IMPLEMENTING THE EMISSION TRADING SCHEME FOR CONTAINER SHIPPING

A preliminary assessment of the economic, trade, logistics, transport, and CO2 impact

By

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Abstract

As part of the Fit for 55 package, the European Commission put forward a set of legislative proposals directly related to maritime transport emissions. In particular, European policy makers argue that the proposed application of an Emission Trading Scheme (ETS) for shipping in 2024 will ideally disincentivise shipowners to use traditional fuels. This is an issue especially in light of the Paris Agreement and the 2020 IMO guidelines for zero carbon emissions. Building upon the quantitative analysis of variations in freight costs – operational and/or capital expenses – for container shipping as a consequence of the implementation of the EU ETS, this study aims at drawing conclusions about the impact of the policy on five different aspects: ***economy*** *(i.e., consumer and producer surplus and net welfare effect),* ***trade*** *(i.e., new trade values),* ***logistics*** *(i.e., variation in container flow),* ***transport*** *(i.e., variations in the share of trade associated with different modes of transport),* ***emissions of CO2 equivalent*** *(i.e., variation in global emissions). This is particularly important as the issue regarding a carbon tax on shipping is currently being debated in the maritime industry and at the European Commission level, while not being exhaustively empirically investigated and analytically modelled. Results suggest that the ETS policy is at best ineffective in reducing carbon emissions and that it would cause a – despite mild and limited – negative economic and trade impact from both a European and global perspective. Findings also show that in none of the simulations modelled trade is transferred from container vessels to other modes of transport in any significant way. We argue that the European Commission should reassess the potential benefits and drawbacks of implementing such a policy, especially considering that results indicate that the EU would suffer a comparatively higher negative economic and trade impact on average compared to extra-EU countries.*

Table of Contents

List of Figures, Tables, and Diagrams

Chapter 1 – Introduction

1.1 Background

Shipping is the most efficient freight transportation mode both in terms of costs and emissions (Stopford, 2009). In fact, being responsible for approximately 80% of global trade by volume, maritime transportation accounts for just around 3% of total greenhouse gas (GHG) emissions (MMKMC, 2021). Nevertheless, as global trade is projected to increase by 1.3% on yearly average, if no measures are taken emissions generated by shipping could rise accordingly contributing to devastating socio-environmental effects (ibid.). On the backdrop of the Paris Agreement of 2015, the International Maritime Organisation (IMO) announced in 2018 an emission reduction plan for shipping (IMO, 2018). The proposed strategy has the ambitious goal of reducing Green House Gas (GHG) by a minimum of 50% by 2050 with 2008 as a baseline, and eventually phase out GHG emissions as rapidly as possible (ibid.). In order to achieve this objective, the two main strategies are retrofitting existing ships to limit GHG emissions and operating new vessels with enhanced onboard technical systems and/or propelled by alternative – more carbon-neutral – fuels. Of course, this would translate into higher fixed costs for shipowners and there are many challenges associated with this long-term plan. One of the most concerning issues regard the current price gap between traditional fuels and green ones (MMKMC, 2021). Therefore, market-based measures such as a carbon taxes might be considered as pragmatic incentives to adopt more CO2 neutral fuels in the face of potential taxation costs (Parry et al., 2018).

In this regard, as part of the *Fit for 55 package*, the European Commission (EC) put forward a set of legislative proposals directly related to maritime transport emissions (European Parliament, 2022). Among these, the EC proposed to extend the EU emissions trading scheme (ETS) directive to include shipping (European Parliament, 2021). The ETS will mean that shipowners must buy from the EU (or from other shipowners) emission allowances – 1 ton of CO2 equals 1 allowance – to be able to operate in European waters and berth in European ports starting from 2024 (ibid.). More specifically, the provision targets any vessel above 5 thousand gross tonnes, and it targets "100 percent of emissions from intra-European routes and 50 percent of emissions from extra-European routes from and to the EU as of 2024" (PwC, 2022). A report by the *Maersk Mc-Kinney Moller Center* suggests that this potential tax could costs shipowners about 50 €/tonne CO2 (MMKMC, 2021), while a more recent study conducted by

CE Delft for the Port of Rotterdam assumed a cost ranging from 30 €/tonne CO2 (low) to 167 €/tonne CO2 (high) (Faber et al., 2022). The eventual application of this proposed mechanism will ideally disincentivise shipowners to use traditional fuels (ibid.). On the 22nd of June 2022, the European Council voted in favour of the application of the ETS for shipping starting from the 1st of January 2024 (European Council, 2022).

1.2 Problem identification

Despite Maersk's ex-CEO Soren Skou also expressed his support regarding the introduction of a carbon tax in shipping, Standard and Poor's reported the reluctance with which such proposal was welcomed the maritime community (Mohindru and Li, 2021). In fact, many in the shipping industry fear that taxation will make freight costs too expensive, it will reduce the already low profitability of many liners and discourage new builds, hence leading to an undesired outcome (ibid.). A preliminary analysis of the impact avoidance on the competitiveness of EU ports conducted by Faber et al. (2022) suggests that the implementation of the EU ETS for shipping could negatively impact the throughput of container terminals. Furthermore, prior studies have argued that the increased expenses potentially associated with this market-based carbon tax might lead to trade diversion form Europe and/or to CO2 leakages arising from switching to alternative, more polluting, modes of transports such as: airplane, train and trucks (Parry et al., 2018; Marrewijk et al., 2012). For these reasons, many in the maritime community (e.g., shippers; freight forwarders) operating in Europe have stressed that the ETS should instead be implemented at a global level through IMO regulations, so that also the incurring costs can be both distributed more evenly and mitigated by means of a reduced allowance price (Mohindru and Li, 2021). The two different scenarios, which will be taken into analysis in this research project, are summarised will be explained into details in **Chapter 5**. For now, it suffices to say that in *Scenario 1* the EU introduces the ETS, thus the ETS price will apply 100% for intra-European voyages, 50% for international trips from/to Europe, while it will not apply for extra-European trade; in *Scenario 2* the ETS will be introduced at a global level, hence the price of ETS allowances will be equal irrespective of trading routes.

1.3 Research question and thesis objectives

In light of the IMO guidelines and EU proposed ETS for shipping, the objective of this research thesis is to shed light on the possible benefits and drawbacks of introducing an EU carbon tax on shipping on top of green transition costs by simulating how such a tax might lead to variations in intermodal transport mix, economic parameters (i.e., net welfare effect, consumer/producer surplus), international trade flows (USD), and GHG CO2 equivalent emissions. Therefore, the **main research question** of this thesis is: ***What is the economic, trade, logistics, transport and carbon-emission impact of the introduction of an EU carbon border tax on container shipping?***

To answer the main research question, it is necessary to address the following **sub-research questions**:

I. What is the EU Emission Trading Scheme (ETS) and how does it work?
II. What are the specific operating factors for the container maritime industry and how do they interact with emissions and the EU ETS?
III. What is meant with 'carbon leakage' and how important is it to take this issue into account when executing this policy?
IV. What are the costs that would follow from inclusion of the maritime container sector onto the EU ETS?
V. What is the best model to use for this RQ?

1.4 Research design and methodological approach

Building upon the quantitative analysis of variations in freight costs – operational and/or capital expenses – for container lines as a consequence of the implementation of the EU ETS, this study aims at drawing conclusions about the impact of the introduction of a *European carbon tax on shipping* on five different aspects: **economy** (i.e., consumer and producer surplus and net welfare effect), **trade** (i.e., new trade values), **logistics** (i.e., variation in container flows) **transport** (i.e., variations in the share of trade associated with different modes of transport), **emissions of CO2 equivalent** (i.e., variation in global emission and trade values/emissions ratio) for selected countries (see Chapter 5).

The research will be articulated according to the following steps:

(1) Identification of main (maritime) container trading EU Member States (MS) and major extra-EU containerised trading partners for the econometric model.
(2) Collection and estimation of the containerised trade values and volume between selected countries and associated CO2 equivalent emissions per mode of transport.

(3) Qualitative review of potential container liner strategies (e.g., alternative fuels) to mitigate the cost effect of the EU ETS; Estimation of the impact of identified promising strategies on the cost-structure of the ship.

(4) Calculation and estimation of variation in NTMs– by means of the Anderson and Wincoop (2004) approach – due to the introduction of the EU ETS in relation to different strategies pursued by container liners.

(5) Estimation of the composite demand and supply elasticities and of the degree of substitution elasticity between different selected modes of transport for the econometric model.

(6) Application of the econometric model to assess the economic, trade, transport and CO2 equivalent impact of the EU ETS for the selected countries.

(7) Analysis and conclusions based on obtained results and policy suggestions.

1.5 Structure of the thesis

The thesis will be structured as follows. The **first chapter** contains the introduction, which opens with the background and problem identification of the study. The research question and objectives are then presented together with the research design, methodological approach, and relevance of the topic for the maritime container industry and EU policy decision. **Second chapter** includes an overview of the market structure of container shipping and a brief summary of previous literature, their outcomes and methodologies adopted. The **third chapter** presents the trends of main maritime shipping segments and an economic and maritime economic description of the countries (or regions) selected for this study. In **chapter four**, we analyse potential strategies that the global container fleet could adopt to mitigate the negative cost effect of the EU ETS. **Chapter five** describes the econometric model with its scope and governing mathematical foundations, as well as its essential elements such as demand, supply, and substitution elasticities, trade values and NTMs shocks. Moreover, after the description of scenarios and strategies simulated in this research, the methods to quantify the NTMs shocks deriving from the implementation of the EU ETS according to different strategies and scenario are presented, and the estimation of TEU trade volumes and CO2 equivalent emissions is explained. Next, **chapter six** is devoted to the presentation of the results obtained from econometric modelling and their translation in terms of trading volumes and CO2 emissions variation for the routes and transportation modes considered. Sensitivity analysis is also addressed. **Chapter seven** concludes with the analysis and discussion of the results obtained –

also in relation to extant literature – and with the assessment of the potential benefits and drawback of the implementation of the EU ETS. The implications of the research results are then discussed highlighting the relevance of the present study for policy design. Finally, we reflect on, and make explicit, the limitations of this thesis and suggest direction for future research on the topic.

1.6 Relevance and scope of the research

The research topic arises from the urge to find a coherent direction to support the sustainable transition in the shipping industry. This is an issue especially in light of the Paris Agreement and the 2020 IMO guidelines for zero carbon. While the cost impact of more environmentally friendly technology on shipping has already been investigated to some extent, the present study adds new significant elements to the research framework on sustainable shipping by modelling the increased freight costs of the EU ETS in order to predict international trade variation per mode of transport. This is particularly important as the issue regarding a carbon tax on shipping is currently being debated in the maritime industry and at the European Commission level while not being exhaustively empirically investigated and analytically modelled. A vital element that also needs to be investigated and which will be addressed by the proposed thesis is the potential CO2 leakage resulting from the implementation of a carbon tax on shipping – i.e., shippers might opt for cheaper, however more polluting, modes of transport. In this sense, the thesis is of academic interest as it represents a first comprehensive attempt to model all these shocks – i.e., sustainable asset investments, carbon tax, CO2 leakage – simultaneously. Being an international industry, and because we want to look at the issue of carbon leakage, an EU carbon border tax will affect all economies and shipowners. The issue will however be of greater relevance for European countries as the European Commission. In fact, the result of the thesis can help the European Commission reflect on the effects of the introduction of an ETS in shipping and assess the feasibility of this measure (e.g., what are the benefits and what are the cons in terms of economic, trade, transport, and emission impacts).

