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Overview of the vessel’s costs under EU emission regulations

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Abstract: An alternative to using auxiliary engines to generate the power required to run the vessel's activities when moored is Cold Ironing, often known as shore-side electricity. The advantages are numerous, the most important being the emission reduction, as no fuel will be used to operate the vessel’s equipment. Although the Cold Ironing benefits are substantial, the implementation costs for both the vessel and the terminals can be significant. Despite the costs, the vessels will reduce the costs imposed by the EU, as EU ETS and FuelEU Maritime put a price on the GHG intensity. The paper examines the voyage of an 8,200 TEU container vessel on the passage Mumbai-Constanta. This passage is examined from the costs point of view in three scenarios: when the vessel burns fuel oil only, without considering EU regulations; when the vessel uses fuel oil under EU regulations; and the costs when the vessel is connected to shore-side electricity in Constanta Port under EU regulations. The results show that the costs increase by 22% when using Cold Ironing, due to the imposed regulations, vessel modification for connection to shore power, and the fact that the Cold Ironing system can be used only when the vessel is moored. Nevertheless, when using port electricity, vessels do not emit any pollutants, which is of great importance for the environment and the population living in the port vicinity.

1. Introduction

Maritime transportation is one of the most important means of transportation of goods worldwide. Maritime transportation has reached over 12 billion tons of cargo shipped internationally in 2023 [Review of Maritime Transport, 2024]. At the same time, maritime transportation is responsible for 3% of total GHG emissions globally. International and European organizations have taken strict measures to reduce the pollution and to fight the global warming. Both IMO and the European Union’s targets are to reduce gradually the net emissions to zero by 2050. Tough measures imposed by IMO and EU put pressure on the Ship Owners and Ship Managers, who are now in the position to find the best operational and technical solution for their vessels. Operational measures can be applied to existing vessels and some of them can have good results on the vessel’s performance. From the numerous options of operational measures, speed management seems to have the highest potential. Other solutions include passage planning, weather routing, hull cleaning, propeller polish, proper maintenance, etc. Technical solutions involve the efficiency of propulsion systems, alternative power systems, such as wind and solar technologies, fuel cells, nuclear power, carbon capture systems, and with the highest potential - alternative fuels with low-carbon content or zero carbon content. Some of these technical measures can be applied to existing vessels, but some others require significant changes in the ship’s design, therefore, those measures can be installed on new ships only. Another important aspect is that not all innovative technologies have reached maturity, consequently, the Ship Owners are in a difficult position to select the best solution for a new build. Besides the technology itself, there are other issues the maritime sector is facing. New technologies require different infrastructure, changes in logistics, new bunkering facilities, and shipyard modifications to build new vessels. Very important are the specialists, who require new expertise. Seafarers worldwide will need to adapt new skills and competence to handle the new systems. Universities and training centers will have to adapt the curricula and develop training to cover new topics.

Cold Ironing isn't a new technology; however, it is not globally available. Presently, in Europe, there are only 25 ports (with at least one operational berth) fitted with this technology [Peddi et al., 2024]. Shore-side electricity has the potential to eliminate the pollution when the vessels are berthed in the port. Having this technology installed onboard, vessels will turn off the auxiliary engines, which are operating to generate the electricity necessary for the onboard systems to run for the loading/unloading activities during port stay. Besides pollution reduction, the benefits of Cold Ironing are numerous. The important advantages are the reduction of noise and vibrations, increased working quality conditions for the personnel involved, business opportunities for the electricity providers, etc. However, the most important is that the pollution is reduced in the port area and the settlements in the port vicinity, finally leading to diminishing health issues and improving the quality of life and environment. Another aspect that should be considered is the electricity sources of production. Even if the electricity has zero emissions, electricity is generated from both fossil sources and renewable resources. In order to reduce pollution, electricity production should rely mostly on green solutions.

The present paper calculates the costs of a given vessel and passage in three situations. When the vessel burns conventional fuels on the entire passage and during port stay with no EU regulations – EU ETS and FuelEU Maritime in place, when the vessel burns conventional fuels on the entire passage and during port stay and it is under EU Regulations, and when the vessel uses conventional fuel while underway and Cold Ironing during the port stay and is under EU regulations. EU ETS is applied to maritime transport starting from 1st January 2024, and the penalty is based on the CO_2 emissions, trading area, EU Allowance, and the phase-in. The FuelEU Maritime applies to maritime transport from 1st January 2025 and the aim of this regulation is the increase of alternative low-carbon fuels in shipping. It requires the vessels to report the GHG intensity of the vessels' energy used and, if not compliant with a target GHG, it imposes penalties. Same as EU ETS, it applies to 50% of the intensity for the passage to/from the EU and 100% for intra-EU voyages. The GHG intensity target is strengthened every five years, aiming for an 80% reduction by 2050.

