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Implications of the EU Emissions Trading System (ETS) on European container routes: A carbon leakage case study

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A B S T R A C T

The paper focuses on the impacts of the inclusion of the maritime sector in the EU Emissions Trading System (ETS). The enforcement of a regional Market-Based Measure (MBM) such as the EU ETS may provide financial incentives to shipping operators to reconfigure their networks and avoid voyages inside the European Economic Area (EEA). This paper investigates the risk of container vessels engaging in evasive port calls by replacing EEA transshipment hubs with nearby non-EEA competitors. We perform a cost–benefit analysis that calculates the cost of EU Allowances (EUAs) for several international services and compares it with a relocation scenario. Our case studies focus on the Piraeus–Izmir and the Algeciras–Tanger Med scenarios and identify the EU carbon price turning point that will render the switch of the transshipment hubs a cost-effective choice for the operator. The results show that the preference of a non-EEA hub will become attractive for carbon prices well below 25 EUR per metric ton of CO_2. Further, in all cases, the hub switch results in a rise in the overall carbon emissions attributed to the service which amplifies the risk of carbon leakage. Our results show that the relocation would lead to revenue loss for the EU ETS and penalization of the EEA transshipment hubs in close proximity with hubs outside the EEA, thus posing a threat to their economic activity and development.

1. Introduction

On 14 July 2021, the European Commission (EC) proposed to extend the scope of the EU Emissions Trading System (ETS) to also include greenhouse gases (GHG) emissions from the maritime sector (ECa, 2021). The revision of the EU ETS is part of the "Fit for 55" package and aims to embrace the EU gal of reaching net-zero GHG emissions by 2050. Except for the inclusion of shipping in the EU ETS, the legislation includes the FuelEU Maritime Initiative, which sets GHG intensity targets and fuel standards for ships, the Energy Taxation Directive, that eliminates fuel tax exemptions within the sector and the Alternative Fuels Infrastructure Regulation, that aims to increase the availability of shore side electricity and Liquefied Natural Gas (LNG) in ports (ECb, 2021).

As a Market-Based Measure (MBM), the EU ETS aims to enforce the "polluter-pays principle" and, thus, provide monetary incentives to stakeholders to reduce their carbon footprint. The ETS builds on the "cap and trade" principle, where a cap on the total amount of GHGs is set and then split among the regulated entities in the form of EU Allowances (EUAs). The Directive does not yet define the method according to which EUAs will be distributed among the Member States (MS). Each company shall report their allowances through their registered MS and purchase their EUAs through auctioning based on their previous year's carbon emissions and in compliance with the reduction targets of the EU ETS. Since the EU Monitoring, Reporting and Verification system (EU MRV) is effectively the foundation of accounting the EU emissions from ships, the extension of the EU ETS utilizes the key principles of the EU MRV establishing the shipping companies and the countries that they are registered to, as the regulated entities (ECc, 2021).

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However, it remains to be seen how charter parties will be involved in the EU ETS regulatory framework. Since for time charter contracts it is the charterer who bears the cost of bunkering and thus the decision on the vessel's service speed and the respective CO_2 emissions, new clauses shall be introduced to protect the shipowner from excessive carbon charges due to the charterer's non conformity with the scheme. According to the Directive, the obligation of surrendering emissions allowances will be phased starting from 20% in 2023 and reaching 100% in 2026. The inclusion of shipping will cover 100% of the CO_2 emissions occurring while sailing between ports of the European Economic Area (EEA), 100% of the CO_2 emissions at berth of an EEA port and 50% of the CO_2 emissions from international voyages between an EEA and a non-EEA port. At the end of each year, shipping companies should demonstrate a balance between allowances and verified emissions and in case of exceeding their purchased allowances, they will need to buy the excess amount from the carbon market. EUAs can be purchased through either the primary market i.e., auctions by the MS through the European Energy Exchange (EEX), or the secondary market by trading of the EUAs through the EEX. Last but not least, the extension of the scope of the EU ETS also to include shipping is only a proposal from the EC. The final form of such measure will have to go under an ordinary legislative procedure which will depend on the outcome of negotiations among the various EU regulatory bodies (Commission, Parliament and Council) and maritime stakeholders.

The proposed EU ETS structure raises the issue whether shipping companies in the container sector that perform ship-to-ship transshipment at EU ports can reduce their payments into the EU ETS by switching their transshipment hub from an EEA transshipment hub to a non-EEA hub. This paper aims at identifying that risk by looking at the Piraeus vs Izmir and Algeciras vs Tanger Med case studies and considering all the parameters that affect the choice of a transshipment hub while designing a liner shipping network. To that effect, we perform a cost–benefit analysis that calculates the newly introduced EU carbon costs of several international services already calling at EEA ports and assesses the costs arising from relocating their EEA transshipment hub.

For the purposes of our analysis, we first comment on the effect that the EU ETS already has on its regulated entities with a focus on aviation, an industry that resembles shipping in many fundamental aspects. We retrieved data from the European Environment Agency[1] (EEA) on the evolution of GHG emissions from 1990 to 2018 attributed to EU's domestic aviation, international aviation and international maritime transport. Fig. 1 shows that despite the inclusion of aviation in the EU ETS in 2013, GHG emissions at both international and domestic level kept increasing. This outcome is a strong indicator that regional schemes may be inadequate in regulating global sectors and can further lead to unfavorable effects such as market distortions and carbon leakage.

Carbon leakage results from the increase in global GHG emissions due to shifting operations outside the regional scope of the rule in the absence of an global climate agreement. Sectors that trade internationally are prone to evade a regional legally binding treaty by reconfiguring their businesses to avoid compliance with the rule. As climate change depends on aggregate global emissions, carbon leakage threatens to undo the effects of unilateral policy efforts.

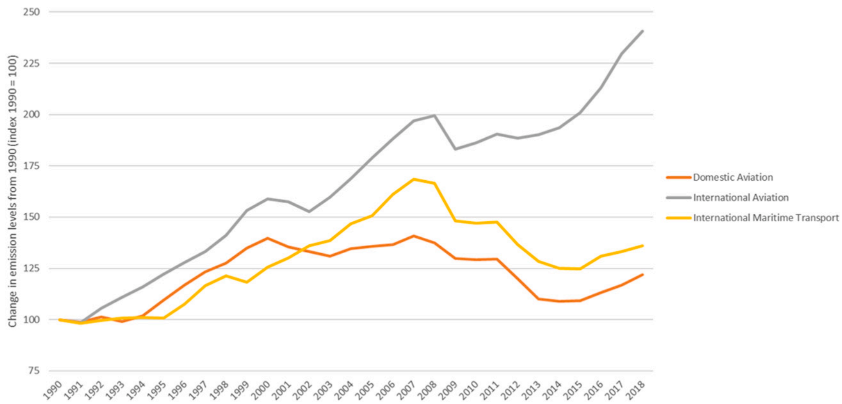

Fig. 1. Evolution of GHG emissions levels for international and domestic aviation and international shipping. Compiled by the authors.
Source: EEA[1].

The rest of the paper is organized as follows. Section 2 conducts a literature review on the impacts of the EU ETS with an emphasis on studies related to the arising risk of carbon leakage. Section 2 also contains a brief review of the transshipment hub choice parameters aiming to clarify the criteria that will determine whether a relocation of the hub can be a feasible solution for shipping networks. Section 3 presents the methodology and explains the rationale behind the choice of the container sector as the case study of the analysis. Section 4 focuses on the Piraeus versus Izmir case study and includes the cost–benefit analysis results of the examined services. Section 5 conducts the same analysis on the Algeciras versus Tanger Med transshipment hub. Finally, Section 6 summarizes the results of this study, highlighting that the carbon leakage risk is substantial and that the scheme may also lead to penalization of the EEA ports and revenue loss for the EU ETS.

1 https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-transport.

2. Literature survey

The introduction of MBMs as effective measures to decarbonize shipping was discussed at the IMO already circa 2010. Various member states and organizations that are actively engaged with the IMO procedures, as well as the scientific community, have proposed several MBMs with intention to control and reduce maritime GHG emissions (Lagouvardou et al., 2020). In a comparative evaluation of MBMs, Psaraftis et al. (2021) highlight that an MBM in the form of a global levy/tax on bunker fuels is a more effective means to emissions reductions among the sector, in contrast to the volatile prices of a regional ETS. In addition, Christodoulou et al. (2021) conclude that the increased costs deriving from the inclusion of shipping into the EU ETS will create competition distortions among the different maritime segments. For example, Roll-on/Roll-off (RoRo) and Roll-On/Roll-Off/Passenger (RoPax) vessels would be penalized under such a measure due to their high fuel consumption per transport work in comparison to oil tankers and bulkers.

Furthermore, Hermeling et al. (2015) examine the legal feasibility of the implementation of the EU ETS in shipping and argue that the scheme puts a burden on routes featuring a high share of regulated emissions, i.e., short routes sailing mainly within EU territorial waters and impede cost-efficient emission abatement among regulated ships. Franc and Sutto (2014) investigate the impacts of a cap and trade scheme on the organization of the container shipping lines and EU ports and highlight the risk of modal shifts from maritime to land transport and, in particular, to road.

The increased risk of administrative, technical and operational challenges from the inclusion of shipping into the EU ETS has also been studied by Enderle (2013). The paper highlights that the carbon price volatility due to its dependency on the market demand will not enhance stability in the sector. On a similar aspect, Psaraftis and Lagouvardou (2019) investigate the importance of a fuel levy in providing stable carbon signals and thus enabling energy producers and shipowners to proceed to investment decisions without the fear of fluctuating carbon costs.