Chapter 2 – Literature Review

In this chapter, we briefly explain what the ETS is and how it works. The following section gives an overview of the market structure of container shipping together with a brief summary of previous literature on the research topic. The chapter concludes summarising the state of the intermodal transport mix in Europe and the comparative emissions level of main modes of transport (i.e., deep sea vessels, trains, trucks, barges, and airplanes).

2.1 The EU Emission Trading Scheme for shipping

The EU ETS is a cap-and-trade system that attempts to decrease greenhouse gas (GHG) emissions by limiting or capping GHG emissions in specific sectors of the economy (European Parliament, 2022; DNV, 2022). Every year, a limited number of EU Allowances (EUAs) are made available for market trading, and this number is lowered yearly in order for the EU to meet its aim of a 55% reduction in GHG emissions by 2030 compared to 1990, and net zero by 2050 (ibid.). The policy applies to cargo and passenger ships above 5000gt beginning in 2024, and offshore ships over 5000gt beginning in 2027 (ibid.). The EU ETS applies to 100% of emissions on journeys and port calls inside the EU/EEA and 50% of emissions on trips into or out of the EU/EEA (ibid.). Shipping companies with vessels operating to or from EU or EEA ports will be obliged to retain adequate EUAs for GHG emissions linked to their vessels and submit these allowances to the relevant authorities on a yearly basis (ibid.). Under the EU MRV rule, each year these firms are expected to monitor, report, and verify their GHG emissions in order to be able to calculate the allowances they should submit (ibid.).

2.2 Container shipping: a brief overview of the market structure

After Maritime Conferences dissolved in 2008 following concerns about price collusion (European Commission, 2008), major container liners re-organised into global alliances (Merk et al., 2018). Global carrier alliances are clusters of container liners which cooperate strictly on operational matters along main trading routes in order to optimise the distribution of traded volume and avoid under capacity sailing, hence driving down costs (Haralambides, 2019). Following an intense process of M&A in the last decade, at present three alliances (i.e., The Alliance, 2M, Ocean Alliance) comprising 8 major container carriers have expanded dramatically reaching over 80% of global market share of the shipping segment (Merk et al., 2018). Ha and Seo (2017) have long argued that the increase in fixed costs as a consequence of economies of scale and the underutilisation of large containership has hampered the survival of many liners. Similarly, the low utilisation performance of most ships has been treated as evidence that container shipping is unfit for competition (Hu, 2018). According to King (2017), the progressive consolidation and alliance formation on the part of container liners have been necessary steps for increasing operational and supply management efficiency, as well as for lowering and stabilising freight rates. It is important to remark that in the past two decades, virtually all container liners – including major ones – have experienced extremely thin margins. Prior the global financial crisis (2007), only about 10% of the major container carriers were generating profit (Bennacchio, 2007). Again, research conducted by Ha and Seo (2017) has highlighted that in the last decade profitability of container liners has been predominantly negative or stagnant and that operational alliances have been a survival necessity.

In this perspective, it follows that increasing operational and voyage costs stemming from the introduction of the IMO 2020 sulphur regulations and the EU ETS can most likely be absorbed only by major alliances and that more independent carriers will find it impossible to keep operating or joining the business (Faber at al., 2022). One of the most serious concerns is the existing price disparity between standard and green fuels (MMKMC, 2021). As a result, market-based policies like as carbon taxes may be viewed as realistic incentives to use more CO2-neutral fuels in the face of prospective taxation costs only for large companies and alliances (Parry et al., 2018). Many in the shipping sector are concerned that taxes would raise freight prices, lower the already poor profitability of many liners, and discourage new builds, resulting in an unfavourable outcome. (Mohindru and Li, 2021). This raises concerns regarding the market competition and further concentration of market power of global alliances. Moreover, it is expected that most fuel and CO2 surcharges due to IMO and EU ETS regulations will be passed to shippers, hence driving down consumer surplus (ibid.). Faber et al.'s (2022) early examination of the impact of avoidance on the competitiveness of EU ports also implies that the adoption of the EU ETS for shipping might have a detrimental impact on container terminal throughput. This will be taken into consideration when modelling the increase in freight rates following the measures taken to comply with the introduction of the EU ETS.

Another crucial issue linked to the ETS regards the possibility avoiding the tax altogether and ultimately generating a trade diversion effect. A recent study conducted by CE Delft identified a series of potentially evasive behaviours which are summarised below (Faber et al., 2022:3).

i. *"Adding an extra port call just outside of the EU;*
ii. *Changing the order of the ports in the existing schedule such that a port close to the EU*
    a. *is the first port of call in the EU region;*
iii. *Removing EU ports from the schedule and feedering to these ports from a non-EU port;*
iv. *Removing some EU ports from the schedule and feedering from an EU port."*

In particular, simulating different scenarios and conducting a quantitative analysis with an estimated average EU ETS price of €68 per ton of CO2 emission equivalent on intra-European routes, Faber et al. (2022) found that a trade diversion effect as well as the strategy of unloading cargo in a port just outside the EU border are both plausible effects as they appear to be profitable at times. If this were to happen, it would negatively impact the EU and put Europe and European ports in a position of serious disadvantage with regards to trade in goods (ibid.). The study concludes that although there are many options to mitigate the risk of evasive manoeuvres, the most effective strategy to ensure the effectiveness and success of the ETS in the shipping industry is to extend the EU ETS or implement similar market-based measures at an IMO level (i.e., internationally) adopting a reduced price (i.e., 75%, or approximately €50/CO2ton). This scenario (i.e., global ETS) will be taken into consideration and compared with the EU ETS when modelling the shock in this research paper.

2.3 Intermodal transport mix in EU and comparative GHG emissions

In recent years, especially in Europe, there have been societal pressures with regards to the modal mix deployed for freight circulation. As the main interface between different modes of transportation, Port Managing Bodies have been called for improving the environmental performance also with regards to the modal shift (Lam and Notterbom, 2014). In this sense, in the absence of the possibility to use deep sea vessels to transport goods to the country of destination, the European Union is pressing logistics operators to make more efficient and intense use of rail and barge for international freight transportation (De Langen et al., 2012). In fact, it appears that inland container traffic within the EU still relies for more than 77% on truck and only about 17% and 6% on rail and barge respectively (Eurostat, 2022a). While part of the reason has to do with the greater flexibility that trucks offer compared to other modes of transportation, the reduced scale of road transport not only tends to create traffic congestion but makes it represents the most polluting freight transportation mode with the only exception of air transport (De Langen et al., 2012). On average a container truck emits as much as 3.9, 2.8, and 1.8 times GHG grams per ton-km compared to a medium sized deep-sea vessel, a cargo train, and an inland barge respectively, but only about 1/10 compared to a cargo plane (Shell, 2022; Unifeeder, 2022; CEFIC, 2021). Prior research has argued that the additional costs associated with ETS deployment might lead to CO2 leakages resulting from the switch to alternative, more polluting means of transportation such as airplanes, trains, and trucks; hence, ultimately to an unintended policy consequence (Parry et al., 2018; Marrewijk et al., 2012). In conclusion, it is clear that despite the progressive and environmentally responsible nature of the EU ETS, the higher fixed costs associated with this policy measure imply a series of significant challenges that needs to be seriously considered and investigated.

2.4 Chapter summary

In this chapter, after explaining what the ETS is and how it works, we provided an overview of the market structure and financial performance of container shipping in recent years with a particular focus on the issues that arise from the ETS implementation, such as increase in market concentration, trade diversion from Europe, and competitive disadvantage of European ports. In the last section, we touched upon the state of the intermodal transport mix in Europe and the comparative emissions level of main modes of transport (i.e., deep sea vessels, trains, trucks, barges, and airplanes).

Chapter 3 – Overview of the main shipping segments

In this section, the three main segments of the international shipping industry are introduced with a particular focus on the container segments which constitutes the focus of the present research. International shipping is a fundamental component of modern economies (Stopford, 2009). Accounting for approximately 80% percent of the volume of cargo traded at a global, the industry has *de facto* always been the main enabler of international trade and bears strong correlation with countries' welfare and GDP (UNCTAD, 2021). This is especially true in today's globalised world whose economy is characterised by an unprecedented degree of supply chain fragmentation (Chopra and Meindl, 2016). Despite not being fixed categories due to the – although limited – vessels' capacity to shift across market segments, it is generally accepted that international shipping can be summarised into three main areas: wet bulk, dry bulk and container shipping (Stopford, 2009). While this thesis will focus on the trade of containerised goods as these can easily be accommodated by other modes of transportation (i.e., air, rail, road, inland waterways transports), it is important to give an overview also wet and dry bulk trade to understand the wider dynamics and scale of international shipping both from an economic and CO2 emission perspective.

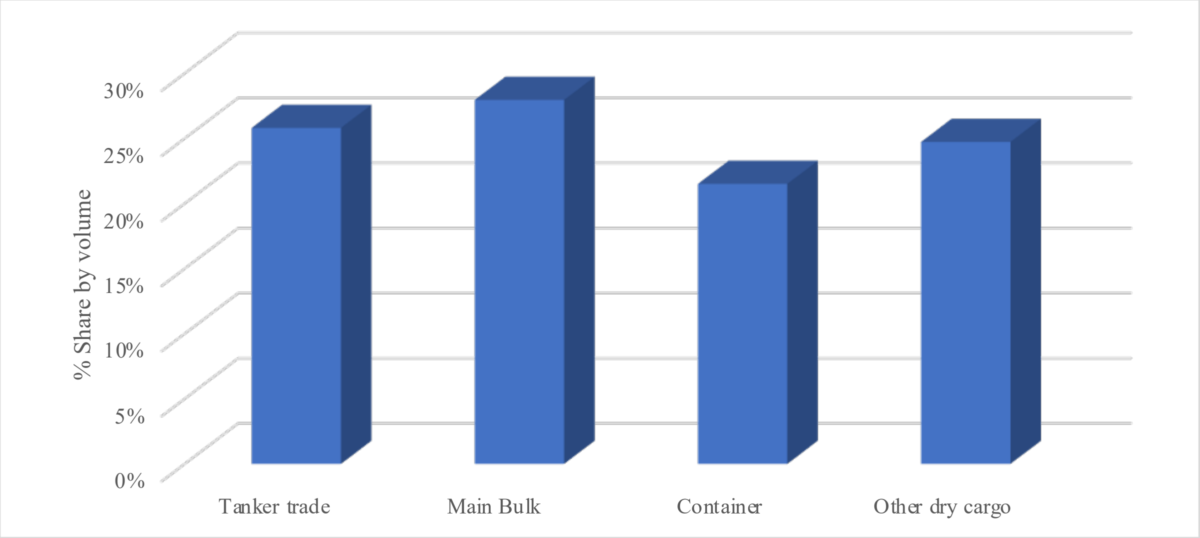

Figure 1. *% Volume share of main international shipping segments (2020). Author's own illustration. Source: UNCTAD (2021).*

3.1 Wet bulk (or tanker trade)

The wet bulk segment mainly consists of crude oil, finished petroleum products, and liquid gas which are virtually entirely transported by deep sea vessels (i.e., tankers) or pipelines (UNCTAD, 2021). The segment as a whole constitutes about 25% of all traded volume by sea (see **Figure 2**) and crude oil more specifically is the most traded single commodity with over 1.8 billion tons shipped in 2020. Most trade is performed from the Arabian Gulf towards the rest of the world with the exception of the USA which has become almost entirely an independent extractor (ibid.). In this sense, the trade of crude oil is characterised by a highly asymmetrical flow in which developing economies account for over 42% of exports (ibid.)