The paper is organized as follows. Section 2 is the literature review; Section 3 is dedicated to research and calculation methodology. It presents the vessel's particulars, the fuel oil consumption for each segment of the passage, the cost calculations for fuel oil consumption, for shore electricity, and the EU ETS and FuelEU Maritime penalties. Section 4 is dedicated to the breakdown of the results obtained, under the considered situations, and discussions based on the results found. Section 5 is allocated to the conclusion remarks.

2. Literature review

Fit for 55 legislative packages was released by the EU with the aim to reduce harmful pollutants from maritime transportation. FuelEU Maritime, as part of this legislative package, promotes the use of cleaner fuels and renewable technologies, to assist decarbonization targets. FuelEU Maritime promotes the use of onshore power supply while the vessels are berthed in an EU port, and it applies to vessels over 5,000 GT calling EU ports. FuelEU Maritime sets a limit on the GHG intensity (target), a target that will strengthen every five years, starting with 2% in 2025 and gradually increasing to 80% by 2050 [Peddi et al., 2024].

The advantages of installing Cold Ironing technology are numerous; however, the drawbacks include costly installation, vessel modification costs, and long payback periods [Bakar et al., 2023], [Glavinovic et al., 2023]. [Seyhan et al., 2022] evaluate a new method of emission reduction, the use of a Cold Ironing system together with an automatic mooring system. This junction will lead to an increased reduction rate of all pollutants. Many studies focus on the need to increase energy production from renewable sources, and the potential of obtaining green energy from wind farms or photovoltaic panels is highly explored [Kelmalis et al., 2024], [Rusu & Onea, 2023], [Lamprinidi et al., 2024]. The survey done by [Le, 2024] shows that the use of shore-side power supply at ports is positively impacted by financial resources and regulations. National and port authorities are mainly responsible for local legislation and necessary funds. The adoption of Cold Ironing can be hampered by a lack of initial funding and standardization. Numerous studies emphasize the importance of Cold Ironing adoption, as the ratio between cost-effectiveness and health costs is sustainable for all actors involved [Canapa et al., 2023], [Sifakis et al., 2022], [Bakar et al., 2023]. Research done by [Spengler & Tovar, 2021] shows that the population living in the coastal area and the traffic mix are the most important factors for moored vessel costs, and they should be taken into consideration for the system implementation. Other studies emphasize the need to invest in renewable technologies that can generate green energy for the port. This type of energy can be then used for the Cold Ironing technology, to supply berthed vessels with electricity obtained from renewable sources. [Sifakis et al., 2022] make an analysis of a combined hydrogen energy storage power plant and shore-side electricity system. The results show that the carbon footprint is reduced by close to zero. The study done by [Pruyn & Willeijns, 2022] for tanker vessels indicates that both modification and electricity costs are not attractive from the economic point of view, however, the emission reduction is substantial. For the small vessels, with low deadweight, the longer berthing times take better benefit from the shore-side electricity use [Martinez-Lopez, 2021].

3. Materials and methods

3.1. Research Methodology

This paper assesses the cost of a given passage for a particular vessel. The study focuses on examining the fuel oil cost if the vessel burns fuel oil only vs the costs when the vessel is connected to shore power in Constanta Port. The study calculates the EU ETS and FuelEU Maritime costs for the specific passage and compares the results. The study takes into consideration the Cold Ironing modification cost and assumes that this cost is paid off over a ten-year period. The Cold Ironing installation onboard this type and size of the vessel is considered 4,000,000 Euro.

The vessel's main particularities are:

Vessel type	Container vessel
Length overall	334 m
Deadweight/ Transport capacity	101,906 t
Gross Tonnage	90,745
Container capacity	8,238 TEU
Year built	2004

The sea route considered is Mumbai – Constanta, via Suez. This passage was considered for its long history in cargo transportation between the two countries, India and Romania. India is a well-known producer and exporter of iron ore and other minerals. The total distance between the ports is 4,428 Nm and the duration of the trip is approximately 20 days. The breakdown of fuel oil consumption and the fuel oil costs associated with the entire voyage are illustrated in Table 1. The study takes into account the following prices for different fuel types:

- LSFO (Low Sulphur Fuel Oil) – 555 EUR;
- MGO (Marine Gas Oil) – 771 EUR.

Table 1. Fuel oil consumption and costs associated with the vessel for the passage Mumbai – Constanta.