The report of Transport and Environment (Defour and Afonso, 2020) is cited in the EC proposal (ECa, 2021) and investigated the risk of policy evasion through by adding an evasive port call in the vessel's schedule prior calling the EEA port. According to their study, the risk of making a stopover at a non-EEA port is minimal for prices around 30 EUR per metric ton (MT) and increases for prices higher than 123 EUR/MT and, under a semi-full scope ETS. Under a full scope ETS design, 6.7% of all voyages, representing 2.7 million MTs of emissions, would be tempted to evade at that CO_2 price. It is noteworthy that the report considers voyages calling at Greece, Spain and the Netherlands, and includes the respective emissions arising from intra-EEA voyages, domestic voyages and emissions at berth. Overall, the study's inputs refer to national-level data and there is no distinction between the various ports of each country, nor does it consider differences in the development and performance among the individual ports. On a similar aspect, Wang et al. (2021) examine the risk of introducing an evasion port on containerships sailing from Singapore to Rotterdam in order to save on emissions allowances from the whole route. Their study concludes that the risk of evasion is real and would be mitigated by the implementation of carbon pricing measures beyond the EU.

Furthermore, the risk of carbon leakage has been studied from the Ricardo organization and is also cited in the EC proposal (Pons et al., 2021b). However, the full report and the methodology behind the study is not published yet. There is a brief analysis on the transshipment hub relocation scenario that involves the Algeciras and Tanger Med ports and concludes that policy evasion will be significant only in 2040 when carbon prices will be around 268 EUR/MT of carbon and while progress on other measures to reduce GHG emissions of ships will be lacking. However, the study does not examine specific services but assumes two scenarios on the distance between EEA and non-EEA ports with case studies of 1000 and 10,000 nm, respectively. Overall, the part of the study cited in the EC proposal concludes that policy evasion will depend on operational factors that influence the transshipment port choice and the transshipment costs associated with proximal non-EEA transshipment hubs.

Our paper retrieves information on the various criteria that constitute the transshipment hub selection problem to assess the guiding principles that can lead to network reconfiguration. Transshipment is the unloading of goods from one ship and its loading into another to complete a journey to a different destination. Several studies conclude that port location and performance, as well as overall costs of transshipment, are the most critical parameters that render a port a successful transshipment hub (Chou, 2010), Kavirathna et al. (2018), Chen et al. (2017). Other aspects involve berth availability, transit times, port fees, frequency and service quality. The transshipment costs may have significant impacts depending on the variations between ports, and it is also essential to consider bunker fuel costs, ETS/fuel levy payments and capital costs. The usage of transshipment hubs remains a decision of shipping companies under the prospects of designing their shipping networks. Such decisions can change if a company revises the allocation of its assets and its commercial strategy.

3. Methodology

This paper performs a cost–benefit analysis to examine the financial interest of liner shipping companies to undertake a network reconfiguration under the prospects of evading the EU ETS. The network reconfiguration entails a swap of an EEA transshipment hub that is already included in the sequence of port calls for a non-EEA hub located in close proximity to the EEA port. To examine this, we gather real schedule data for several international services calling at EEA transshipment hubs and we calculate the additional EU ETS compliance cost as dictated in the Directive (ECc, 2021). Further, we replace these ports with nearby non-EEA hubs with similar performance that compete with the EEA hubs. The calculation of the additional cost from reconfiguring the network due to the relocation of the transshipment hub allows us to compare our results with the annual EU ETS compliance cost for each service. We focus on the container sector, which is the most dominant source of GHG emissions in the maritime sector (Faber et al., 2020). Also, the ship-to-ship transshipment operation is more prevalent in the container sector than in other shipping sectors. As containerships operate in an increasingly competitive and market-oriented business environment, annual voyage costs, including the EU ETS costs, are prime inputs for the network design problem.

Considering that a change in arrival and departure times can have significant impacts on pre-booked canal transits, tight delivery schedules, and on the ‘‘on-time’’ arrival in regards to the connection with the feeder vessels, we shall proceed by assuming that transit times will remain unchanged despite the relocation of the hub. This assumption implies that inter-port transit times will remain unchanged after relocating the transshipment hub because the chosen non-EEA competitors are in very close proximity to the initial EEA ports. This assumption is reasonable as the selected hubs are geographically located very close to each other. Another justification of that choice is that operators can act indifferently to the amount of CO_2 arising while sailing to or from the non-EEA port and thus increase the vessels’ service speed in order to catch up for the deviation distance. That action can lead to carbon leakage due to the lack of a global regulatory climate treaty covering the non-EEA ports.

Another aspect of the transshipment distance/cost-assessment problem is the estimation of the voyage costs arising due to the relocation, scenario. The reconfiguration of the ocean trade lane entails an increase on bunker costs due to the deviation distance. Further, as The identification of the vessels that operate on the examined voyages allows us to retrieve data on their design speed and fuel consumption from the Clarksons fleet database[2]. Data on the relationship of service speed and the respective fuel consumption considering that container vessels’ draft remains approximately the same regardless of the loading condition were retrieved for several size category container vessels from a shipping company. Finally, our model’s estimations were compared to the 72nd version of the 2020 THETIS MRV database, which was published by the European Maritime Safety Agency (EMSA)[3] for the vessels that operate on the examined services.

This paper also assumes that the inclusion of shipping in the EU ETS will not alter the service speed in the routes under the EU jurisdiction, other than those that involve the route legs just prior to and just after the transshipment hub under scope. If operators react in the EU ETS by introducing the practice of slow steaming as a further operational measure to lower emissions, it may be necessary to increase the number of ships in the string to compensate for the speed reduction in these segments. Investigating such a scenario is outside the scope of this paper, however we shall comment on it in the concluding section.

The assumption that the vessels under scope are hired in the time charter market and that transit times remain unchanged means that freight rates will not be influenced by the swap of the hub and thus, no loss of freight income will incur. The same rationale is adopted for the operating costs (i.e., crew, lubricants, stores, spares, repairs, maintenance, dry docking, insurance (H&M and P&I) and management fees) that will not vary upon the relocation of the transshipment hub as they mainly depend on the vessel’s annual operating days. Finally, we consider the costs of each port namely port tariffs that include port dues, pilotage, mooring, terminal costs, and the cost of each move with respect to the transshipment of the containers. After personal communication with the Piraeus port and from various other online sources, we assume an average of 3,000 transshipment moves per containership call (IHS Markit, 2021). A move is defined as a loading or an unloading operation.

The model examines five realistic services of two container shipping lines operating between the Far East and North Europe and between South America and Northern Europe. Table 1 shows the parameters under scope for the construction of our model. The selected EU hubs under investigation are the Piraeus and Algeciras container terminals, where more than 90% of the traffic serves as transshipment cargo (Grifoll et al., 2018). Firstly, we evaluate for every service the amount of CO_2 emissions that are subject to the EU ETS and estimate the annual carbon allowance cost each company shall surrender at the end of the reporting period to comply with the regulation. Following this analysis, we replace the EEA transshipment hubs of the routes (i.e., Piraeus and Algeciras) with their non-EEA competitors (i.e. Izmir and Tanger Med port), respectively. The calculation of the extra carbon cost added to the service’s voyage cots allows us to compare the EEA to the non-EEA transshipment hub scenarios. Our goal is to identify for each of the studied cases the EU carbon price turning point that renders the relocation of the transshipment hub a cost-effective choice for the operator.

The following considerations are also important:

a. Even though this paper focuses on ports primarily serving as transshipment hubs, it also considers the amount of cargo that constitutes local (import and export) traffic. As we mentioned earlier, about 10% of the cargo carried on the mainline vessels that call at the Piraeus or Algeciras port is local traffic that must be delivered to its final destination in the event of relocation. Several solutions can facilitate that request. One way could be to introduce a new (dedicated) feeder service between the original EEA hub and the replacement non-EEA hub, the sole purpose of which would be to handle such local traffic. This would entail an additional cost to the line, and as such, this option is considered not financially attractive and will not be examined here. Instead, we assume that the local containers can be loaded to another service that calls the EEA port and its service will remain unchanged. There can even be a dedicated service that loads predominantly local containers and very few transshipment containers (for example, local traffic in Piraeus is on the order of 500,000 to 600,000 TEUs per year).

b. The above equations are valid for both mainline and feeder vessels. However, in this paper, the calculations are performed only for mainline vessels. In principle they can also be performed for the feeder vessels that handle the transshipment traffic carried by the mainline vessels. Even though data on feeder services in Piraeus and Algeciras exists, it is difficult to associate a specific feeder service with a specific mainline service. Each of the 3,000 or so transshipment boxes of the mainline vessel will typically end up in more than one feeder vessels, depending on the ultimate destination of each container. In addition, and due to the short-haul sailing distances of the feeder services, our analysis showed that the additional costs arising from the evasion of the EU ETS for these services are much lower than those of the corresponding main vessels.

[2] https://www.clarksons.net/wfr/.

[3] https://mrv.emsa.europa.eu/.

Table 1
Symbol Table.