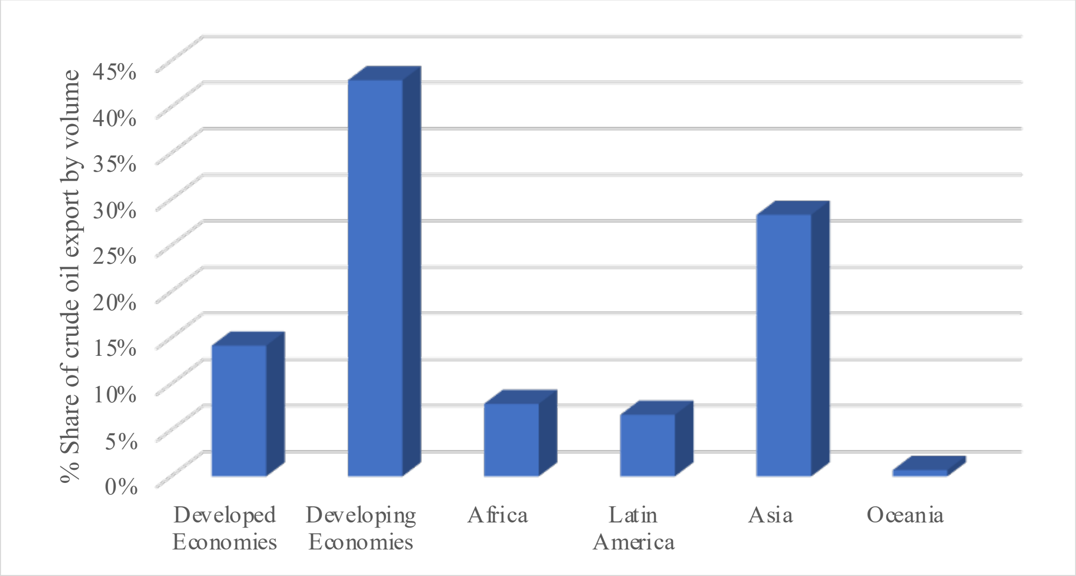

Figure 2. *% Volume share of crude oil export by region (2020). Author's own illustration. Source: UNCTAD (2021).*

The oil trade shipping segment has been the hardest hit by the pandemic. During the period 2019/2021 UNCTAD (2021) estimated that tanker trade – comprising crude oil, finished petroleum-derivates and gas – suffered an 8% decrease bringing volumes to 2.9 billion tonnes compared to 3.2 billion tonnes associated with pre-pandemic levels. This has been due to weak demand combined with increasing inventory costs and supply shortage on the part of OPEC+ members which agreed to cut 5.8 million barrel a day in production to face the spike in oil prices in August 2021 (ibid.).

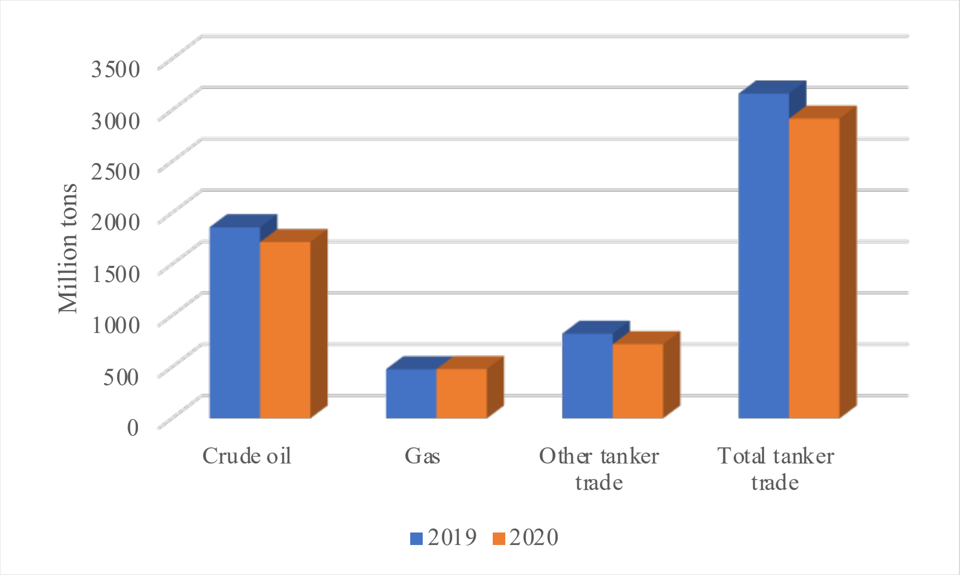

Figure 3. *Volume of global tanker trade 2019-2020 in million tons. Author's own illustration. Source: UNCTAD (2021).*

As shown in **Figure 3**, while both crude oil trade and other tanker trade suffered a comparable decrease, gas trade continued to grow (+0.4%) despite at a slower rate than expected (UNCTAD, 2021). Although much of the shock certainly bears a strong relationship with the pandemic and the surge in tanker commodity prices, in the long-term projections indicate that the trend is going to continue with oil trade progressively diminishing in favour of gas and other less-polluting energy mixes (DSF, 2021; De Langen et al., 2021). According to the Fourth IMO GHG Study (2021), tanker trade shipping is responsible for around 25% of all maritime emission due to a combination of the volume involved in trade and the advanced age of the tanker fleet compared to other segments (IMO, 2021).

3.2 Dry Bulk

Dry bulk trade is dominated by three main commodities (*main bulk*): iron ore, coal, and grain but also comprises the so-called *minor bulk* which are steel and forest products. Dry bulk is generally transported by means of bulk carrier vessels. The dry segment has also been hit by the pandemic however to a much lesser degree compared to tanker trade. UNCTAD (2021) estimates that the volume of dry bulk trade dropped down by 1.5% to 5.167 billion tonnes during 2020.

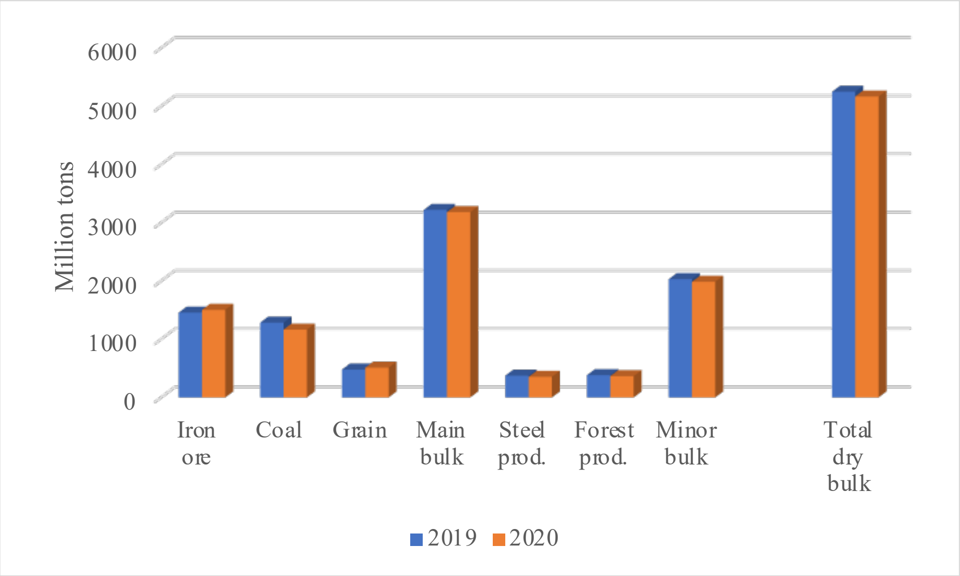

Figure 4. *Volume of global dry bulk trade 2019-2020 in million tons. Author's own illustration. Source: UNCTAD (2021).*

Partly, this is due to the different regional flow that characterised dry bulk trade in which China features as the main importer by far. In this sense, the negative effects have been mitigated to a great extent by China, whose rapid economic rebound boosted imports to balance more suppressed demand in other regions (ibid.). It suffices to say that China imports almost 80% of all iron ore traded, – mostly from Australia (58%) and Brazil (23%) – 20% of coal – mainly from Indonesia (35%) and Australia (31%) – and is the largest producer and user of steel in the world with a stake of approximately 60% (ibid.). More generally, the past year has seen iron ore trade patterns mostly unaltered registering +3.2% as well as increase in grain trade of 7.1% (ibid.). Partly, grain trade held firm because of the combination of remarkably abundant Brazilian harvest and the progressive bounce back of USA-China trade relations (ibid.). However, with the exception of iron ore and grain, the trade associated with all the other dry bulk commodities decreased, with coal being the hardest hit (-9.3%) due to lower electricity demand, other pandemic-related factors, and the effects of a more structural trend towards cleaner energies (ibid.). DSF (2020) predicts that as the energy transition will entail smarter and greener alternatives, and as China will decrease its steel consumption, the volume of seaborne dry bulk trade will decrease and slowly change in nature towards non-ferrous metals that are required to produce renewables and complementary technologies (i.e., lithium, bauxite, copper etc.). Despite being the largest shipping segment in terms of volume, the dry bulk segment represents the smallest segment in terms of total maritime emission (GHG) with an estimated share of 18% (IMO, 2021).

3.3 Container segment

Container shipping involves the trade of a vast array of goods among which food, perishables (frozen and unfrozen), electronics, machinery, equipment, and manufactured goods more generally (Stopford, 2009). Exploiting economies of scale along major trading routes, it is safe to say that the almost entirety of perishable, manufactured and consumer goods are intercontinentally transported by containerships to be then dispatched through lower capacity modes of transport such as train, trucks, barges and airplanes (ibid.). Because of the standardised unit of storage and in which they are transported (i.e., container), containerised goods are the most suited to switch across modes of transport (ibid.). In fact, containers can easily be discharged/loaded from/on a vessel, barge, truck, or train – or any combination and sequence of these four modes – with only few simple steps. Another characteristic of containerised goods is that that they are often higher value products that are more sensitive to price devaluation compared to bulk, thus typically require faster time-to-market delivery. For this reason, the trade of containerised goods is better predisposed to exploit and bear the costs of intermodal transport including airplanes – although air transport does not typically involve containerised storage. It is precisely because of the greater intermodal capacity of containerised goods that the container segment has been chosen as the focus of this thesis.