	Fuel oil consumption by types of fuel	
	LSFO	MGO
Mumbai port	10.5	
Mumbai - Suez	781	
Suez - Constanta	373	6
Constanta port		16
Fuel quantity (t)	**1,164.5**	**22.0**
Fuel cost (EUR)	**645,831.7**	**16,957.6**
Total fuel cost (EUR)	**662,789.3**	

Next, it is assumed that shore-side electricity is available in Constanta Port and the vessel is fitted with the system that allows connection to the shore electricity. For the purpose of this study, the connection/disconnection times are considered null. The Cold Ironing cost in Constanta Port depends on the auxiliary engine energy necessary for the operational activity during the port stay and the cost of electrical energy in the port.

In Constanta, the cost of energy for non-household consumers was in 2024, 0.2 Euro/kWh [EUROSTAT, 2024]. The following details are known for the port stay:

- Duration of port stay in Constanta Port is 36.2 hrs;
- Auxiliary engine energy necessary for the port stay is 40,700 kWh.

3.2. Calculation Methodology

The fuel oil consumption costs are calculated using the formula (1):

$$Cost_{FOC} = \sum_{k} FOC_k \times C_k \tag{1}$$

where:

$Cost_{FOC}$ is the fuel oil consumption cost for the entire voyage (EUR);

k is the fuel type;

FOC_k is the fuel consumption per type of fuel (t);

C_k is the cost of 1 ton of fuel oil per fuel type (EUR).

The shore-side electricity cost is calculated using the formula (2):

$$Cost_{CI} = AuxEn \times C_{CI} \tag{2}$$

where:

$Cost_{CI}$ is the Cold Ironing cost for the duration of port stay (EUR);

$AuxEn$ is the electricity necessary for the vessel to carry out various operations during port stay (kWh);

C_{CI} is the cost of 1 kWh of shore-side electricity (EUR/kWh).

As per EU Regulations, the vessels have to pay for CO_2 emissions when entering EU waters. The EU Allowance cost of 1 ton of CO_2 varies continuously and it is based on the market situation, having towards the end of 2024 an average price of 80 Euro/tCO_2e. The EU ETS cost is calculated by the formula (3) [Directive 2003/87/EC, 2003]:

$$EU\ ETS = \frac{\sum_k (FOC_k \times C_{Fk}) \times A_r}{Tr} \times EUA \tag{3}$$

where:

k is the fuel type;

FOC_k is the fuel consumption per type of fuel (t);

C_{Fk} is the fuel quantity to CO_2 mass conversion factor or emission factor for fuel k;

A_r is Annual-rate (2024: 40%, 2025: 70%, from 2026: 100%);

EUA is the EU Allowance price (EUR);

Tr is a Trading area (100% within the EU; 50% from/to EU).

FuelEU Maritime is another system that penalizes emissions, and the cost depends on the GHG Intensity Actual and Target, the fuel oil consumption, and the lower calorific value per fuel type. The penalty is calculated using the formulas (4) and (5) [Regulation (EU) 2023/1805, 2023]. In case the vessel is connected to Cold Ironing, the vessel can have a compliance surplus that can be used for pooling or banking, subject to limitations and approvals imposed by the regulations.

$$FuelEU\ Maritime = \left| \frac{GHG_T - GHG_A}{GHG_A} \right| \times (\sum_k FOC_k \times LCV_k + \sum_j El_j) \times \frac{2{,}400\ (Euro)}{41{,}000} \quad (4)$$

$$GHG_A = \frac{\sum_k FOC_k \times LCV_k \times EmF_{WtW}}{\sum_k FOC_k \times LCV_k + El} \quad (5)$$

where:
GHG_T is the GHG Target for the reporting year (gCO_2 eq/MJ);
GHG_A is the GHG Actual achieved during the reporting year (gCO_2 eq/MJ);
k is the fuel type;
FOC_k is the fuel consumption per type of fuel (t);
LCV_k is the Lower Calorific Value per fuel type (MJ/g);
j is the Cold Ironing point;
El_j is the Electricity consumption for the connection point j (MJ);
41,000 is a constant equal of 1 ton of VLSFO energy, eq to 41,000 MJ;
EmF_{WtW} is the Emission Factor Well to Wake (gCO_2 eq/MJ).

4. Results and discussions

4.1. Results

The breakdown of costs when vessels are connected to shore power vs burning fuel oil are shown in Table 2 and Table 3.

Table 2. Breakdown of costs when vessels are connected to shore power in Constanta Port vs fuel oil costs (EUR).