Symbol	Definition	Description/Comment
X	Number of ports along route	
x	Port index	$x = 1, \dots, X$
P_x	Port P_x	
P_{x-1}	Port P_{x-1}	Port immediately prior to port x
m	Transshipment hub port index	
P_m	Original transshipment hub port	In EEA
P_m^*	Alternate transshipment hub port	Outside EEA
$d_{x-1,x}$	Distance between ports P_{x-1} and P_x	
A_x	Arrival time at port P_x	
D_x	Departure time from port P_x	
$Days_{x-1,x}^V$	Voyage time between ports P_{x-1} and P_x	See Eq. (1)
$Days_x^B$	Days at berth at port P_x	See Eq. (2)
$v_{x-1,x}$	Average service speed between ports P_{x-1} and P_x	See Eq. (3)
$fc_{x-1,x}^V$	At sea per day fuel consumption between ports P_{x-1} and P_x	See Section 3
fc_x^B	At berth per day fuel consumption at port P_x	See Section 3
$FC_{x-1,x}^V$	At sea total fuel consumption between ports P_{x-1} and P_x	See Eq. (4)
FC_x^B	At berth total fuel consumption at port P_x	See Eq. (5)
c	Carbon coefficient	See Table 2
${CO_2}_{x-1,x}^V$	At sea CO_2 emissions between ports P_{x-1} and P_x	See Eq. (6)
${CO_2}_x^B$	At berth CO_2 emissions at port P_x	See Eq. (7)
$R_{x-1,x}^V$	Fraction of CO_2 emissions that count for ETS payment for the voyage between ports P_{x-1} and P_x	$\begin{cases} 0, & \text{if both ports are outside the EEA} \\ 0.5, & \text{if only one of the ports is in the EEA} \\ 1, & \text{if both ports are in the EEA} \end{cases}$
R_x^B	Fraction of CO_2 emissions that count for ETS payment at berth at port P_x	$\begin{cases} 0, & \text{if port is outside the EEA} \\ 1, & \text{if port is in the EEA} \end{cases}$
C_P	EU Carbon Price	In EUR/MT of CO_2
C_p^0	EU Carbon Price Turning Point	See Eq. (20)
$ETS_{x-1,x}^V$	Cost of CO_2 allowances for the voyage between ports P_{x-1} and P_x	See Eq. (8)
ETS_x^B	Cost of CO_2 allowances at berth in port P_x	See Eq. (9)
T_m	Transshipment tariff at hub P_m	In EUR/move
T_m^*	Transshipment tariff at hub P_m^*	In EUR/move
B	Bunker price	See Table 2
N_m	No. of transshipment moves at hub P_m	Equal to no. of transshipment moves at hub P_m^*
ETS_{cost}	Total cost of ETS allowances if P_m is used as hub port	See Eq. (12)
ETS_{cost}^*	Total cost of ETS allowances if P_m^* is used as hub port	See Eq. (13)
$FUEL_{cost}$	Total fuel cost if P_m is used as hub port	See Eq. (14)
$FUEL_{cost}^*$	Total fuel cost if P_m^* is used as hub port	See Eq. (15)
$PORT_{cost}$	Total transshipment cost if P_m is used as hub port	See Eq. (10)
$PORT_{cost}^*$	Total transshipment cost if P_m^* is used as hub port	See Eq. (11)
$TOTAL_{cost}$	Total cost if P_m is used as hub port	See Eq. (16)
$TOTAL_{cost}^*$	Total cost if P_m^* is used as hub port	See Eq. (17)
$\Delta Total_{cost}$	Difference in total voyage costs for the two cases	See Eq. (17)
ΔETS_{cost}	Difference in total cost of ETS for the two cases	See Eq. (18)
$\Delta FUEL_{cost}$	Difference in total fuel cost for the two cases	See Eq. (19)
$\Delta PORT_{cost}$	Difference in transshipment costs for the two cases	See Eq. (20)
Ψ	Difference in CO_2 that fall under the EU ETS for the two cases	See Eq. (21)

Port to port distances were retrieved from Searoutes[4]. Table 2 presents the fuel price data used as inputs to our model. The values represent the average 2021 prices for the three most common marine fuels as recorded by MABUX[5]. Significant variations on fuel

[4] https://classic.searoutes.com/.
[5] https://globalmaritimehub.com/mabux-global-bunker-market-in-2021.html.

Table 2
Fuel prices and emissions factors for various marine fuels. (1USD = 0.8458EUR).
Source: MABUX and the 4th IMO GHG Study.

Fuel Type	Emission factor (MT CO_2/MT fuel)	Fuel Price (EUR/MT)
Heavy fuel oil (HFO)	3.114	432.51
Very Low Sulfur Fuel Oil (VLSHFO max 0.5%)	3.188	585.47
Diesel/Marine Gas oil (MGO 0.1%)	3.206	682.50

prices are expected to influence the carbon pricing turning point C_p^0 of each case study. Higher bunker prices coincide with higher fuel and thus voyage costs for the relocation scenario and, in that case, as a consequence of Eq. (20) higher break-even points. The effect of the fuel prices on the carbon price has been addressed in each of the examined scenarios and is presented in Sections 4.3 and 5.3.

Eq. (1) to (20) express the mathematical relationships among the variables shown in Table 1. In particular, the calculation of the total costs in Eq. (16) and (17) includes both scenarios under scope, whether the route stands as a compliance route with the ship calling at the EEA transshipment hub or as an evasion route, where the ship is calling at the non-EEA port.

$$Days^V_{x-1,x} = A^x - D^{x-1}, \quad x = 2, \dots X \tag{1}$$

$$Days^B_x = D^x - Ax, \quad x = 1, \dots X \tag{2}$$

$$v_{x-1,x} = dx - 1, x / Days^V_{x-1,x}, \quad x = 2, \dots X \tag{3}$$

$$FC^V_{x-1,x} = fc^V_{x-1,x} \times Days^V_{x-1,x}, \quad x = 2, \dots X \tag{4}$$

$$FC^B_x = fc^B_x \times Days^B_x, \quad x = 1, \dots X \tag{5}$$

$$CO_2{}^V_{x-1,x} = c \times FC^V_{x-1,x}, \quad x = 2, \dots X \tag{6}$$

$$CO_2{}^B_x = c \times FC^B_x, \quad x = 1, \dots X \tag{7}$$

$$ETS^V_{x-1,x} = R^V_{x-1,x} \times CO_2{}^V_{x-1,x} \times C_P, \quad x = 2, \dots X \tag{8}$$

$$ETS^B_x = R^B_x \times CO_2{}^B_x \times C_P, \quad x = 1, \dots X \tag{9}$$

$$PORT_{cost} = N_m \times T_m \tag{10}$$

$$PORT^*_{cost} = N_m \times T^*_m \tag{11}$$

$$ETS_{cost} = \sum_{x=2}^{X} ETS^V_{x-1,x} + \sum_{x=1}^{X} ETS^B_x, \quad \text{with hub being } P_m \tag{12}$$

$$ETS^*_{cost} = \sum_{x=2}^{X} ETS^V_{x-1,x} + \sum_{x=1}^{X} ETS^B_x, \quad \text{with hub being } P^*_m \tag{13}$$

$$FUEL_{cost} = B \times \left(\sum_{x=2}^{X} FC^V_{x-1,x} + \sum_{x=1}^{X} FC^B_x \right), \quad \text{with hub being } P_m \tag{14}$$

$$FUEL^*_{cost} = B \times \left(\sum_{x=2}^{X} FC^V_{x-1,x} + \sum_{x=1}^{X} FC^B_x \right), \quad \text{with hub being } P^*_m \tag{15}$$

$$TOTAL_{cost} = ETS_{cost} + FUEL_{cost} + PORT_{cost} \tag{16}$$

$$TOTAL^*_{cost} = ETS^*_{cost} + FUEL^*_{cost} + PORT^*_{cost}$$

$$\Delta Total_{cost} = Total_{cost} - Total^*_{cost} = \Delta ETS_{cost} + \Delta FUEL_{cost} + \Delta PORT_{cost} \tag{17}$$

where:

$$\Delta ETS_{cost} = ETS_{cost} - ETS^*_{cost} = (ETS^V_{m-1,m} + ETS^B_m + ETS^V_{m,m+1})\Big|_{P_m} - (ETS^V_{m-1,m} + ETS^B_m + ETS^V_{m,m+1})\Big|_{P^*_m} \tag{18}$$

$$\Delta FUEL_{cost} = FUEL_{cost} - FUEL^*_{cost} = B \times \left[(FC^V_{m-1,m} + FC^B_m + FC^V_{m,m+1})\Big|_{P_m} - (FC^V_{m-1,m} + FC^B_m + FC^V_{m,m+1})\Big|_{P^*_m} \right] \tag{19}$$

$$\Delta PORT_{cost} = PORT_{cost} - PORT^*_{cost} = N_m \times (T_m - T^*_m)$$

One of the issues addressed in the paper is to find the EU Carbon pricing turning point C_p^0 that eliminates the difference between the total voyage costs prior and after relocation of the transshipment hub. The following equations are relevant in that regard:

$$\Delta Total_{cost}\big|_{C_p^0} = 0$$

$$\Delta ETS_{cost} + \Delta FUEL_{cost} + \Delta PORT_{cost} = 0 \Leftrightarrow \Delta ETS_{cost} = -(\Delta FUEL_{cost} + \Delta PORT_{cost})$$

Using Eq. (18), Eq. (8) and (9) we can factor out the carbon price C_p^0, hence:

$$\Delta ETS_{cost} = C_p^0 \times [(R_m^B \times CO_{2m}^{\ B} + R_{m-1,m}^V \times CO_{2m-1,m}^{\ V} + R_{m,m+1}^V \times CO_{2m,m+1}^{\ V})\big|_{P_m} - (R_m^B \times CO_{2m}^{\ B} + R_{m-1,m}^V \times CO_{2m-1,m}^{\ V} + R_{m,m+1}^V \times CO_{2m,m+1}^{\ V})\big|_{P_m^*}]$$

Hence:

$$C_p^0 = -\frac{\Delta FUEL_{cost} + \Delta PORT_{cost}}{\Psi} \tag{20}$$

where:

$$\Psi = (R_m^B \times CO_{2m}^{\ B} + R_{m-1,m}^V \times CO_{2m-1,m}^{\ V} + R_{m,m+1}^V \times CO_{2m,m+1}^{\ V})\big|_{P_m} - (R_m^B \times CO_{2m}^{\ B} + R_{m-1,m}^V \times CO_{2m-1,m}^{\ V} + R_{m-1,m}^V \times CO_{2m,m+1}^{\ V})\big|_{P_m^*} \tag{21}$$

4. The Piraeus versus Izmir case study

The major European transshipment hubs located in the East Mediterranean region are the Piraeus port in Greece, the Gioia Tauro, Taranto and Cagliari ports in Italy and the Marsaxlokk port in Malta (The World Bank Group, 2021). The non-European competitors of those ports are mainly found in Turkey; the Izmir, Aliaga, Nemport port located in the Aegean region and the Port Said port in Egypt close to the entrance of the Suez Canal. These ports have a strong market position for serving the East Med and act as transshipment hubs for serving the Black Sea ports.