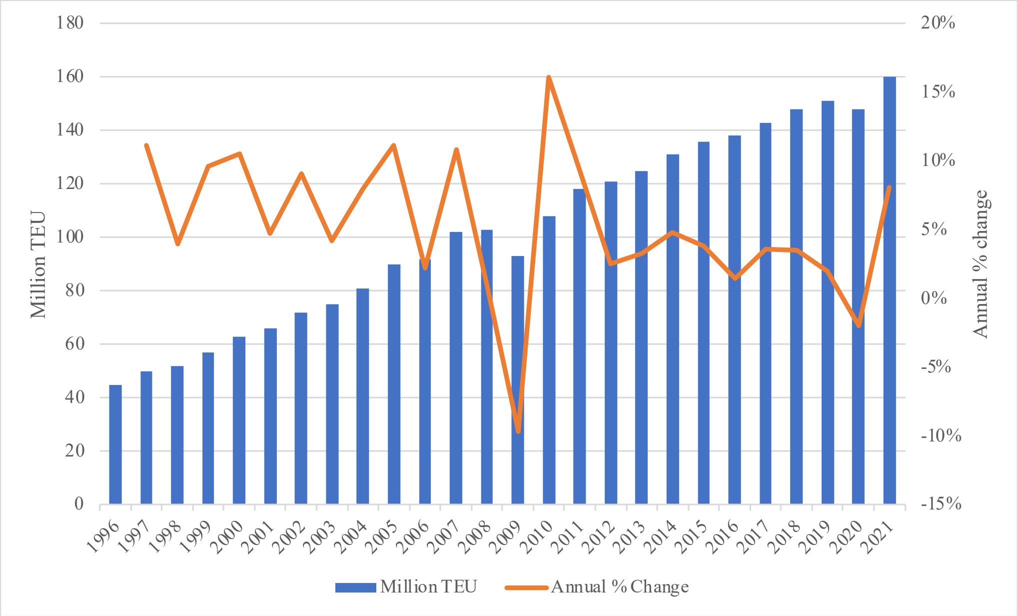

Figure 5. *Global containerised trade (1996-2021) in million tons. Author's own illustration. Source: UNCTAD (2021).*

Global containerised trade has been by far the fastest growing international shipping segment and has quadrupled in the past 25 years. It has also proven to be exceptionally resilient to economic shocks and generally demonstrated a quick capacity to recover (see **Figure 5**). This has been particularly the case during the acute phases of the pandemic. In fact, in 2020 containerised trade has suffered comparatively less than the other major international shipping segments falling only 1.1% on a year-to-year basis and quickly increased its volume by approximately 9% in 2021 notwithstanding significant global supply chain and logistics congestions. The main reasons for this fast recovery in 2021 were the easing of economic impacts, the quick bounce-back of the Chinese economy which plays a major role in containerised trade due to the volume of its manufacturing output, the surge in consumers' spending on manufactured goods during lockdown phases, and the retailers' need to quickly re-build inventories as social-measures eased (UNCTAD, 2021).

More generally, containerised trade is expected to keep increasing at a stronger rate than any other international shipping segment in the future. In fact, according to both UNCTAD and Clarkson Research (see **Figure 6**), the volume of containerised trade is projected to an average of more than 5% annum in the next 5 years compared to a 2.7% annual growth when considering seaborne trade as a whole (UNCTAD, 2021; Clarksons Research, 2021). This generated concerns given that container shipping is estimated to represents about 26.5% of total maritime emission, thus being the largest polluting segment in terms of GHG released (Kramel et al., 2021). Moreover, trade simulations that take into account a longer-term horizon seem even to indicate that in most scenarios containerised trade will be the only shipping segment subjected to continuous growth after 2030, while also continuing to be the fastest growing in the short term (De Langen et al., 2012; UNCTAD, 2021; see **Figure 6**). As touched upon in the literature review section, this bears important implications for ports' infrastructural development, intermodal facilities, and logistics at large, as well as for environmental policy making and world trade (ibid.).

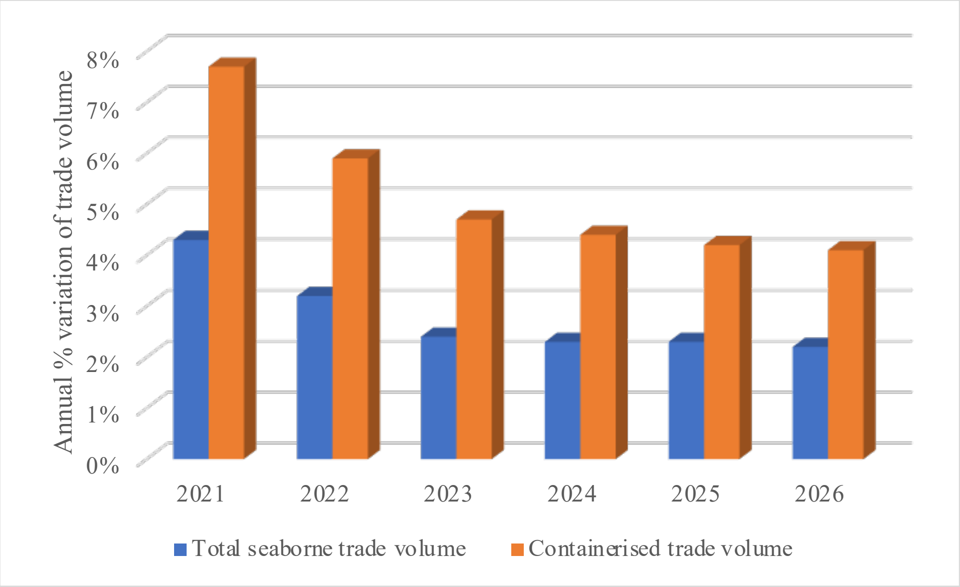

Figure 6. *International maritime trade development forecast (2021-2026). Author's own illustration. Source: UNCTAD (2021).*

3.3.1 Containerised goods flow and regional output

The main trade routes of container shipping are the Trans-Pacific, Transatlantic, and Asia-Europe lane. As anticipated, the flow of containerised goods is highly asymmetrical due to the massive output of the Chinese manufacturing industry and its export capacity. In fact, in terms of TEU flow East Asia exported almost 350% more than it imported from North America and about 237% more compared to the container volume it imported from Europe in 2021. This marked trade imbalance certainly indicates not only the global fragmentation of supply and value chains, but also the clear dependency of Western developed economies on Chinese industries. As shown in **Figure 7**, North America features as a weak export-oriented economy also when it considering its containerised trade relation with Europe which, in 2021, exported almost double the volume of what it imported from North America.

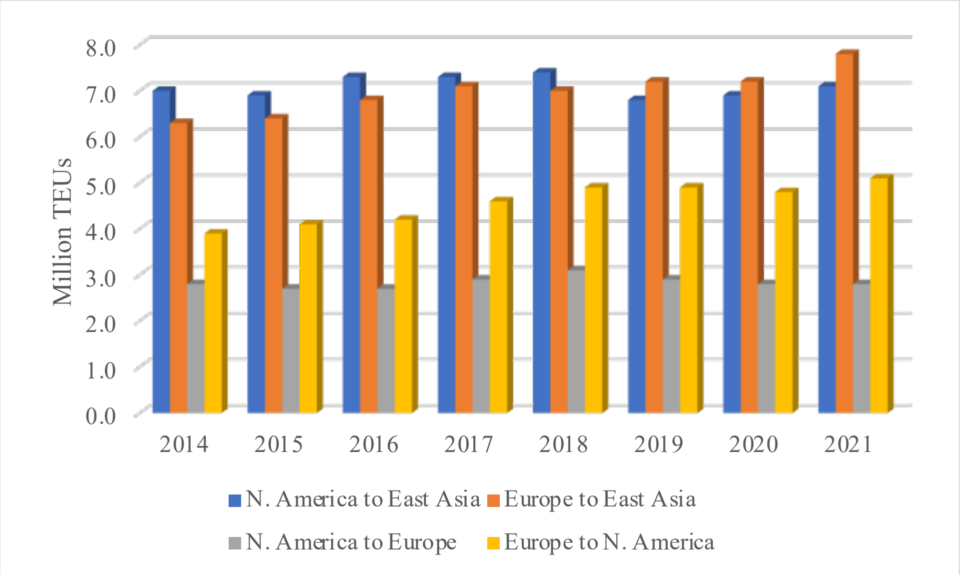

Figure 7. *Containerised exports on major West-to-East routes. Author's own illustration. Source: UNCTAD (2021).*

Notwithstanding that the Trans-Pacific lane is characterised by the highest flow by TEU volume, with the only exception of Chinese ports, the ensemble of European ports register by far the greatest combined TEU throughput which is approximately twofold compared to that of North America (see **Figure 7**). Considering that international shipping contributes to approximately $90 billions to Europe's GDP and that container trade accounts for more than 50% of value generated from freight shipping, the strategic importance of container shipping for the EU can hardly be exaggerated and any trade diversion effect resulting from the implementation of the EU ETS might have significant consequences for Europe's economic well-being (ECSA, 2020; Faber at al., 2022).

3.4 Economic and maritime economic description of selected countries

In this research thesis, as explained in detail in Chapter 5, we will deploy a global partial equilibrium economic model which drives results starting from data the trade values exchanged (import/export) between nations and their associated elasticities (i.e., import, export, and substitution). Because we can reasonably expect that the implementation of the EU ETS will affect European imports and exports the most, we decided to analyse the effect on two major maritime EU regional blocks individually – i.e., (1) Top Mediterranean EU Maritime Economies; (2) Top Continental EU Maritime Economies. The rest of EU countries have been grouped into a wider regional block (i.e., Rest of EU). Main extra-EU trading partners for EU have been selected either individually (i.e., disaggregated data) or in regional groups (i.e., Top Asian Maritime Economies). Finally, we aggregated all remaining world countries and labelled them ROW (i.e., Rest of the World). In this section, we provide a brief economic and maritime economic description of the countries (or regions) selected for the study.

Top Continental EU Maritime Economies (aggregated data):

Belgium

Belgium is 7th largest economic power of the European Union. Its economy is strongly characterised by trade as its massive port infrastructure indicates. The Port of Antwerp-Bruges (formerly Port of Antwerpen) alone registered a yearly container throughput of over 12 million TEUs, positioning the port as the second largest in Europe with only a 20% volume difference in container volume compared to the Port of Rotterdam (Port of Antwerp-Bruges, 2022). In fact, Belgium ranks as the 4th EU country in terms of yearly container volume and has by far the greatest container volume/population and container/volume GDP ratio of the EU (Trading Economics, 2022). Because of its obvious international importance as a hub for container trade, we treat Belgium individually (i.e., disaggregated data). Major categories of containerised goods imported in, and exported by, Belgium are road vehicles and pharmaceutical products (UN Comtrade, 2022). Most trade is performed with developed EU countries (ibid.).

Germany

With a GDP of over $4.2 billion, Germany is by far the largest economy in Europe. With approximately 19 million TEUs handled in 2020, Germany is the EU country with the highest container throughput (World Bank, 2022). The country has an extended inland waterway system and several ports, among which the Port of Hamburg – with a yearly throughput of almost 10 million TEUs in 2019 – and the complex of the Ports of Bremen which handled about 5 million TEUs in the same year (Mohit, 2021). Due to its competitive industrial sector, main exports as well as imports are represented by road vehicles, electronic machines and appliances, industrial machines, and pharmaceutical products (UN Comtrade, 2022). Most trade is performed with EU member states (i.e., The Netherlands, Poland, France, Italy), however the largest individual trading partners are China and the USA (ibid.).

The Netherlands (NL)

Thanks to the Port of Rotterdam and its unique infrastructure and competitive advantage, the Netherlands represents a key hub of maritime trade for the EU. In fact, with the only exception of a handful of Chinese ports (e.g., Shanghai, Shenzhen, Ningbo-Zhoushan etc.) the Port of Rotterdam is the largest, and arguably the smartest, port in the world (UNCTAD, 2021). In 2020, the Port of Rotterdam alone handled more than 15 million TEUs (PoR, 2021). Exports are mostly directed to Germany, Belgium, and France while imports see also China and the USA as key players (UN Comtrade, 2022). In terms of containerised goods, the Dutch trade mainly involves office machines, electric machinery and telecommunication equipment (ibid.).

