption. *Resources Policy* 77, p. 102701. doi: 10.1016/J.RESOURPOL.2022.102701.

Lagouvardou, S., Psaraftis, H.N. and Zis, T. 2020. A literature survey on market-based measures for the decarbonization of shipping. *Sustainability (Switzerland)* 12(10). doi: 10.3390/SU12103953.

Papadis, E. and Tsatsaronis, G. 2020. Challenges in the decarbonization of the energy sector. *Energy* 205. doi: 10.1016/j.energy.2020.118025.

Rhodes, E., Scott, W.A. and Jaccard, M. 2021. Designing flexible regulations to mitigate climate change: A cross-country comparative policy analysis. *Energy Policy* 156, p. 112419. doi: 10.1016/J.ENPOL.2021.112419.

Schinas, O. and Bergmann, N. 2021. Emissions trading in the aviation and maritime sector: Findings from a revised taxonomy. *Cleaner Logistics and Supply Chain* 1. doi: 10.1016/j.clscn.2021.100003.

SIGTTO 2022. *SIGTTO Anual Report*.

Smith, T. et al. 2015. *Third IMO GHG Study 2014*. London.

Smith, T.W.P. et al. 2014. *Third IMO GHG Study 2014*. London.

Splash 24/7 2023. LNG carrier rates on a charge. Available at: https://splash247.com/lng-carrier-rates-on-a-charge/ [Accessed: 12 March 2023].

Statista 2022. Largest ETS markets by coverage 2022. Available at: https://www.statista.com/statistics/1315109/largest-ets-markets-by-coverage/ [Accessed: 4 March 2023].

StealthGas 2023. Market Report LPG carriers. Available at: https://www.stealthgas.com/weekly-market-report-mainmenu--117.html [Accessed: 11 March 2023].

Taghi Zarrinkolah, M. and Hosseini, V. 2023. Methane slip reduction of conventional dual-fuel natural gas diesel engine using direct fuel injection management and alternative combustion modes. *Fuel* 331, p. 125775. doi: 10.1016/J.FUEL.2022.125775.

Trading Economics 2023. EU Carbon Prices: 2005-2022 Historical. Available at: https://tradingeconomics.com/commodity/carbon [Accessed: 12 March 2023].

UE 2015. *REGULATION (EU) 2015/ 757 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 29 April 2015 - on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/ EC*.

UN 2017. *PERCENTAGE OF TOTAL POPULATION LIVING IN COASTAL AREAS Oceans, Seas, and Coasts Coastal Zone Core indicator*.

UNCTAD 2022. *Review of Maritime Transport*.

UNFCCC 2018. World Nations Agree to At Least Halve Shipping Emissions by 2050 | UNFCCC. Available at: https://unfccc.int/news/world-nations-agree-to-at-least-halve-shipping-emissions-by-2050 [Accessed: 5 March 2023].

Ushakov, S., Stenersen, D. and Einang, P.M. 2019. Methane slip from gas fuelled ships: a comprehensive summary based on measurement data. *Journal of Marine Science and Technology (Japan)* 24(4), pp. 1308–1325. Available at: https://link.springer.com/article/10.1007/s00773-018-00622-z [Accessed: 17 March 2023].

Villoria-Sáez, P., Tam, V.W.Y., Río Merino, M. del, Viñas Arrebola, C. and Wang, X. 2016. Effectiveness of greenhouse-gas Emission Trading Schemes implementation: a review on legislations. *Journal of Cleaner Production* 127, pp. 49–58. doi: 10.1016/J.JCLEPRO.2016.03.148.

Wu, Y., Huang, Y., Wang, H. and Zhen, L. 2022. Joint Planning of Fleet Deployment, Ship Refueling, and Speed Optimization for Dual-Fuel Ships Considering Methane Slip. *Journal of Marine Science and Engineering* 10(11), p. 1690. doi: 10.3390/jmse10111690.