The imminent inclusion of shipping in the EU ETS entails an increase in the total voyage costs associated with calling at an EEA port and influences the competition among the East Med transshipment hubs. Prior to our investigation on the commercial reasons that would justify the relocation of a transshipment hub inn the area, this paper gathers and analyzes specific data on port performance and port development. Our first case study focuses on the Piraeus port in Greece and the Izmir port in Turkey. The ports have a distance of 210 nm and in the following subsections, we present brief background information on their special characteristics that will establish our comparative assessment. Fig. 2 shows the location of and distance between the two transshipment hubs on the map and the respective reconfiguration of the mainline service in the event of hub relocation.

Fig. 2. Graphical representation of the Pireaus to Izmir transshipment relocation scenario for a mainline service sailing from Far East to Europe through the Suez Canal.

4.1. The Piraeus Port

The total Piraeus container port consists of three terminals and has a capacity of 6.7 million TEUs. Terminal 1 is run by the Piraeus Port Authority SA (PPA), which after 2016 has become a company in which China COSCO Shipping Ports Limited is the majority shareholder. Terminals 2 and 3 have been run since 2010 by another COSCO Shipping Ports Limited subsidiary named Piraeus Container Terminal SA (PCT). Approximately 90% of the traffic at Piraeus is transshipment cargo rendering the port a key hub in the Mediterranean and the 4th largest container port in Europe (PortEconomics, 2021). According to InforMare[6], in 2020, port activity, primarily measured by port traffic, for Piraeus amounted to 5.44 million TEU, with a decrease of −3.7% vs. 2019, which followed four consecutive years of growth in volumes.

Under the prospects of our cost–benefit analysis, we assess the overall costs of a containership attributed to calling at the Piraeus Port. As mentioned in Section 3, the analysis assumes an average of 3,000 transshipment moves per call for each mother vessel.

6 http://www.informare.it/news/gennews/2021/20210257-porto-Pireo-traffico-Y-2020uk.asp.

Table 3
Results of the analysis on AEU1 service from Far East to North Europe through Piraeus.

Service			AEU1	Name of Carrier			COSCO Shipping Lines	
No. of ships deployed in the service			12	Service Cycle Duration (days)			84	
Average Capacity Range (TEU)			19000–21000					
Port of Call	A_x	D_x	$v_{x-1,x}$	$fc^V_{x-1,x}$	$CO_2{}^V_{x-1,x}$	$CO_2{}^B_x$	$ETS^V_{x-1,x}$	ETS^B_x
Yantian	29/08 04:00	30/08 01:00	–	–	–	40.871	–	0.00
Ningbo	02/09 17:30	04/09 16:00	7.6	16.96	194.72	90.50	0.00	0.00
Shanghai	05/09 12:00	07/09 12:30	7.2	15.00	38.92	94.39	0.00	0.00
Xiamen	09/09 15:00	11/09 05:00	10.1	34.31	224.86	73.96	0.00	0.00
Singapore	14/09 22:30	16/09 01:00	18.2	144.70	1,680.38	51.577	0.00	0.00
Felixstowe	11/10 14:00	14/10 04:45	14.0	76.27	6,066.65	122.13	0.00	0.00
Gdansk	18/10 17:00	21/10 06:00	14.6	84.07	1,180.78	118.72	35,423.44	7,123.28
Wilhelmshaven	23/10 15:00	24/10 15:00	11.7	49.37	365.16	46.71	21,909.59	2,802.60
Zeebrugge	25/10 10:00	26/10 08:00	13.3	67.48	166.35	42.82	9,980.91	2,569.05
Piraeus	01/11 14:00	02/11 20:00	18.4	148.65	2,893.45	58.39	173,607.25	3,503.25
Singapore	15/11 02:00	16/11 05:00	19.0	160.08	6,106.22	52.55	183,186.50	0.00
Yantian	19/11 13:00	–	17.8	137.70	1429.38	–	0.00	–

The calculation of the transshipment cost followed the data retrieved from the PPA website and, more specifically, from Tariff No. 3: Service provision for works of Loading–Unloading and Storage of Containers (OLP, 2021) and the "Regulation and Tariffs" (OLP, 2018). This Tariff involves a sliding scale in which the transshipment price per move is a decreasing function of the total number of annual transshipment moves that a company registers in Piraeus. Considering the charging policies of the port and the dependency of the price on the total number of transshipment moves performed by a shipping company in a year, we shall assume that a price of 41.5 EUR/move, which is the lowest in the sliding scale, applies to our case. Indeed, it is expected that since the services investigated in this study belong to COSCO Shipping Lines, the most competitive prices would be charged as the company has significant transshipment traffic per year at the port.

4.2. The Izmir Port

There are 4 Turkish ports located in the Aegean Region that serve the container traffic: the TCDD Izmir Port, the Nemport Port, the Ege Gübre Port and the SOCAR Container Terminal. Among those, the TCDD Izmir Port is the largest in cargo volume and service diversity and has a capacity of 1,165,000 TEU. The port handled 605,000 TEU in 2019 and right now is at the privatization stage; but so far has been publicly operated (Oral, 2020).

According to the World Economic Forum[7], port infrastructure in the country from 2012 to 2019 has increased significantly. The Turkish Transport and Infrastructure Ministry reported that the volume of cargo transshipment via Turkish Izmir port in the first ten months of 2021 exceeded 5.8 million MTs (Trend, 2021). The recent investments ("Izmir Port Dredging and Extension Project" and the "North Aegean Port Project") highlight the growing interest in the port and aim at improving the performance and reliability of Izmir (Konecranes, 2021; Çeri Fidan, 2020). The TCDD Izmir port has a maximum draft of 10 m but the Public Railway Company TCDD, has decided to commence dredging operations in the gulf, aiming to reach 17 m berth depth (Alpcan, 2019).

Data on the port costs we retrieved from (VDA, 2003). Transshipment tariffs of the SOCAR Container terminal account for 60 USD per move for laden containers and 45 USD per move for empty containers (SOCAR, 2021). This analysis assumes that all the transshipment volume performed at Piraeus will be shifted to Izmir and thus, 3,000 moves per call will need to be facilitated at the competitor port. For calculating the annual transshipment costs and considering the ports charging policies, we assume that half of these containers are fully loaded and half are empty and that no special arrangement between the port and the shipping line on transshipment tariffs. In case transshipment costs at Izmir are overestimated, the carbon price break-even point would decrease.

4.3. Results

Tables 3–5 present the results of our analysis on the calculation of the initial carbon cost attributed to each service before relocating the hub. Our calculations were based on real-time data on the arrival and departure times of the vessels operating at a specific service.

Following our results, and considering the available data on the vessels annual CO_2 emissions already reported under the EU MRV regulation, we cross-referenced and compared the results of our model with the data reported for the same vessels in the 72^{nd} version of the 2020 THETIS MRV database[8]. Variables to be compared were the annual days spent at sea and the CO_2 emissions of the vessels under study from EEA ports to non-EEA ports, from non-EEA ports to EEA ports, between EEA ports, and at berth

[7] https://www.theglobaleconomy.com/Turkey/seaports_quality/.
[8] https://mrv.emsa.europa.eu/#public/eumrv.

Table 4
Results of the analysis on AEU3 service from Far East to North Europe through Piraeus.

Service			AEU3	Name of Carrier			COSCO Shipping Lines	
No. of ships deployed in the service			12	Service Cycle Duration (days)			84	
Average Capacity Range (TEU)			19000–21000					
Port of Call	A_x	D_x	$v_{x-1,x}$	$fc^V_{x-1,x}$	$CO_{2\,x-1,x}^V$	$CO_{2\,x}^B$	$ETS^V_{x-1,x}$	ETS^B_x
Xingang	21/09 20:00	22/09 23:30	–	–	–	53.522	–	0.00
Qingdao	23/09 16:00	25/09 12:00	17.5	119.91	256.71	85.65	0.00	0.00
Dalian	26/09 14:00	28/09 05:00	13.7	66.22	223.40	75.90	0.00	0.00
Shanghai	29/09 21:00	01/10 10:30	13.8	67.20	348.78	72.98	0.00	0.00
Ningbo	02/10 17:45	03/10 18:30	4.6	4.62	18.71	48.17	0.00	0.00
Singapore	08/10 14:30	09/10 14:30	17.6	121.55	1,829.43	46.71	0.00	0.00
Piraeus	23/10 07:00	24/10 15:00	17.0	111.85	4,767.36	62.28	143,020.75	3,736.80
Rotterdam	30/10 08:00	01/11 22:00	20.6	179.02	3,182.13	120.67	190,927.89	7,240.05
Hamburg	02/11 23:00	05/11 11:00	11.8	45.65	148.06	116.78	8,883.69	7,006.50
Antwerp	06/11 18:00	08/11 06:00	11.2	40.17	161.57	70.07	9,694.22	4,203.90
Shanghai	30/11 08:00	01/12 20:00	19.5	157.54	10,833.39	70.07	325,001.77	0.00
Xingang	03/12 19:00	–	14.8	80.21	489.142	–	0.00	–

Table 5
Results of the analysis on AEU7 service from Far East to North Europe through Piraeus.