Top Mediterranean EU Maritime Economies:

France

France is the second largest economy of the European Union. Its main ports are situated in Marseille and Le Havre. However, these two ports combined accommodate only half of the volume handled by the Port of Antwerp-Bruges (Eurostat, 2022b). This suggests that to a great extent trade in goods is performed on land. In fact, it is not surprising that among France's main trading partners we find Germany, Italy, Spain, and Belgium (UN Comtrade, 2022). China and the USA also represents key trading partners both with regards to imports and exports (ibid.). Main containerised goods exported are road vehicles, electrical machines, transport equipment, and pharmaceutical products; electric machines and road vehicles also dominates France's imports.

Greece

Despite the modest size of its economy, Greece is an important hub for the EU with respect to maritime trade. In fact, with approximately 5.75 million TEUs handled in 2020, Greece has a container throughput comparable to France (World Bank, 2022). This is both because of its strategic position within the Mediterranean basis as well for recent developments in the Port of Piraeus which now ranks as the fourth biggest European port with regards to container traffic (CEIC, 2022). Greece main containerised exports are directed to Italy, Germany, and Turkey and consist mainly of medicaments, aluminium, and vegetables and fruit (UN Comtrade, 2022). With regards to imports, container volume is relatively low and Iraq and Russia feature among main trading partners (ibid.).

Italy

Italy is the third largest economy in Europe. Its main ports are Trieste and Genoa. Due to its intense manufacturing output and strategic geographical location, container traffic in Italy reached 10 million TEUs in 2020 (World Bank, 2022). Main trading partners are the USA, China, Germany, Japan and the UK (UN Comtrade, 2022). In terms of containerised goods, Italy mainly exports and imports electronic appliances such as transistors and valves, as well as road vehicles (ibid.)

Spain

With the only exception of Germany, Spain has the highest container throughput in Europe – approximately 17 million TEUs handled in 2020 (World Bank, 2022). Main Spanish ports are Algeciras, Valencia, and Barcelona (Eurostat, 2022b). Major trading partners are France, Germany, Italy, and Portugal with regards to exports, while unsurprisingly China represents a major source of imports (UN Comtrade, 2022). The largest volume of containerised goods traded is represented by road vehicles and parts (ibid.).

Rest of EU

All other European member states have been grouped together either because of the limited size of their economy or for the marginal role that maritime trade plays in their economy. The countries included are: Austria, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, and Sweden (European Union, 2022).

UK

Positioned in-between Germany and France in terms of GDP size, the UK is one of the largest economies in the world and registered a container throughput of around 10 million TEUs in 2020 (World Bank, 2022). Some of the most important ports in the UK are the Port of London, Port of Southampton, and the Port of Liverpool (Saurabh, 2021a). Its largest trading partners are the USA, Germany, China, France, and the Netherlands (UN Comtrade, 2022). The UK mainly trades road vehicles, electrical machinery, telecommunication and industrial equipment and machinery, as well as medicaments, while clothing represents predominantly an import product (ibid.).

USA

The USA is the world's largest economy in terms of GDP. Major ports are the Port of Los Angeles, Port of Long Beach, Port of New York and New Jersey, and Port of Corpus Christi (Saurabh, 2021b). All container ports combined handled approximately 55 million TEUs in 2020 (World Bank, 2022). Main USA containerised imports are represented by road vehicles, pharmaceutical products, telecommunication equipment, industrial machinery, office machines, and clothing; while the USA exports mostly road vehicles, electronic machinery and appliances, industrial machinery, and scientific equipment (UN Comtrade, 2022). Key trading partners are China, Canada, Mexico, Japan, and Germany (ibid.).

Top Asian Maritime Economies:

China

China has been for about two decades the world's fastest developing economy and it is second only to the USA in terms of GDP. It represents by far the largest manufacturing country in the world. Ten of the major ports in the world by volume – e.g., Shanghai, Shenzhen – are located in China. It is not surprising that Chinese ports handles the highest number of containers in the world – about 245 million TEUs in 2020 (World Bank, 2022). Major trading partners of containerised goods are the USA, Republic of Korea, Japan and Germany (UN Comtrade, 2022). Main containerised imports feature electronic machinery appliances, other machinery parts, office machines and motor vehicles; exports are dominated by electrical machinery, telecommunication equipment, office machines, clothing and accessories, and miscellaneous manufactured goods (ibid.).

India

India is among the fastest rising economies. In 2020, Indian ports handled about 16 million TEUs (World Bank, 2020). Despite its economy still heavily relies on agriculture, it also has a strong export-oriented manufacturing sector. Main containerised exports are miscellaneous manufactured goods, medicaments, textile yarn and fabric, clothing and accessories and road vehicles (UN Comtrade, 2022). Major trading partners are the USA, China and the United Arab Emirates (ibid.). Containerised imports feature electronic machinery and apparatuses and office machines (UN Comtrade, 2022).

Japan

Japan is the third largest economy in the world with a GDP of around $5 trillion (World Bank, 2022). Being an island, Japan's maritime traffic is particularly intense and registered a container throughput of over 21 million TEUs in 2020 (ibid.). Japan is globally renowned for its manufacturing sector which is remarkably specialised in the production of electronic machinery and appliances, automobiles, ships, industrial machinery and precision equipment (Asialink, 2022). Its main exports destination are the USA, China, Republic of Korea and

Germany (UN Comtrade, 2022). Japan's main containerised imports are represented by pharmaceutical products, office machines, clothing and accessories, and electronic machinery and parts (ibid.). Most of these products are imported from China, the USA, Australia and the Republic of Korea (ibid.).

South Korea

With a GDP of over $1.81 trillion in 2020, South Korea is the third largest economy in Asia – after China, India, and Japan – and ranks as the tenth in the world (World Bank, 2022). Having handled over 28 million TEU in the same year, South Korea is also remarkable trading country in terms of containerised goods (World Bank, 202w). Main containerised import categories are typically similar to containerised export categories: machinery and vehicles, manufactured goods, and food and drinks (UN Comtrade, 2022). Main import trading partners are USA, Japan, and Australia, while most of exports are directed in China, USA, and Vietnam (ibid.).

ROW (Rest of the World)

ROW includes all other world's countries whose trade values have been collected in an aggregate manner through WITS and/or Eurostat database. This was necessary as the econometric model adopted is a global simulation model which is programmed to work with the totality of world trade, be this for a specific or general category of products.

3.5 Chapter summary

In this chapter we introduced the main shipping segments (i.e., wet bulk, dry bulk, and container segment), their underlying commodities, and their share of CO2 emissions equivalents to give an overview of international trade from a maritime and environmental perspective. We also briefly described main trade routes as well as recent and future trade trends for all shipping segments. Particular attention has been devoted to the market structure of the container segments as this will be the object of research. We then proceeded with motivating and describing the country selection which was deemed as most appropriate to represent international trade of containerised goods in the light of the research objectives and the econometric model adopted (see Chapter 5 for more details).

Chapter 4 – Compliant Strategies

4.1 Fuel mix and ETS

Fuel represents a significant portion of the costs involved in the shipping sector. In fact, estimations indicate that fuel alone account for about 70% of operating costs (Stopford, 2009; Jordan and Hickin, 2017). Therefore, the impact on freight rates resulting from any increase in the cost of fuel might endanger the profitability of shipowners. While this is less the case for mid- to long-term time charters characterising the wet and dry bulk business, most container liners have implemented a specific invoice (i.e., fuel surcharge) to mitigate potential losses by passing part of the costs to final customers (Mannadiar, 2018). Moreover, unlike the wet and dry bulk segment, container shipping typically has a complex but detailed charging system (e.g., size of shipment; frequency of shipment; priority/urgency etc.) which better equip it to optimise cost-allocation, thus diluting the costs arising from the ETS implementation across its market structure (Stopford, 2009; Chrysouli, 2018).

With increasing supranational and societal pressure for environmentally responsible conduct, many potential strategies to mitigate the negative cost impact of the ETS policy have been developed in recent years, such as alternative fuels' deployment. However, due to the relative novelty of these technologies, it is reasonable to argue that at present there is no single direction that the market for alternative fuels will take in the short- to mid-term. For this reason, in this research paper we selected some among the most promising alternatives and combined them together to forecast the impact of the ETS in different (likely) scenarios. In particular, we modelled the impact of the ETS on three different strategies which can be considered to represent different development stages in the deployment of alternative fuels in container shipping. The three strategies (based on fuel mix adopted) are summarised in **Table 2**.

Strategy 1: Current Fuel Mix	
HFO (Heavy Fuel Oil)	49.6%
LSFO (Light sulphur fuel oil)	32.3%
MGO (Marine Gasoil)	12.1%
LNG (Liquid Natural Gas)	5.9%

Strategy 2: VLSFO + LNG	
LSFO (Light sulphur fuel oil)	50%
MGO (Marine Gasoil)	35%
LNG (Liquid Natural Gas)	15%

Strategy 3: LNG + Green Ammonia	
LNG	50%
Green Ammonia	50%

Table 1. *Summary of fuel mix for each strategy considered. Author's own compilation.*

As anticipated in Chapter 2, and analysed in detail in Section 5.4.6, the impact of the ETS on these strategies will be assessed in two distinct scenarios.

4.1.1 Strategy 1: Current fuel mix

The first strategy we considered corresponds to the current global share of fuels for container shipping. The present fuel mix is characterised by 49.6% of HFO[1], 32.3% of LSFO[2], 12.1% of MGO[3], and about 5.9% of LNG[4] (see **Table 1**)[5]. While there are many viable sources of fuels for container shipping, and it is projected that there will be many more in the future, at present traditional HFO is still by far the most used worldwide (Placek, 2021). Part of the reasons for that relates to low price, vessels' engine design, and high energy/density ratio. Since HFO has been used for decades already, meaning that its market size and supply availability make this type of fuel significantly cheaper compared to others, especially considering its high energy/density ratio. In fact, fuels such as LSFO and MGO are respectively 65.4% and 111.6%

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[1] Heavy fuel oil.
[2] Low sulphur fuel oil.
[3] Marine Gasoil.
[4] Liquified Natural Gas.
[5] Placek (2021).

more expensive (Ship & Bunker, 2022). Moreover, although there is some degree of flexibility, the vast majority of container ships' engines have built specifically for HFO combustion. Since vessels can have a life cycle of over 30 years, it is not a mystery to understand why HFO is still among the most widely used fuels.

In recent year, especially with the deadline of the 2020 IMO Sulphur Regulations approaching, the use of LSFO fuels – especially VLSFO[6] and ULSFO[7] – has been growing (Placek, 2021). Comprising respectively only <0.5% and <0.1% of sulphur content, VLSFO and ULSFO are compliant fuels for 2020 IMO Regulations (UNTAD, 2021). At a general level, LSFO are estimated to emit on about 4% less CO2-equivalent emissions compared to HFO (Comer and Osipova, 2021).

Other fuels that have been gaining momentum are MGO (12.1%) and LNG. Marine gasoil (MGO) refers to maritime fuels that are entirely made up of distillates and it often consists of a combination of several distillates (Comer and Osipova, 2021). MGO is typically associated with 8% less CO2-equivalent emissions when compared to HFO and for this reason plays an important role in the energy transition. Finally, about 6% of the global container fleet is LNG propelled.