	Vessel
Port Stay (hrs)	36.2
Aux Engines Energy while moored (kWh)	40,700
Fuel oil consumption (t)	16
Fuel oil cost (EUR)	**12,332.8**
Cold Ironing cost (EUR)	**8,140.0**

Table 3. Total costs when the vessel burns fuel oil vs when connected to shore power in Constanta Port on the entire passage (EUR).

	Vessel
Total cost when burning fuel (EUR)	662,789.3
Total cost when using CI (EUR)	658,597.0

The purpose of the EU ETS system is to incentivize businesses to consistently lower their emissions through financial means. To maintain the price at a reasonable level, the EU issues and regulates the permits (limit). If necessary, the unused EUAs can then be traded. Unlike other activities, shipping does not receive free allowances. The EU ETS calculation for the vessel (when using fuel oil and Cold Ironing in the port), for the passage Mumbai-Constanta is presented in Table 4 and Table 5.

Regulations pertaining to FuelEU Maritime will take effect on 1st January 2025. A GHG Intensity limit is established for vessels over 5,000 GT, and it will be reinforced every five years. Fuel oil, lower calorific value, electricity, and GHG intensity target and actual are the factors used to determine the FuelEU Maritime penalty. The GHG intensity baseline is 91.16 gCO_2 eq/MJ, and the reduction is set to 2% for 2025, which means the GHG intensity target is set to 89.34 gCO_2 eq/MJ for 2025. From 2030 the GHG intensity target will be set to 85.69 gCO_2 eq/MJ. The FuelEU Maritime penalty costs for the case when the vessel burns fuel oil only and the case when using Cold Ironing in port, are shown in Table 6.

Table 4. EU ETS for the vessel for the passage Mumbai-Constanta (EUR).

	Fuel consumption LSFO	Fuel consumption MGO	Trade Area ratio	EU Allowance (EUR)	EU ETS (EUR)
Mumbai Port	10.5		0%	85	0
Sea voyage	1154	6	50%	85	153,544
Constanta Port		16	100%	85	4,360
Total					**157,904**

Table 5. EU ETS for the vessel for the passage Mumbai-Constanta when burns fuel on the entire voyage compared when the vessel is connected to shore-side electricity in Constanta Port (EUR).

	Vessel	
Phase in allowance	**Fuel Oil only**	**CI in port**
2024 - 40%	63,162	61,417
2025 - 70%	110,533	107,481
2026 - 100%	157,904	153,544

Table 6. FuelEU Maritime for the vessel for the passage Mumbai-Constanta when burns fuel on the entire voyage compared when the vessel is connected to shore-side electricity in Constanta Port (EUR).

		Vessel	
	Year	**Fuel Oil**	**Cold Ironing in the port**
Phase in allowance FuelEU (EUR)	2025-2030	31,889	9,330

The total costs for the vessels were determined for the following situations:

- Scenario 1- vessel uses fuel oil only, no consideration for European environmental rules;
- Scenario 2 - vessel uses fuel oil and European environmental rules apply; In 2024 only ET ETS applies for 40% of the emissions; in 2025 EU ETS for 70% of the emissions and FuelEU Maritime; from 2026 EU ETS will be applied for 100% of the emissions and FuelEU Maritime regulation;
- Scenario 3 - vessel has a Cold Ironing technology, European environmental rules apply, and the CI modification costs will be amortized over a 10-year period.

The results are shown in Table 7 and Figure 1.

Table 7. Expenses for the vessel under the three scenarios (x1000 EUR).

	Vessel		
	Scenario 1	**Scenario 2**	**Scenario 3**
2024	662.79	725.95	744.12
2025	662.79	805.21	799.52
2026-2030	662.79	852.58	845.58