Service			AEU7	Name of Carrier			COSCO Shipping Lines	
No. of ships deployed in the service			10	Service Cycle Duration (days)			70	
Average Capacity Range (TEU)			13000–15000					
Port of Call	A_x	D_x	$v_{x-1,x}$	$fc^V_{x-1,x}$	$CO_{2\,x-1,x}^V$	$CO_{2\,x}^B$	$ETS^V_{x-1,x}$	ETS^B_x
Xiamen	16/06 16:00	17/06 16:00	–	–	–	49.82	0.00	0.00
Nansha	18/06 17:00	19/06 13:00	13.2	72.09	233.83	41.52	0.00	0.00
Hong Kong	19/06 20:00	20/06 16:00	10.0	36.29	32.96	41.52	0.00	0.00
Yantian	21/06 01:00	21/06 20:00	6.9	14.58	17.03	39.44	0.00	0.00
Cai MepTan	24/06 01:00	24/06 13:00	17.1	133.94	921.06	24.91	0.00	0.00
Singapore	26/06 19:00	27/06 19:00	11.5	50.87	356.44	49.82	0.00	0.00
Piraeus	11/07 14:00	11/07 15:00	16.8	129.76	5572.73	2.08	167,181.89	124.56
Hamburg	20/07 05:30	22/07 05:30	14.8	95.02	2546.03	99.65	152,761.91	5,978.88
Rotterdam	23/07 07:15	24/07 13:15	12.3	60.33	201.58	62.28	12,094.59	3,736.80
Zeebrugge	25/07 06:00	26/07 02:00	5.2	7.31	15.89	41.52	953.23	2,491.20
Felixstowe	26/07 12:00	28/07 14:00	8.0	21.02	27.28	103.80	818.37	0.00
Singapore	18/08 16:30	19/08 22:30	16.5	123.53	8117.98	62.28	0.00	0.00
Hong Kong	23/08 16:30	24/08 12:30	16.1	116.89	1365.04	41.52	0.00	0.00
Xiamen	01/09 16:00	–	1.5	0.35	8.95	–	0.00	0.00

Table 6
Comparison of the annual time spent at sea and CO_2 emissions estimated from the model and reported in the 72nd report of the THETIS MRV database.

Service	Model's estimates			Thetis MRV database			Deviation		
	AEU1	AEU3	AEU7	AEU1	AEU3	AEU7	AEU1	AEU3	AEU7
Time spent at sea (hours)	4,490.04	5,533.95	3,042.64	4,824.7	5,310.96	3,298.4	−7%	4%	−8%
CO_2 towards EEA ports (MT)	28,755.93	23,363.12	24,299.26	30,605.28	25,316.19	21,994.95	6%	8%	−9%
CO_2 from EEA ports (MT)	17,386.43	51,350.28	20,790.99	16,693.37	47,497.58	20,005.64	−4%	−8%	−4%
CO_2 between EEA ports (MT)	19,311.88	16,550.96	12,217.81	18,308.61	16,210.38	12,652.26	−5%	−2%	4%
CO_2 at berth at an EEA port (MT)	1,512.94	1,752.79	1,269.39	1,483.58	1,701.65	1,354.02	−2%	−3%	7%

in EEA ports. Table 6 presents the results of our comparison and indicates that our model approaches sufficiently well the THETIS reported data.

Following our analysis, we replaced Piraeus with the Izmir port and recalculated the aforementioned voyage costs. Table 7 presents the results of our analysis in estimating the key parameters that will alter under the prospects of relocating the transshipment hub from Piraeus to Izmir. As expected the total emissions that fall under the EU ETS will decrease together with the total carbon costs that will need to be surrendered as EUAs. However the overall emissions attributed to the service will rise which indicates a significant increase on the risk of carbon leakage.

Among the various outputs of Table 7, the values of Ψ, the volume of carbon emissions that escape from the EU ETS pricing due to the hub relocation, are worthy of note. This can be as high as 5,761.85 MT of CO_2 per weekly call (AEU1 service), which is translated into 322,423 MT of CO_2 on a yearly basis and for this service alone. For all three of the services examined (AEU1, AEU3 and AEU7), the equivalent amount is 804,111 MT of CO_2 per year. This attests to the significant side-effects of the hub relocation.

Table 7
Results on the cost assessment and the estimation of the carbon leakage risk after the relocation of the transshipment hub from Piraeus to Izmir.

Service		AEU1	AEU3	AEU7
No of Vessels deployed in the service		12	12	10
Avg. Capacity Range (TEU)		19000–21000	19000–21000	13000–15000
Non-relocation (GRPIR)	Days spent sailing from, to or between EEA ports	26.18	43.81	24.58
	Days spent at berth at an EEA port	5.71	7.92	4.13
	CO_2 Emissions from sailing from, to or between EEA ports (MT)	10,711.96	19,092.98	8,363.50
	CO_2 Emissions at berth at an EEA port(MT)	266.64	369.79	205.52
	Total EU Carbon allowance cost (60 EUR/MT of CO_2)	440,11	699,72	346,14
	Total CO_2 Emissions	20,432.36	23,081.45	20,068.01
Relocation (TRIZM)	Days spent sailing to ports from, to or between EEA ports	13.93	30.13	10.79
	Days spent at berth at an EEA port	4.46	6.58	4.08
	CO_2 Emissions from sailing from, to or between EEA ports (MT)	5,008.51	14,761.61	3,111.17
	CO_2 Emissions at berth at an EEA port (MT)	208.25	307.51	190.73
	Total EU Carbon allowance Cost (60 EUR/MT of CO_2)	178.695	470,588	111,303
	Total CO_2 Emissions	21,539.53	23,599.93	20,451.96
Additional port cost due to relocation (EUR)		13,050	13,050	13,050
Additional fuel cost due to relocation (EUR)		55,502.66	71,926.41	58,988.59
CO_2 Emissions excluded from the EU ETS due to relocation Ψ (MT)		5,761.85	4,393.18	5,267.12
Additional CO_2 Emissions due to relocation — Carbon leakage (MT)		1107.17	518.47	383.95

Table 8
Influence of bunker prices on the EU carbon price break-even point (C_p^0 in EUR/MT of CO_2) for the examined services.

Fuel Price (EUR/MT)	300	400	500	600	700	800
AEU1	11.84	14.79	17.74	20.69	23.64	26.59
AEU3	16.50	20.86	25.22	29.58	33.94	38.30
AEU7	13.58	17.00	20.41	23.83	27.24	30.66

Table 9
Results on the cost–benefit analysis on the transshipment hub relocation problem and the estimation of the EU carbon price turning point for evading the EU ETS — The Piraeus and Izmir case study.

Service	Origin	Transit	Destination	$d_{x-1,x}$	$v_{x-1,x}$	$FC^V_{x-1,x}$	$CO^V_{2x-1,x}$	$R^V_{x-1,x}$	$ETS^V_{x-1,x}$ ($C_p = 60$)	ETS^B_x ($C_p = 60$)	C_p^0
AEU1	Zeebrugge	Pireaus		2759	18.4	929.18	2893.45	100%	173607.25	6072.00	15.73
		Pireaus	Singapore	5573	19.0	1960.89	6106.22	50%	183186.50	3503.00	
	Zeebrugge	Izmir		2910	24.3	1058.51	3296.22	50%	98886.46	2569.05	
		Izmir	Singapore	5572	19.0	1960.03	6103.54	0%	0.00	0.00	
AEU3	Singapore	Pireaus		5573	17.0	1530.94	4767.36	50%	143020.75	3736.80	22.25
		Pireaus	Rotterdam	2817	20.6	1021.88	3182.13	100%	190927.89	10976.80	
	Singapore	Izmir		5612	17.1	1557.28	4849.37	0%	0.00	0.00	
		Izmir	Rotterdam	2969	21.7	1162.04	3618.59	50%	108557.72	7240.05	
AEU7	Singapore	Pireaus		5573	16.8	1789.58	5572.73	50%	16781.89	124.56	18.09
		Pireaus	Hamburg	3061	17.0	871.61	2546.03	100%	152761.91	6103.44	
	Singapore	Izmir		5612	17.3	1820.36	5668.60	0%	0.00	0.00	
		Izmir	Hamburg	3214	17.6	1101.36	3429.65	50%	102889.47	5605.20	

Our analysis, also, focused on the effect of fuel prices on the EU carbon price turning point. Higher bunker prices coincide with higher voyage costs and it is evident from Eq. (20) that the C_p^0 will increase. Table 8 shows the break-even point (in EUR/MT of CO_2) for different bunker prices for each of the examined services. Despite the increase, carbon prices remain significantly low and well below the current EU carbon price ($C_p = 60$ MT of CO_2).

Finally, Table 9 shows our results on the cost–benefit analysis on relocating the transshipment hub. The calculation of the different costs attributed to the relocation of the hub allowed us to estimate the EU carbon price turning point that renders the shift of the hub a cost-effective choice for the liner operator. Our outputs indicate that the shift becomes cost-effective at prices even lower than the current EU carbon market price.