4.1.2 Strategy 2: LSFO, MGO, and LNG

As summarised in **Table 1**, the second strategy we propose represents a more advanced phase in the green transition process in which 40% of the global container ship fleet runs on LSFO, 30% on MGO, and the remaining 30% adopts LNG. We estimated that *Strategy 2* emits on average about 7.7% less CO2-equivalent emission compared to *Strategy 1* (see Section 5.4.6 for detailed explanation). This has to do mainly with the increased use of LNG which comprises mostly of methane and produces less CO2 upon burning than fossil fuels – over 20%[8] less when compared to HFO in terms of CO2-equivalent emissions. In fact, LNG has been found to have the ability to considerably reduce emissions (Blanton and Mosis, 2021). In fact, the benefits of LNG propulsion comprehend enhanced energy efficiency given by to high calorific output (SEA-LNG, 2019). For instance, it has been measured that an 18000 TEUs container

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[6] Very low suplphur fuel oil.

[7] Ultra-low suplhur fuel oil.

[8] Tank-to-wake.

ship running on HFO burns on average 150% more tons of fuel oil compared to an LNG propelled vessel of the same size (ibid.). This also means that LNG is typically 40-to-30% cheaper than HFO[9]. For these reasons, as well as its low price in relation to its energy-density, LNG is currently considered among the most promising alternative to fossil fuels and therefore projected to be one of the most likely substitute in the short term (ibid.). In fact, according to Clarksons data, the orderbook shows that around 30% of tonnage will be LNG – i.e., 781 units (Ovcina Mandra, 2022).

LNG vessel retrofit installation generally costs between $25 and $30 million, whilst newbuilds with LNG propulsion cost more than $15 million. Given the unreasonably high prices, LNG propulsion is likely to be limited to mega container vessels (SEA-LNG, 2019). Moreover, until LNG bunkering is available in most ports around the world, LNG will be a feasible strategy only for vessels which have regular port visits assuring LNG bunkering (i.e., liner vessels).

4.1.3 Strategy 2: LNG and Green Ammonia

Given the limitations associated with LNG, a one-sided emphasis on this particular option as an alternative fuel is best viewed as a short-term transition strategy. In fact, the only way to meet ambitious zero-net-carbon strategy is by deploying green fuels with no carbon impact. Many different options are available, and while it is likely that there will be a combination of alternatives, it is not clear which fuel will predominate (Ovcina Mandra, 2022; Jacobsen et al., 2022). Nevertheless, combining projections with the orderbook shows that green ammonia and hydrogen are among the most popular solutions (ibid.). In fact, Clarcksons reports that currently 130 ammonia-ready ships and 6 hydrogen-ready vessels are currently have been already ordered (ibid.). For these reasons, we decided *Strategy 3* to incorporate the two most visible trends in terms of alternative fuels – that is, LNG and green Ammonia (see **Table 1**). A summary of pros and cons regarding the promising feasibility of Ammonia as a marine fuel are summarised in below[10].

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[9] Based on Ship & Bunker (2022) as well as on author's own estimation.

[10] Quoted directly from the Global Maritime Forum's webinar of the 14th of March 2022 (Ovcina Mandra, 2022:ns).

“**Opportunities/upsides to ammonia:**

- Zero Carbon: As there is no carbon atom in the ammonia molecule, it does not emit CO2 during combustion.
- Energy density: Ammonia has an energy density similar to methanol and more favorable than hydrogen. Additionally, it requires less cooling than cryogenic liquid hydrogen.
- Low(er) cost: Synthesis of Ammonia from zero carbon hydrogen using the Haber-Bosch process is efficient and fully scaled. The Haber-Bosch process requires less energy than the synthesis of methanol or e-methane, meaning that Ammonia will always be cheaper than either of these zero-emission fuel options.
- Scalability: Ammonia has a long-term potential. The decreasing cost of renewable energy will support the scalability of Ammonia as a marine fuel.

Challenges:

- Overall cost: Green ammonia remains more costly than incumbent fuels, with prices expected to drop with the scale-up of the production of green hydrogen.
- Safety: Ammonia is highly toxic, flammable and corrosive. It is a risk for humans and aquatic life in case of accident and leakage, requiring strict safety standards, measures, and training.
- Regulatory collaboration: A high level of alignment and harmonisation is needed between international standard setters and local regulators to scale the production, bunkering and use of ammonia as a shipping fuel.
- Sustainability: The production of ammonia requires a sustainability system consisting of a sustainability standard and a sustainability certification based on robust sustainability criteria in order to avoid negative impacts on environment, on society and on and socio-economic factors upstream in production processes” (Ovcina Mandra, 2022:ns).

4.2 Strategy impact on vessel cost structure and freight rates

4.2.1 Cost structure

All ships across any market segment are subjected to various kinds of costs over their life span. While no homogeneous or standardised cost structure can be found due to the existence of a large variety of vessels with unique specifications and requirements, there are nevertheless similar cost structures characterised by approximately the same proportion between cost elements. Stopford (2009) broadly broke down the elements of a typical cost structure for an average vessel as follows:

Total expenses for the vessel	**Capital (CAPEX)**	**39%**
	Operating (OPEX)	**35%** of which fuel 70%
	Voyage (VOYEX)	**22%**
	Maintenance and others	**4%**

Table 2. *Cost structure and cost elements of an average vessel. Author's own illustration based on Stopford (2009).*

Capital expenses (CAPEX) represent the highest share of the cost structure. These are mainly determined by the specific modalities in which the ship has been financed. Variable elements include: agreed currency, loan size, loan structure, time horizon of the loan, as well as moratorium (ibid.) **Operating expenses (OPEX)** refer to the costs incurred when operating the ship on a daily basis such as: wages, fuel consumption (70% of OPEX), administration and insurance, and stores (ibid.). **Voyage expenses (VOYEX)** are the costs associated with a particular voyage and can be therefore considered variable expenses. These are mostly related to canal fees, type and use of engine, fuel price, and port dues (ibid.). Finally, a small share of total costs (4%) is represented by maintenance expenses which occur whenever the ship is dry-docked in order to be repaired and surveyed (ibid.).

4.2.2 Impact of ETS on costs and NTMs shock

The implementation of an ETS clearly impacts the operating costs (OPEX) for ship owners. Nevertheless, the magnitude of the cost impact is dependent upon operators' chosen strategy (i.e., fuel mix) and scenario developed (i.e., European ETS or global ETS). Each fuel mix will impact several interrelated cost elements such as fuel price and CAPEX, but most importantly the volume of CO2 emission equivalent, hence the number of allowances needed to keep operating the vessel, and ultimately the cost of the ETS. Note that while intuitively we should expect the share of fuel cost on total vessel expenses to depend on the travelled distance, Stopford (2009) showed that the share fuel cost is rather stable across routes. This is because typically there is a positive correlation between vessel size and voyage length. Therefore, in reality the average impact of fuel cost on total expenses appears to be around 70% for all routes. Again, as explained in Section 4.1, the strategies modelled are: use of current fuel mix (*Strategy 1*); 40% use of LSFO, 30% of MGO and 30% use of LNG (*Strategy 2*); and use of LNG and Green Ammonia (*Strategy 3*). We consider the price of the ETS allowances to be static for simplicity.

4.3 Chapter summary

Given the impact that fuel and its associated CO2-equivalent emission level have on OPEX after the introduction of the ETS, we introduced and motivated three among the most promising alternatives and combined them together in pairs to forecast the impact of the ETS in different (likely) future scenarios (see **Table 1**). After giving an overview of these potential strategies, we analysed the cost structure for running a vessel following Stopford (2009). Finally, we briefly addressed the ways in which the deployment of these mitigating strategies in the face of the ETS implementation will impact the cost structure of running a freight vessel, which will be modelled as NTMs.

Chapter 5 – Methodology

5.1 Choice of model

Assessing and measuring the economic impact of shocks affecting international trade is complex because of its interrelation and partial overlap with other regulations, policies and externalities as well as the short- and long-term macro-economic dynamics (Mankiw and Taylor, 2020). The introduction of a ETS in the shipping sector has been long regarded as a major shock for the industry and therefore it is of crucial important to assess its impact and make forecasts based on empirical analysis. This is particularly true for the European Union as it has been the first supranational body to propose a policy of this kind. Moreover, as the goal of the implementing the ETS is to tackle GHG emissions, assessing its degree of success in environmental terms is equally vital. In order to conduct an empirical analysis of the economic impact of the ETS on global trade, we need to make use of key data and indicators such as trade values between countries (or regions) and elasticities of the commodity (or category of commodities) under scrutiny. Once these data are gathered, with the appropriate econometric tool it is then possible to model a disturbance (or policy shock) with the objective of registering quantitative changes in international economic and trade dynamics; from which it is also possible to derive changes in environmental indicators by measuring changes in freight transportation mix. Typically, three main types of models are used in the industry for this purpose – i.e., General Equilibrium (GE), Partial Equilibrium (PE), and Gravity models (Chamingui and Thabet, 2018).

Gravity models take the name from the homonym Newtonian law. Thus, these models are based on the assumption that trade between countries is directly proportional to the size of their economy (i.e., GDP), while being inversely related to their distance. Distance includes parameters such as socio-cultural, political, and language barriers as well as freight costs and current economic relations (e.g., trade agreements, tariff and not-tariff barriers). For this reason, while this model is particularly appropriate to detect the effects of a trade policy shock when there is significant integration between the countries (or regions) considered, it has proven to be less effective for large scale analyses that involve *distant* trading partners (ibid.). Since the objective of this paper is to forecast the impact of the ETS implementation both at European and international level (see Chapter 1), it is required to adopt an ex-ante method through the use of Partial or General Equilibrium simulation models (ibid.; Francois and Hall, 2002).

Taking into account the interrelated effects of labour, capital and service between different sectors, the General Equilibrium model use an ex-ante approach that quantifies the impact of the introduction of a new policy in the future by means of computer simulations (Chamingui and Thabet, 2018). This is done considering demand and supply interactions across multiple markets (ibid.). For these reasons, GE models are typically used in case of large-scale policy implementation affecting interactions between different sectors (ibid.). Despite their comprehensiveness from both an economic and trade perspective, these GE models are often highly complex simulation models relying on large amounts of data and thus normally used at a national and/or decision-making level.

On the other hand, the Partial Equilibrium approach considers the effects of particular policies within a specific industry. The World Bank (2010:na) describes the PE approach and highlights its differences compared to GE as follows:

> "partial equilibrium implies that the analysis only considers the effects of a given policy action in the market(s) that are directly affected. That is the analysis does not account for the economic interactions between the various markets in a given economy. In a general equilibrium setup all markets are simultaneously modeled and interact with each other."

As it can be evinced from this definition, the major benefits of using a PE model are minimal data requirements (i.e., trade values, elasticities, tariff) and effectiveness for conducting in-depth industry-level policy analyses (ibid.).

	Partial Equilibrium (PE)	**General Equilibrium (GE)**
Level of analysis	Equilibrium of the whole economy	Equilibrium of a specific economic sector
Deployment	Mainly used for macroeconomic studies	Typically deployed in microeconomics
Time horizon of effects	Long-term	Short- to mid-term
Industry focus and linkages	Intra- and inter-sectoral effects across the entire economy	Specific focus on a single industry – no spill over and linkages effects are considered
Parametric requirements	Extensive parameters use across all industries	Few simple parameters concerning a single specific industry
Level of aggregation	Disaggregated effects are considered	Disaggregated effects are considered

Table 3. *Partial and General Equilibrium key characteristics comparison. Author's own illustration. Source: WITS; Chemingui and Thabet (2018).*

While the GE model is well-suited to forecast long-term impacts on the economy as a whole as it is comprehensive of data and linkages across all sectors, because this paper aims at investigating the effects of the ETS introduction on the container shipping and on CO2 emissions it is more appropriate to make use of the PE model for series of reasons. To begin with, data regarding the shipping industry are still quite speculative and precise trade figures remain difficult to collect. Second, the influence of container shipping on other industries as well as on variables such as capital and labour are highly nuanced often detectable on a very long-term horizon, hence necessitating substantial research and massive quantitative exercise which are beyond the scope of this research project. Furthermore, elasticity and other technical economic figures characterising the shipping sector miss systematic research and are often particularly complex to estimate because of cargo diversification. However, although the PE model lacks cross-sectorial interactions, it is considered appropriate to deal with these data challenges and provides enough resources for modelling policy impacts stemming from moderate variations in NTMs. Furthermore, converting economic and trade outputs generated by PE models it is also possible to derive percentage changes in environmental indicators by measuring changes in freight transportation mix (see Section 5.4).