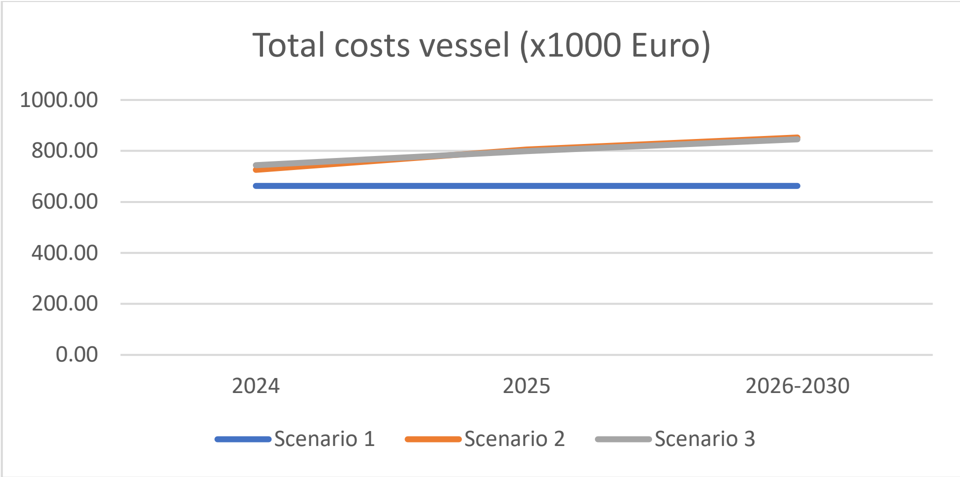

Figure 1. Total expenses for the vessel (x1000 EUR).

4.2. Discussions

In the first part, the paper calculates the costs for the vessel considered (Table 3) when the vessel burns fuel oil throughout the voyage versus when the vessel is connected to shore power in Constanta Port. It is noted that the costs are slightly lower, by 1%, for the second case, however, it depends on the electricity price in the port. Tables 4 and 5 calculate the EU ETS penalties under different scenarios and phase-in. Table 6 shows the FuelEU Maritime penalties for the period 2025-2030, both when the vessel uses fuel oil on the entire passage and Cold Ironing in the port. When using CI in the port, the vessel is FuelEU compliant, therefore the penalties decrease by 70% on the entire passage. Table 7 summarizes the costs under the three scenarios, for the situation when the vessel is connected to shore-side electricity, the vessel modification cost is also considered. It is observed that for the period 2026-2030 - when EU ETS will apply for 100% emissions and FuelEU Maritime for the GHG intensity target of 89.34 gCO_2 eq/MJ – the CI option is preferable, even if the vessel has an additional cost for the modification.

The CI total cost depends on the electricity cost in the port; the study took into consideration an electricity price of 0.2 Euro/kWh, however, the real price of port electricity is not yet known, since Constanta Port does not have a Cold Ironing system operational. The modification cost was estimated to be 4 million Euros, nevertheless, actual costs depend on the drydock, materials, market demand, etc.

The study is limited to the period 2026-2030, from 2030 the EU regulations set another GHG intensity target, a limit that is strengthened every five years.

The paper calculation methodology, the assumptions, and the results can be further used for a cost estimation for any given passage and any specific vessel.

5. Conclusions

The case study analyzed the passage Mumbai – Constanta from the perspective of a container vessel. It is observed that in the following years, the Ship Owner or the Ship Manager of the vessel has more costs associated with the new EU ETS and FuelEU Maritime regulations compared with the time before 2024 when no EU regulations were in force. The EU regulations costs could be reduced if the emissions in European waters are reduced. Cold Ironing could be a solution; however, the emission reduction is in the port only, not on the sea passage. The CO_2 emissions for the entire passage when burning fuel oil only are 3696.8 t and the emissions are 3645.5 t when using CI in Constanta Port. It means a 1% reduction in emissions quantity, compared with a cost increase of 22% from 2026 when the vessel has to pay penalties for EU ETS and FuelEU Maritime, as well as to pay off the Cold Ironing system installation onboard. The total costs can further decrease if the cost of electricity in the port is reduced. Regardless of the costs imposed by EU regulations and Cold Ironing installation costs, both onboard and in the port, Cold Ironing results in no emissions released into the atmosphere while the vessel is moored. There are numerous benefits to using the Cold Ironing system in the port, including higher quality of the air, less noise and vibrations from the vessel's auxiliary engines, and improved working conditions for both the port personnel and the ship's staff. Cold Ironing is a promising technical measure, and it is advantageous for vessels that are trading in EU waters. Shipping took responsibility for net-zero emissions by 2050, and comply with all IMO and EU regulations, for a cleaner means of transport. All parties involved in shipping activities should take proper action to reduce the amount of GHG emissions and to limit the effects of climate change.

Starting from the study methodology, further investigations on the costs of a specific voyage can be developed. Different operational and/or technical measures can be examined, and under which circumstances they impact the final costs under current IMO and EU regulations.

Another area of investigation can be the analysis of a fleet of vessels on an annual basis, and how much the EU regulations will influence the company's costs.

Abbreviations

CI	Cold Ironing
CO_2	Carbon Dioxide
EU	European Union
EU ETS	European Union Emission Trading System
EUA	European Union Allowances
GHG	Greenhouse Gases
GT	Gross Tonnage
IMO	International Maritime Organization
LSFO	Low Sulphur Fuel Oil
MGO	Marine Gas Oil
VLSFO	Very Low Sulphur Fuel Oil

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