Figs. 3–5 depict the total annual voyage costs in million EUR for several EU carbon market prices for each service. The figures intersect on the carbon price turning point C_p^0 that equalizes the costs of the non-relocation and the relocation scenarios. For carbon prices lower than C_p^0 there is no strong financial incentive transshipment hub reconfiguration. For prices beyond the C_p^0 there is clear motive to proceed to redesign the network to evade the EU ETS. The vertical difference of the plotted lines represents the EU ETS revenue loss for several carbon prices. One can observe that in all three cases, the EU carbon price turning points are rather low, and certainly lower than the current EU carbon price (60 EUR/MT CO_2).

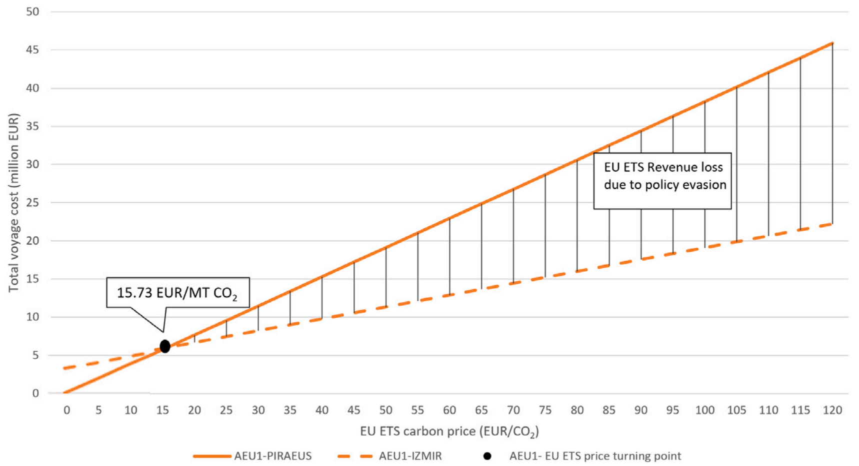

Fig. 3. Annual voyage costs of the AEU1 service attributed to the EU ETS.

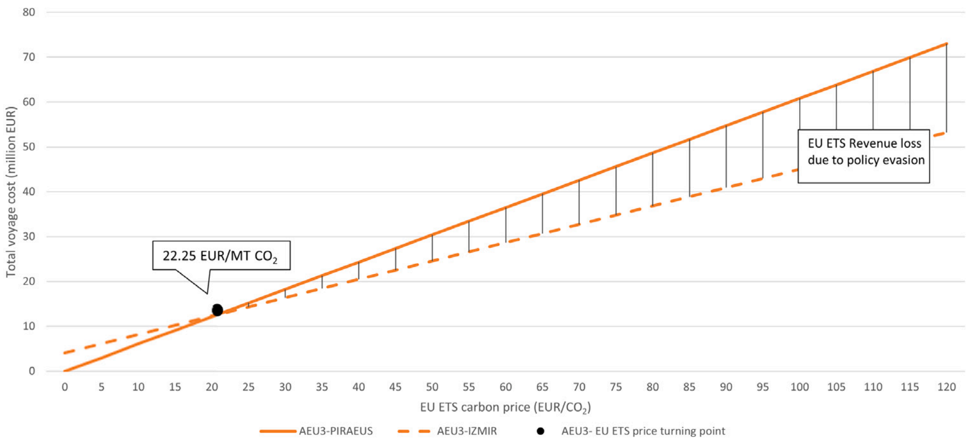

Fig. 4. Annual voyage costs of the AEU3 service attributed to the EU ETS.

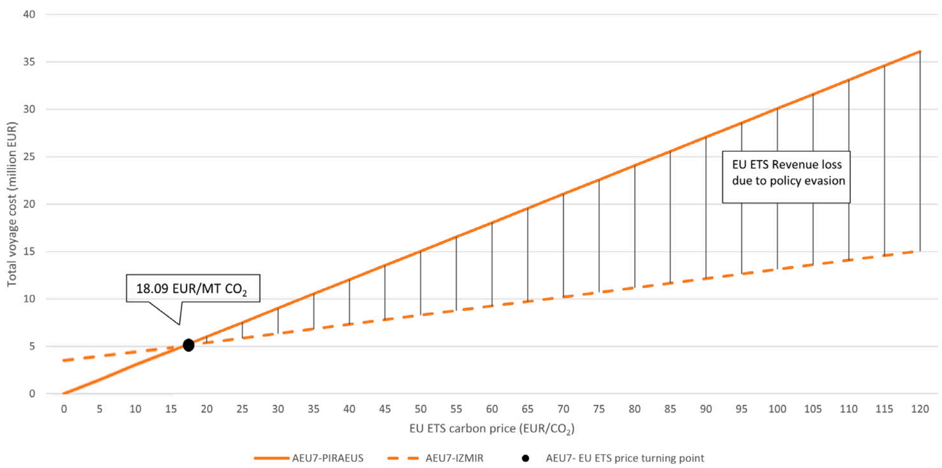

Fig. 5. Annual voyage costs of the AEU7 service attributed to the EU ETS.

With respect to the feeders as mentioned in Section 3, this paper does not include calculations for the feeder services that would relocate to Izmir as a result of the mainline hub relocation there. Note that for containers that originate from or are destined to the Black Sea and are transshipped in Piraeus, Izmir is a more attractive hub location from a cost perspective due to geographical proximity, and even if the EU ETS cost is not included. Plus, as Izmir is not in the EEA, the EU ETS revenues for feeder services serving the Black Sea would be either non-existent or very low (in the latter case being limited to 50 percent of the emissions if the port just prior to or after Izmir is in the EEA — that is, in Greece, Bulgaria or Romania, and zero otherwise).

5. The Algeciras versus Tanger Med case study

Due to their competitive gateway feature, the ports located in the Strait of Gibraltar act as major transshipment hubs. This case study focuses on the Algeciras port in Spain and on the Tanger Med port in Morocco and investigates the potential of proceeding to transshipment hub relocation under the prospects of evading the EU ETS. The two ports have a distance of 30 nm between each other. They are both characterized by adequate and advanced port facilities and container handling efficiency. We study two international services that call at Algeciras and calculate the arising EUAs carbon costs. We follow the methodology of Section 3 and assume that there will be no change in transit times and due to the ports' enhanced efficiency no alteration on time spent at berth to facilitate the transshipment. Fig. 6 shows the location of and distance between the two transshipment hubs on the map and the respective reconfiguration of the mainline service in the event of hub relocation.

5.1. The Algeciras Port

The port of Algeciras has a total capacity of 5.9 million TEUs and is operated by APM Terminals and TTI Algeciras. Approximately 93% of the port's cargo volume is dedicated to transshipment operations rendering the port one of the largest hubs in West Med. According to PortEconomics (2021) the port ranked 6th in the list of European ports with the highest container throughput for 2019 and 2020. As reported by InforMARE[9], the Spanish port recorded a 6.1% decline in traffic in contrast to the 30% increase in the neighboring Tanger Med after 2019. Since the port belongs to APM Terminals, it only serves vessels operated by Maersk and transshipment tariffs remain confidential. According to the Ricardo report (Pons et al., 2021a), rates at Algeciras are higher than those at the Tanger Med port. This results to lower bounds for EU carbon prices that render the evasion of the policy a cost-effective solution for the liner operator. For the sake of our analysis we shall assume a 10% increase on transshipment tariffs for the Algeciras terminal versus those at Tanger Med.

Fig. 6. Graphical representation of the Algeciras to Tanger Med transshipment relocation scenario for a mainline service sailing from U.S. to Europe through the Strait of Gibraltar.

5.2. The Tanger Med Port

The port Tanger Med I has two container terminals with a total rated capacity of 3 million TEUs. The first container terminal (TC1) is operated by APM Terminals Tanger, a subsidiary of APM Terminals Group. The second container terminal (TC2) is operated by EUROGATE TANGER, ContshipItalia and the two maritime companies MSC and CMA-CGM. With the recent construction of Tanger Med 2, the port increased its total capacity to 9 million TEUs. According to data from InforMARE[10] in 2019, when Tanger Med 2 became operational, the Moroccan port moved 4.8 million TEUs, corresponding to an increase of 38% from 2018. At the same time, in the port of Algeciras, the container traffic fell by −2.74%. Transshipment rates range among the different terminals at around 60 EUR/move for a 20' container and 67 EUR/move for a 40' container regardless of its loading condition.

9 http://www.informare.it/news/gennews/2021/20211556-porto-Algeciras-traffico-ottobre-2021uk.asp.
10 https://www.informare.it/news/gennews/2020/20200082-porto-Tanger-Med-traffico-Y-2019uk.asp.

Table 10
Results of the analysis on AE10 service from Far East to North Europe through Algeciras.

Service			AE10	Name of Carrier			A.P. Møller–Mørsk	
No. of ships deployed in the service			13	Service Cycle Duration (days)			91	
Average Capacity Range (TEU)			19000–21000					
Port of Call	A_x	D_x	$v_{x-1,x}$	$fc^V_{x-1,x}$	$CO_{2x-1,x}^V$	CO_{2x}^B	$ETS^V_{x-1,x}$	ETS^B_x
Yantian	10/11 03:45	11/11 07:49	–	–	–	54.63	0.00	0.00
Tanjung Pelepas	14/11 14:50	15/11 17:01	18.7	154.16	1,580.51	50.96	0.00	0.00
Algeciras	03/12 02:00	04/12 08:00	16.6	115.95	6,273.06	58.39	6,392.48	119.00
Bremerhaven	07/12 22:00	08/12 22:00	18.7	155.02	1,729.76	46.71	3,525.38	95.20
Gdansk	10/12 18:06	16/12 11:50	10.9	41.21	235.80	268.06	480.57	546.33
Bremerhaven	18/12 22:04	19/12 09:30	8.1	20.14	152.19	22.25	310.17	45.35
Rotterdam	20/12 07:00	21/12 03:00	12.2	54.32	151.54	38.93	308.85	79.33
Tanjung Pelepas	13/01 19:30	15/01 09:00	14.7	85.49	6,306.09	72.98	6,426.13	0.00
Shanghai	19/01 22:00	21/01 10:00	20.5	193.32	2,734.10	70.07	0.00	0.00
Xingang	24/01 07:00	25/01 18:59	7.8	18.31	163.91	70.03	0.00	0.00
Qingdao	27/01 6:00	28/01 09:00	8.2	20.77	94.35	52.55	0.00	0.00
Gwangyang	30/01 03:00	31/01 06:00	11.1	43.19	235.36	52.55	0.00	0.00
Ulsan	01/02 16:00	01/02 17:00	4.0	3.56	15.71	1.95	0.00	0.00
Ningbo	02/02 16:00	03/02 23:00	23.3	265.25	791.58	60.33	0.00	0.00
Yantian	08/02 15:00	–	6.7	12.56	182.54	–	0.00	0.00

Table 11
Results of the analysis on TA6 service from America to North Europe through Algeciras.