5.2 Global Simulation Model (GSIM)

Staring from the assumptions that traded products are heterogeneous and may be distinguished by their origin, at the end of the 1960s Armington (1969) proposed a simplified model to represent and explain nations' exports and imports. Following this approach, Francois and Hall (2002) designed the Global Simulation (GSIM) model which could initially work with a maximum of 24 countries. The GSIM model considers the tariff and/or non-tariff shock arising from one (or more) policy implementation (e.g., ETS), together with domestic production surpluses/shortages and current trade values, to measure the impact of the policy on consumers/producers, production, as well as on the trade flow between selected countries.

Let us take **Figure 8** to best illustrate the dynamics of international trade involved from an economic perspective when a tariff (or non-tariff) shock is introduced. Demand – or composite demand to be precise – represents both demand for domestic and foreign product/s; similarly, supply can serve either or both domestic and foreign demand. In particular, international trade is involved whenever domestic supply does not meet domestic demand (i.e., domestic production shortage) – hence, imports – and/or in case domestic supply exceeds (i.e., production surplus) local demand – thus, exports. **Figure 8** serves as an example. First, as a country starts to engage in international trade (no import tariff is set) and moves away from autarky, price drops ($P_1 < P_0$) and domestic supply will decrease ($Q_1 < Q_0$) since domestic producers are less incentivised to supply at reduced price. By contrast, reduced price increases demand ($Q_2 > Q_0$). These contrasting moves lead to a domestic production shortage (i.e., meaning domestic supply is unable to meet domestic demand) which needs to be addressed through imports (i.e., $Q_1 < Q_0$). Now we simulate the introduction of an import tariff (or non-tariff measure). The tariff triggers a price increase ($P_{1+t} > P_1$) which initiates the inverse mechanisms: domestic producers are more incentivised by the higher price hence supply increases (Q_1 to Q_3); consumers will now buy fewer domestic goods, thus demand drops (Q_2 to Q_4); finally, since domestic producers are now able to meet domestic demand, the quantity of imports decreases from $Q_2 – Q_1$ to $Q_4 – Q_3$. We see how these movements of supply and demand have the effect of shifting the equilibrium in various ways. An important underlying assumption is that the world is a closed system and that therefore all regions must be in equilibrium form a global perspective – i.e., total imports equal total exports. With this assumption, the mechanism described above and illustrated by **Figure 8** can be applied to all countries and regions considered in this research paper.

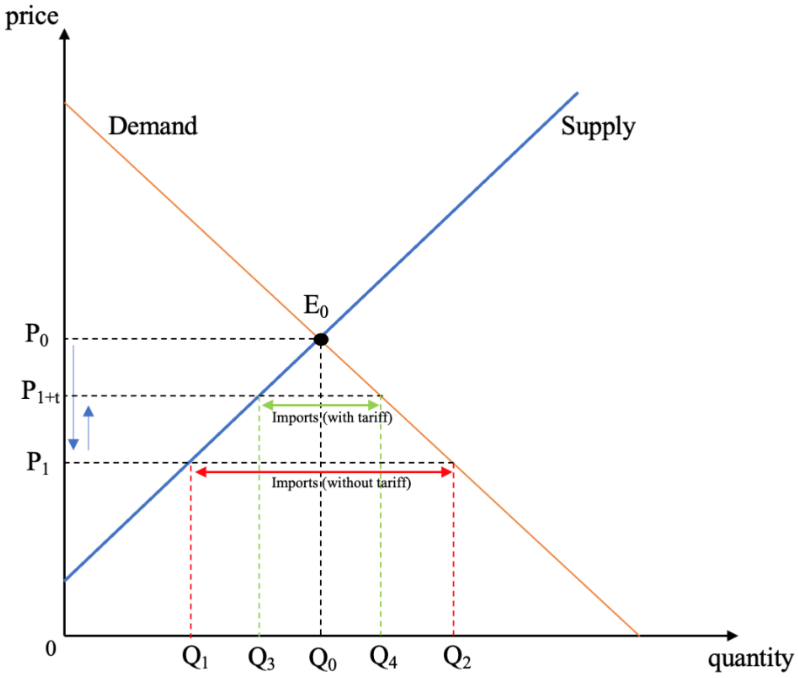


Figure 8. *The effects of a tariff on a (small) country. Author's own illustration. Based on Professor Berden's lecture notes.*

In fact, the GSIM model starts with an initial situation (i.e., current elasticities, tariff rates, trade values and non-tariff barriers) to then simulate the application of a shock (e.g., a tariff, elasticity and/or NTM change as in the case of the ETS policy). This creates a disturbance in the international trade equilibrium (i.e., production surplus and/or shortage) triggering a shift of demand and supply toward a new global equilibrium point. Prices connect each country (or region), thus when prices (or costs) vary as a result of, or in response to, variations in demand and supply, gradually the system reaches equilibrium again. Finally, when trade is in equilibrium again, me may analyse the new figures regarding trade values, prices, production outputs, welfare parameters in order to quantify and assess the policy impact.

5.3 Technical description of the GSIM model

Fundamentals parameters for the functioning of the GSIM model are elasticities. To arrive at the values of own- and cross-price demand elasticities, we start by assuming that import demand for product *i* from country *r* for each importing country *v* is a function of its price and total expenditure for that product category (Francois and Hall, 2002), hence:

$$M_{(i,v),r} = f\left(P_{(i,v),r}, P_{(i,v),s\neq r}, y_{(i,v)}\right)$$

Equation 1

in which $P_{(i,v),r}$ is the domestic price for goods from region *r* for country v, $P_{(i,v),s\neq r}$ is the global price in country v for product i, and $y_{(i,v)}$ stands for total expenditure on imports of product *i* in country *v*. It is important to remark that $P_{(i,v),r}$ also contains the tariff rate imposed $t_{(i,v),r}$. It follows that, if we consider the tariff rate in the form of a percentage, its value needs to be summed to 1 – that is, T=1+t. Hence, taking $P_{i,r}*$ to be the world price of product *i* when exported by country *r*, we can establish the following:

$$P_{(i,v),r} = \left(1 + t_{(i,v),r}\right)P_{i,r} *= T_{(i,v),r}P_{i,r} *$$

Equation 2

Following Francois and Hall (1997), assuming homothetic preferences for expenditures and taking income $\eta_{(i,v)(y,s)} = 1$, and $\theta_{(i,v),s}$ to represents the share of demand expenditure at domestic prices, we can express composite demand elasticity for (importing) country *v* as follows:

$$E_{M,v} = \frac{\eta_{(i,v)(y,s)}}{\theta_{(i,v),s}} - 1$$

Equation 3

from Francois and Hall (2002) we also have the following relation:

$$N_{(i,v),(r,s)} = \theta_{(i,v),s}E_s + \eta_{(i,v),(r,v)}\left(\eta_{(i,v),(y,s)} - \theta_{(i,v),s}\right)$$

Equation 4

where $N_{(i,v),(r,s)}$ stands for cross-price elasticity and E_s stands for substitution elasticity. Thus, making substitutions we get to the relationship:

$$N_{(i,v),(r,s)} = \theta_{(i,v),s}(E_m + E_s)$$

Equation 5

we can now simplify and derive the equations for both aggregate import demand (i.e., **Equation 5**) and substitution (i.e., **Equation 6**) elasticities:

$$E_m = \frac{N_{(i,v),(r,s)}}{\theta_{(i,v),s}} - E_s$$

Equation 6

$$E_s = \frac{N_{(i,v),(r,s)}}{\theta_{(i,v),s}} - E_m$$

Equation 7

Now, to ultimately derive aggregate export supply elasticity we first need to define supply to world markets – that is, the quantity of *i* exported by *r* – $X_{i,r}$ as a function of world price P^*:

$$X_{i,r} = f\left(P_{i,r}\,*\right)$$

Equation 8

Differentiating equations **1**, **2**, and **8** we can derive the following:

$$\hat{X}_{i,r} = E_{X(i,r)}\hat{P}_{i,r}\,*$$

Equation 9

where ^ indicates a proportional change[11], $\hat{X}_{i,r}$ stands the variation of quantity of product *i* exported by country *r*, and $E_{X(i,r)}$ represents the aggregate export supply elasticity. Finally, we manipulate **Equation 9** to isolate export supply elasticity, which we can express as:

$$E_{X(i,r)} = \frac{\hat{X}_{i,r}}{\hat{P}_{i,r}\,*}$$

Equation 10

---

[11] Meaning $\hat{x} = \frac{dx}{x}$.

Again, manipulating and differentiating equations **1**, **2**, and **8** we can define the variation of imports quantity as follows:

$$\hat{M}_{(i,v),r} = N_{(i,v),(r,r)}\hat{P}_{(i,v),r} + \sum_{s\neq r} N_{(i,v),(r,s)}\hat{P}_{(i,v),s}$$

Equation 11

Making further substitutions from the system of equations above and summing over import markets we get a workable equilibrium model based on world prices:

$$\begin{aligned}\hat{M}_{i,r} = \hat{X}_{i,r} \Rightarrow \quad E_{X(i,r)}\hat{P}_{i,r} * &= \sum_{v} N_{(i,v),(r,r)}\hat{P}_{(i,v),r} + \sum_{v}\sum_{s\neq r} N_{(i,v),(r,s)}\hat{P}_{(i,v),s} \\ &= \sum_{v} N_{(i,v),(r,r)}\left[P_r * + \hat{T}_{(i,v),r}\right] + \sum_{v}\sum_{s\neq r} N_{(i,v),(r,s)}\left[\hat{P}_s * + \hat{T}_{(i,v),r}\right]\end{aligned}$$

Equation 12

After we solve this system for world prices, **Equation 11** and **Equation 12** can be used to derive export quantities and import quantities respectively. Combining these with partial equilibrium measures of variation in exporter (i.e., producer) surplus ΔPS and importer (i.e., consumer) surplus $\Delta CS_{i,v}$ we obtain a measure of welfare effects. This is formalised in **Equation 13**:

$$\begin{aligned}\Delta PS_{(i,r)} &= R^0_{(i,r)} \cdot \hat{P}_{i,r} * + \frac{1}{2} \cdot R^0_{(i,r)} \cdot \hat{P}_{i,r} * \cdot \hat{X}_{i,r} \\ &= \left(R^0_{(i,r)} \cdot \hat{P}_{i,r} *\right) \cdot \left(1 + \frac{E_{X,(i,r)} \cdot \hat{P}_{i,r} *}{2}\right)\end{aligned}$$

Equation 13

where $R^0_{(i,r)}$ is the export revenues benchmark at world prices. Variations in consumer (i.e., importer) surplus are expressed in the equation below.