Service			TA6	Name of Carrier			A.P. Møller–Mørsk	
No. of ships deployed in the service			9	Service Cycle Duration (days)			63	
Average Capacity Range (TEU)			8000–11999					
Port of Call	A_x	D_x	$v_{x-1,x}$	$fc^V_{x-1,x}$	$CO_{2x-1,x}^V$	CO_{2x}^B	$ETS^V_{x-1,x}$	ETS^B_x
Gioia Tauro	17/11 07:00	18/11 23:00	–	–	–	77.85	0.00	743.68
Naples	19/11 20:00	20/11 20:00	8.1	9.10	24.80	46.71	236.88	446.21
La Spezia	21/11 19:00	23/11 07:00	13.8	70.60	210.70	70.07	2,012.74	669.31
Barcelona	24/11 08:00	25/11 23:00	15.4	108.23	351.08	75.90	3,353.73	725.09
Algeciras	26/11 23:00	28/11 12:01	22.3	446.29	1,389.75	72.04	13,275.94	688.22
Sines	01/12 15:00	03/12 07:00	3.7	3.45	4.38	77.85	41.84	743.68
Freeport	09/12 21:00	10/12 21:00	13.1	58.37	2,067.45	46.71	9,874.89	0.00
Veracruz	15/12 06:00	15/12 22:00	12.2	44.68	608.69	31.14	0.00	0.00
Altamira	18/12 23:00	19/12 15:00	20.7	336.17	3,184.12	31.14	0.00	0.00
Houston	21/12 07:00	23/12 19:00	12.0	41.09	213.27	116.78	0.00	0.00
Miami	28/12 02:00	01/01 02:00	9.0	13.68	182.88	93.42	0.00	0.00
Gioia Tauro	18/01 13:00	–	11.6	36.06	1,960.20	–	6,873.16	0.00

Table 12
Comparison of the annual time spent at sea and CO_2 emissions estimated from the model and reported in the 72nd report of the THETIS MRV database.

Service	Model's estimates		Thetis MRV database		Deviation	
	AE10	TA6	AE10	TA6	AE10	TA6
Time spent at sea (hours)	3,205.33	4,922.50	3,451.20	4,987.81	−7%	−1%
CO_2 towards EEA ports (MT)	25,092.26	11,369.18	23,733.69	11,614.44	6%	−2%
CO_2 from EEA ports (MT)	25,224.34	11,991.18	27,207.16	10,697.64	−7%	8%
CO_2 between EEA ports (MT)	9,077.14	11,488.07	9,784.35	12,874.31	−7%	−8%
CO_2 at berth at an EEA port (MT)	1,550.51	2,438.45	1,480.38	2,511.00	5%	−3%

5.3. Results

Following our analysis, we assessed the Algeciras and the Tanger Med port case study and calculated the deviation distance for each service, the total CO_2 emissions and the overall voyage costs. Our results are then compared with the costs of EU ETS allowances required for the service.

Tables 10 and 11 present the results of our analysis on the calculation of the initial carbon cost attributed to each service before the relocation of the hub. Our calculations are based on real-time services that operate through Algeciras and data on the arrival and departure times were retrieved from the liner's website.

Table 12 presents the results of our comparison between the data reported under the EU MRV regulation for the vessels under scope and our model's estimates. We used the results of the 72nd version of the 2020 THETIS MRV database.

Table 13
Influence of bunker prices on the EU carbon price break-even point (C_p^0 in EUR/MT of carbon) for the examined services.

Fuel Price (EUR/MT)	300	400	500	600	700	800
AE10	−0.80	−0.32	0.17	0.65	1.13	1.61
TA6	0.59	4.75	8.90	13.06	17.21	21.37

Table 14
Results on the cost assessment and the estimation of the carbon leakage risk after the relocation of the transshipment hub from Algeciras to Tanger Med.

Service		AE10	TA6
No of Vessels deployed in the service		13	9
Avg. Capacity Range (TEU)		19000–21000	8000-11999
Non-relocation (ESALG)	Days spent sailing from, to or between EEA ports	49.80	33.04
	Days spent at berth at an EEA port	9.30	9.00
	CO_2 Emissions from sailing from, to or between EEA ports (MT)	14,848.43	13,242.81
	CO_2 Emissions at berth at an EEA port(MT)	434.34	420.42
	Total EU Carbon allowance cost (60 EUR/MT of CO_2)	539,591.87	481,930.64
	Total CO_2 Emissions	21,512.25	18,171.37
Relocation (MAPTM)	Days spent sailing to ports from, to or between EEA ports	32.43	32.04
	Days spent at berth at an EEA port	8.05	7.46
	CO_2 Emissions from sailing from, to or between EEA ports (MT)	8,591.19	11,853.37
	CO_2 Emissions at berth at an EEA port (MT)	375.95	348.38
	Total EU Carbon allowance Cost (60 EUR/MT of CO_2)	296,478.49	438,564.40
	Total CO_2 Emissions	21,572.46	18,264.05
Additional port cost due to relocation (EUR)		−9,000	−9,000
Additional fuel cost due to relocation (EUR)		8,351.85	12,856.05
CO_2 Emissions excluded from the EU ETS due to relocation Ψ (MT)		6,268.92	1,456.06
Additional CO_2 Emissions due to relocation — Carbon leakage (MT)		60.20	92.68

Table 15
Results on the cost–benefit analysis on the transshipment hub relocation problem and the estimation of the EU carbon price turning point for evading the EU ETS — The Algeciras and Tanger Med case study.

Service	Origin	Transit	Destination	$d_{x-1,x}$	$v_{x-1,x}$	$FC^V_{x-1,x}$	$CO_2{}^V_{x-1,x}$	$R^V_{x-1,x}$	$ETS^V_{x-1,x}$ ($C_p = 60$)	ETS^B_x ($C_p = 60$)	C_p^0
AE10	Tanjung Palepas	Algeciras		6928	16.6	2,014.47	6,273.06	50%	188,191.93	3,053.25	0
		Algeciras	Bremerhaven	1609	18.7	555.48	1,729.76	100%	103,785.52	2,802.60	
	Tanjung Palepas	Port Tangier		6948	16.7	2,028.73	6317.45	0%	0.00	0.00	
		Port Tangier	Bremerhaven	1615	18.8	560.56	1,745.58	50%	52,367.32	2,802.60	
TA6	Barcelona	Algeciras		534.00	22.30	446.29	1,389.75	100%	83,385.09	4,322.62	6.08
		Algeciras	Sines	278.00	10.30	25.91	80.69	100%	4,841.09	4,671.00	
	Barcelona	Port Tangier		543.00	22.60	475.95	1,482.12	50%	44,463.53	0.00	
		Port Tangier	Sines	283.00	10.50	27.75	86.42	50%	2,592.50	4,671.00	

Our analysis also examined the effect of fuel prices on the EU carbon price turning point. Higher bunker prices coincide with higher voyage costs and it is evident from Eq. (20) that the C_p^0 will increase. Table 13 shows the break-even point (in EUR/MT of CO_2) for different bunker prices for each service. Despite the increase, carbon prices remain significantly low and well below the current carbon price ($C_p = 60$). Negative break-even points indicate that the relocation is already cost effective, even before the service is regulated under the EU ETS.

Table 14 presents the results of the analysis for the Tanger Med hub. As expected, the total emissions that fall under the EU ETS regulations will decrease, however the overall emissions attributed to the service will increase. Our results indicate that the risk of carbon leakage is real and should be taken into consideration by the EU policy makers.

Table 15 shows our results on the cost–benefit analysis. The calculation of the different costs attributed to the relocation of the hub allowed us to estimate the EU carbon price turning point that renders the shift of the hub cost-effective for the liner operator.

Figs. 7 and 8 depict for each service, the relation of the total annual voyage costs in million EUR to the EU carbon price for each service. The figures intersect on the break-even point C_p^0 that equalizes the non-relocation and the relocation costs. For carbon prices lower than C_p^0 there is no strong financial incentive to change the transshipment hub. However, for prices beyond the C_p^0 overall voyage prices increase and there is clear motive to proceed to network reconfiguration. The vertical difference of the plotted lines shows the EU ETS revenue loss in case of relocation. In the specific scenario of Algeciras the price differential of the voyages prior and after the relocation was negligible and thus our results indicate that the relocation would be cost-effective for zero-carbon prices.

As mentioned in Section 3, the relocation of the feeders to Tanger Med as a result of the mother service reconfiguration is excluded from this analysis. For containers that sail to or from African ports and are transshipped in Algeciras, Tanger is a more

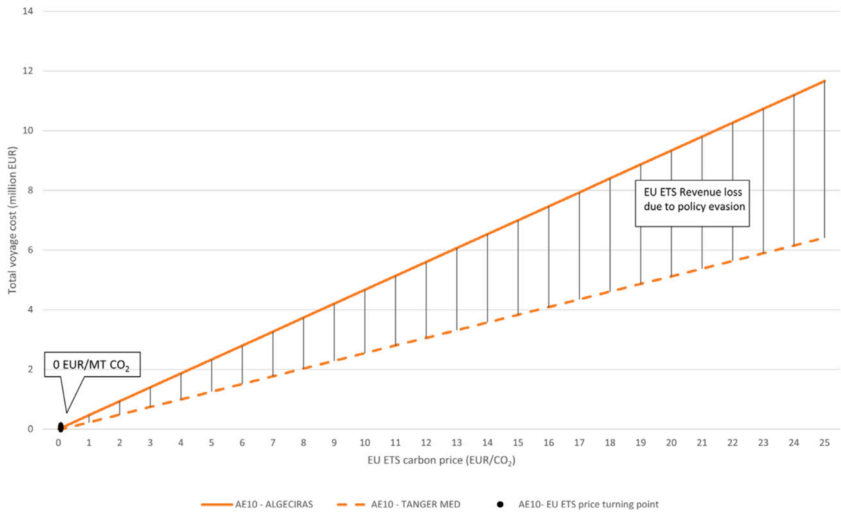

Fig. 7. Annual voyage costs of the AE10 service attributed to the EU ETS.

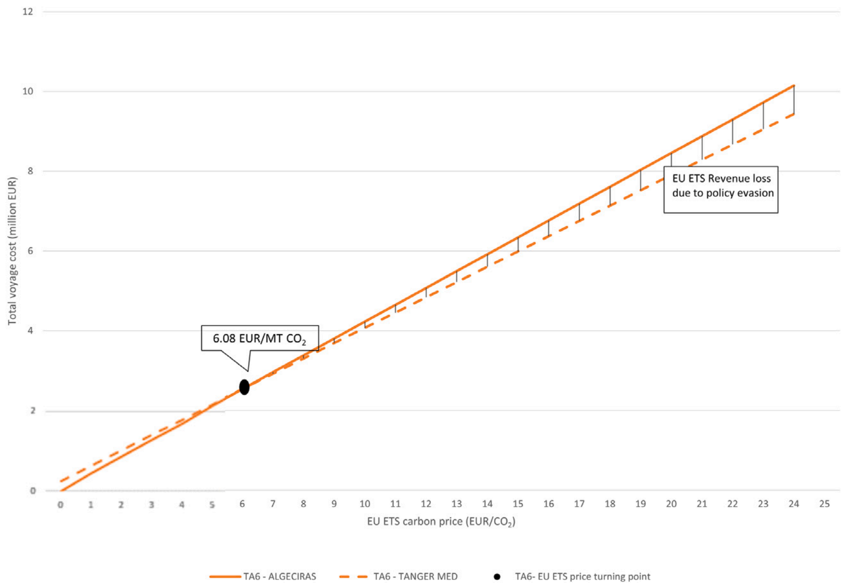

Fig. 8. Annual voyage costs of the TA6 service attributed to the EU ETS.

attractive hub location from a cost perspective due to geographical proximity, and even if the EU ETS cost is not included. In addition, as Tanger Med is not in the EEA, the EU ETS revenues for feeder services serving the EEA ports would be 50% lower than utilizing Algeciras as the transshipment hub.

6. Discussion

As this paper was being finalized, the European Parliament (EP) contemplated a more robust version of the European Commission's (EC) proposal, namely to include 100% of the CO_2 emissions between EEA and non-EEA ports instead of 50% (EPa, 2022). Even though it is unclear what the final version of the proposed legislation would entail, this being the outcome of negotiations among the EC, the EP, and the Council, the 100% version would surely provide a stronger economic incentive for container operators to relocate their transshipment hubs outside the EEA.

It is expected that since a shipowner is the responsible party for compliance but has no financial interest on the cargo itself, it is natural that there will be some negotiations between the shipowner and the cargo owners when it comes to the allocation of carbon costs. There is an expectation that commercial charter party terms to include carbon pricing in the near term. The latest signals from the EC are that in time charter contracts, the charterer will pay the ETS carbon costs (EPa, 2022).

Fully 61% of the world fleet is not owned by an EU company. Looking at the statistics in the baseline period for the EU MRV we saw that 46% of these port calls were from vessels owned by companies outside the EU. So there will be some administrative work in setting up registry accounts, managing these obligations, and trading emissions allowances.

As stated earlier (Section 3), our model assumes that no speed reduction due to the EU ETS will occur when the vessel sails legs under the EU ETS jurisdiction. It is, however, conceivable that such speed reductions may occur, given that the ETS cost will have to be added to the cost of fuel in those legs. Papers that investigate speed reduction when a ship crosses into a more expensive fuel regime include Fagerholt et al. (2015) and Fagerholt and Psaraftis (2015), both in the context of more expensive, low-sulfur fuel, and for scenarios when ships move in and out of Emissions Control Areas (ECAs). In the context of the EU ETS, speed reduction in route legs under the EU ETS jurisdiction may be a second-order effect of the proposed legislation, and complement the transshipment hub relocation response, which would be the first-order effect. Such a speed reduction would indeed reduce CO_2 in the intra-EU legs, however in other legs, the reduction might be lower. In fact it is conceivable that to catch up and recoup delays caused by speed reduction, vessels would sail faster in the non-EU legs and thus would increase the overall CO_2.

Alternatively, the speed reduction in the EU legs may necessitate the inclusion of additional ships into the service to maintain trade throughput, and this might entail a reconfiguration of the lines' networks and schedules. Whether or not such a reconfiguration would be cost-effective would depend on the cost of adding more shipping capacity, among other factors. The study of all these second-order effects is outside the scope of this paper.

There is also a third-order effect of the proposed legislation, which might result from the second-order effects. Speed reduction in the areas under the EU ETS jurisdiction may result in shifts to road-based modes, to the extent that these are alternatives to intra-EU maritime traffic. This would run contrary to the EU policy of shifting cargo from land to sea. Papers that examine such modal shifts include Psaraftis and Kontovas (2010) in the context of speed reduction in intercontinental shipping, and Zis and Psaraftis (2019) in the context of EU sulfur legislation. The study of the third-order effect is also outside the scope of this paper.

7. Conclusions

In July 2021, the EC proposed to include shipping into the EU ETS as part of a package to reach its intermediate targets of reducing at least 55% of EU GHG emissions by 2030. The enforcement of regional MBMs such as the EU ETS to regulate sectors that operate at an international level entails a high risk for policy evasion. This paper focused on container routes and examined the scheme's effectiveness in achieving GHG emissions reductions. Our results showed that the inclusion of shipping in the EU ETS entails significant side effects such as carbon leakage, loss of ETS revenue and penalization of the EEA ports.

We focused on the container sector, the dominant source of maritime GHG emissions, and investigated the potentials for liner network reconfiguration under the prospects of evading the EU ETS. Since the choice of the transshipment hub is significantly affected by port location we selected EEA ports that are in close proximity with ports outside the EEA and are or may have the potential to become advanced transshipment hubs. As proximal transshipment hubs compete for the traffic related to a specific region or economic area, there are solid financial drivers that may lead liner operators to use alternative competing hubs outside the EEA to commence transshipment operations and avoid surrendering their EU carbon allowances. Such a decision could penalize the EU ports and lead to a corresponding revenue loss for the EU ETS.

This study focused on several international services that call two of the key EEA transshipment hubs in the Mediterranean Sea, namely the Piraeus port in Greece and the Algeciras port in Spain. Our model calculated, among other things, the EU carbon costs for each of the examined services and the costs attributed to the relocation scenario. These are the extra bunker fuel costs and the cost due to transshipment tariffs differential for each case.

In all cases, the switch of the hub implies an increase in the overall sailing distance of the vessel. Since the respective new voyage will be entirely or partially excluded from the EU scheme, there are not enough incentives for reducing the GHG emissions while sailing towards the competitor non-EEA port. To absorb the time lost due to the extra sailing distance the vessel can increase the service speed, which leads to an increase in total carbon emissions for the service and further amplifies the risk of carbon leakage.

The estimation of the EU carbon turning point that renders the relocation of the hub cost-effective allows us to quantify the risk of evasion of the scheme. Our first case study compared the hub of Piraeus with the nearby ports in Turkey (Izmir area) and concluded that the risk of evasion of the system is real at a price of less than 25 EUR/MT of carbon. Furthermore, the plans to expand the Izmir terminals further encourage the operators to shift their transshipments to the nearby non-EEA port.

The second case study of this paper focused on the comparison between the Algeciras port in Spain and the Tanger Med port in Morocco. The ports that have been major competitors on transshipment volumes have also been included in the impact assessment (IA) of the EC proposal published in October 2021. The IA alerted that a preference to Tanger Med will become viable in the medium term; however, our paper showed that the switch might become in the nearest future especially with the prominent expansion of the Tanger Med 2 terminal. Our model indicated that the relocation of the hub is possible at prices as low as 6 EUR/MT of CO_2.

All of the above seem to amplify the results of this paper and indicate that the inclusion of shipping into the EU ETS may very well be a project with very good intentions, however it may entail significant side-effects that should be considered very carefully before the relevant legislation is enacted. In addition, such an inclusion might undermine the IMO discussion on MBMs, as it may be difficult to connect a regional MBM such as the EU ETS with a global MBM such as a levy, which is one of the options under discussion at the IMO, and the preferred option of the shipping industry.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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