$$\Delta CS_{(i,v)} = \left(\sum_r R^0_{(i,v),r} \cdot T^0_{(i,v),r} \right) \cdot \left(1/2E_{M,(i,v)} \hat{P}_{(i,v)}{}^2 \cdot \text{sign}\left(\hat{P}_{(i,v)}\right) - \hat{P}_{(i,v)}\right)$$

where $\hat{P}_{(i,v)} = \sum_r \theta_{(i,v),r} \hat{P}_r * + \hat{T}_{(i,v),r}$

Equation 14

Consumer surplus is quantified with regard to the composite import demand curve in **Equation 14**, where $P_{(i,v)}$ expresses the price of composite imports and $R^0_{(i,r)} \cdot T^0_{(i,v),r}$ indicate spending at internal prices. We may combine variations in production surplus, consumer surplus, and import tariff revenues to approximate welfare changes. Now, in the above system world prices are treated as fixed in order to be able to calculate trade diversion and creation effects. Therefore, it follows that changes in price are triggered by tariff rates variation. Thus, we have:

$$\begin{aligned} \hat{M}_{(i,v),r} &= N_{(i,v),(r,r)} \hat{P}_{(i,v),r} + \sum_{s \neq r} N_{(i,v),(r,s)} \hat{P}_{(i,v),s} \\ &= N_{(i,v),(r,r)} \hat{T}_{(i,v),r} + \sum_{s \neq r} N_{(i,v),(r,s)} \hat{T}_{(i,v),s} \end{aligned}$$

Equation 15

Finally, decomposing **Equation 15** further, we can isolate both trade creation $TC_{(i,v),r}$ and diversion $TD_{(i,v),r}$ effects and formalise them respectively by means of the following equations:

$$TC_{(i,v),r} = M_{(i,v),r} \times \left[N_{(i,v),(r,r)} \hat{T}_{(i,v),r} \right]$$

Equation 16

$$TD_{(i,v),r} = M_{(i,v),r} \times \sum_{(\neq f)} N_{(i,v),(r,s)} \hat{T}_{(i,v),s}$$

Equation 17

Index	**Model Notations**
r, s	Exporting countries (or regions)
v, w	Importing countries (or regions)
i	Product category
Variables	
M	Imports (quantity)
X	Exports (quantity)
$E_{M,(i,v)}$	Aggregate import demand elasticity
$E_{X,(i,r)}$	Export supply elasticity
E_s	Substitution elasticity
$N_{(i,v),(r,r)}$	Domestic price demand elasticity
$N_{(i,v),(r,s)}$	Cross-price elasticity
$T_{(i,v),r}$	Power of tariff, T=(1+t)
$\theta_{(i,v),s}$	Share of demand expenditure (at domestic prices)

Table 4. *Index and model notation. Compiled by the author. Source: Francois and Hall (2002).*

5.4 Data requirements and estimation methods of the economic, trade, transport, and CO2-equivalent emission impact of the ETS

As explained in the previous sections, in this research paper we adopt the GSIM econometric model to measure and assess the *economic*, *trade*, *container flow, and carbon emission* impacts arising from the introduction of the ETS – both at a European and global level – simulating different strategies and scenarios (see Chapter 1 and 4). For this purpose, **Table 5** lists the data inputs that are needed. In the next sections, we will discuss step by step how these data have been collected and/or estimated.

Data requirements for the GSIM model		Section
i	*Select countries and/or regions appropriately for the scope of research;*	5.4.1
ii	*Current trade values and volumes of containerised goods between selected countries (or regions) disaggregated per mode of transport (i.e., deep sea, rail, truck, barge, and plane) – obtained through the WITS and Eurostat databases;*	5.4.2
iii	*Current tariff rates for containerised goods – accessed on the WITS database – and eventual final (post-shock) ones;*	5.4.3
iv	*Initial NTMs estimated through Anderson's and Wincoop's (2004) method and adjusted for actual tariff rates;*	5.4.4
v	*Scenario definition (necessary framework from which to estimate final NTMs)*	5.4.5
vi	*Final NTMs – estimated according to the strategies deployed and scenarios considered;*	5.4.6
vii	*Supply and demand elasticities of containerised commodities (based on extant literature);*	5.4.7
viii	*Substitution elasticity between modes of transports (sourced and estimated based on previous literature);*	5.4.8

Table 5. *List of data requirements for the GSIM model*

5.4.1 Country selection

As anticipated, a global partial equilibrium economic model drives results starting from data the trade values exchanged (import/export) between nations and their associated elasticities (i.e., import, export, and substitution). Since it is a global simulation model (i.e., GSIM), all world's countries need to be taken into account. Because we can reasonably expect that the implementation of the EU ETS will affect European imports and exports the most, we decided to analyse the effect on two major maritime EU regional blocks individually – i.e., (1) Top Mediterranean EU Maritime Economies; (2) Top Continental EU Maritime Economies). The rest of EU countries have been grouped into a wider regional block (i.e., Rest of EU). Main extra-EU trading partners for EU have been selected either individually (i.e., disaggregated data) or in regional groups (i.e., Top Asian Maritime Economies). Finally, we aggregated all remaining world countries and labelled them ROW (i.e., Rest of the World). These countries and regions have been selected as they represent the largest regional blocs in terms of containerised trade and have been aggregated together based on geography and shared trade agreements. An economic and maritime economic description of the countries selected for the study can be found in Section 3.4. We provide a list of selected countries (or regions) below.

- **Top EU Mediterranean Maritime Economies (TEUMME)**
  Italy, France, Spain, and Greece;
- **Top EU Continental Maritime Economies (TEUCME)**
  Germany, Netherlands, and Belgium;
- **Rest of EU**
  Austria, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, and Sweden;
- **UK**
- **USA**
- **Top Asian Maritime Economies (TAME)**
  China, India, Japan, and South Korea;
- **Rest of the World (ROW)**

  All other world's countries

5.4.2 Bilateral multimodal trade values and volumes between selected countries

We collected bilateral trade values for containerised goods divided by the five main modes of transport (i.e., ship, truck, rail, barge, plane) in USD for the period January-December 2021. For what it concerns bilateral trade values between EU member states (including the UK) and between EU member states (UK included) and all other countries, these data were readily available on the Eurostat database. Values in Euro were converted into USD at the exchange rate corresponding to the 31st of December 2021. Similarly, the Eurostat database provides data about the volume (expressed in tonnes) corresponding to the bilateral trade flows between selected countries. This information is important from a logistical standpoint as it enables to assess the change in container flow between trading partners after the EU ETS shock has been simulated. In fact, assuming an average full container weight (i.e., 13 tonnes), we can estimate how a variation in traded volume (or weight) translates into a variation in TEUs handled. We collected data only for containerised goods by filtering out in the database all categories of products which are typically not transported in containers (e.g., ores, grain, oil, gas, and other dry and wet bulks that are normally transported in bulk carriers and tankers). This way we reasonably assumed that the products considered are to a great extent easily transferrable across the modes of transport taken into account. The same procedure was repeated to collect bilateral trade values between other countries by consulting the WITS database (i.e., UN Comtrade database) while filtering out non-containerised goods. However, WITS does not always provide data about the modal split of traded goods nor about the traded volume. Therefore, at times it was necessary to look for existing estimates about the modal split in different national databases (e.g., US Bureau of Transport Statistics.; National Bureau of Statistics of China; ISTAT; CBS Statistics Netherlands; Statistics Bureau of Japan). Whenever data about traded volume by mode of transport was not available, this was estimated by looking at a country with similar import/export characteristics (i.e., similar categories of products are exported and/or imported) and with readily available data (e.g., Germany), and applying the same $/ton ratio (i.e., ratio between USD exchanged and tonnes traded for the same mode of transport) for the same mode of transport so as to give a realistic estimate. The full matrixes of bilateral trade values and volumes between selected countries has been attached in **Appendix 1** and **2** respectively.

5.4.3 Final Tariff rates

In the previous section, we described the collection of bilateral trade values and volumes were gathered by mode of transport for the countries under examination. However, as previously mentioned, information about tariff measures, NTMs (non-tariff measures, sometimes express in trade cost equivalents (TCEs)), and elasticities are required in order for the model to work. Regarding final tariff rates, while the introduction of the ETS affects vessel's operating and ownership costs (see Chapter 4), it does not involve a variation in current tariff rates. For this reason, the values for final tariff rates will be the same as the initial ones for each strategy and scenario. Again, tariff values were sourced browsing the WITS database by excluding non-containerised goods (see Section 3.5). A full table is available in **Appendix 3**.

5.4.4 Initial NTMs (TCEs)

Data requirement *iv* is obtained through estimation following Anderson's and Wincoop's (2004) method. In particular, initial NTMs are obtained adjusting Anderson's and Wincoop's (2004) framework for current tariff rates.

Anderson's and Wincoop's (2004) method

As anticipated, the estimation of TCEs followed the method put forward by Anderson and Wincoop (2004), which considers NTMs to be constituted by border barriers, regional supply chain costs, and transportation costs. In their paper, Anderson and Wincoop (2004) estimated these three costs to represent respectively 44%, 55%, and 21% of total NTMs trade cost equivalents. Hence, considering 1.0 as baseline we have a total of:

$$\mathbf{1.44} \times \mathbf{1.55} \times \mathbf{1.21} = \mathbf{2.70}$$

over the commodity price. In other words, TCEs were estimated to represent 170% of commodity value. Although the trade barriers of more developed economies are typically lower than those of developing countries as a result of traits such as political stability, ease of doing business, and labour regulations, we use the above estimate across all selected economies.

Correcting Anderson's and Wincoop's (2004) framework

Nevertheless, for the present case an adjustment needs to be made. In fact, in their study, Anderson and Wincoop (2004) include tariffs in their estimate of total trade costs. To be precise, they include tariff costs in what they refer to as border barriers – that is, in the 44% of total costs. Thus, for instance, export tariffs for the USA toward Belgium were found to be 1.018 (or 1.8%). Adjusting for this data we will hence not have a NTMs of 170%, but rather:

$[1.44 - (1.018 - 1)] \times 1.55 \times 1.21 = 2.667$; that is, 166.7% TCE.

Equation 18

Applying this correction, we calculated initial NTMs (or TCEs) for all for all countries involved in the study. For a full overview see **Appendix 4**.

5.4.5 Scenarios and strategies selected for designed simulations

We now summarise once more the scenarios and strategies simulated in this study as this is crucial to in order to understand the estimation process of final NTMs. Again, in *Scenario 1* the EU introduces the ETS, thus the ETS price will apply 100% for intra-European voyages, 50% for international trips from/to Europe, while it will not apply for extra-European trade; in *Scenario 2* the ETS will be introduced at a global level, hence the price of ETS allowances will be equal irrespective of trading routes. As touched upon in Chapter 4, in this research paper we modelled three strategies in two different scenarios for a total of six simulations. While this is not by any means exhaustive of all potential scenario and strategies, the present scenario development choice is motivated by previous research papers as well as by likely developments in the shipping industry in the mid- to long-term. The three strategies (based on fuel mix adopted) and two scenarios (based on the geographical scope of the ETS) considered are summarised once more in **Table 6** and **7**.

Strategy 1: Current Fuel Mix	
HFO (Heavy Fuel Oil)	49.6%
LSFO (Light sulphur fuel oil)	32.3%
MGO (Marine Gasoil)	12.1%
LNG (Liquid Natural Gas)	5.9%

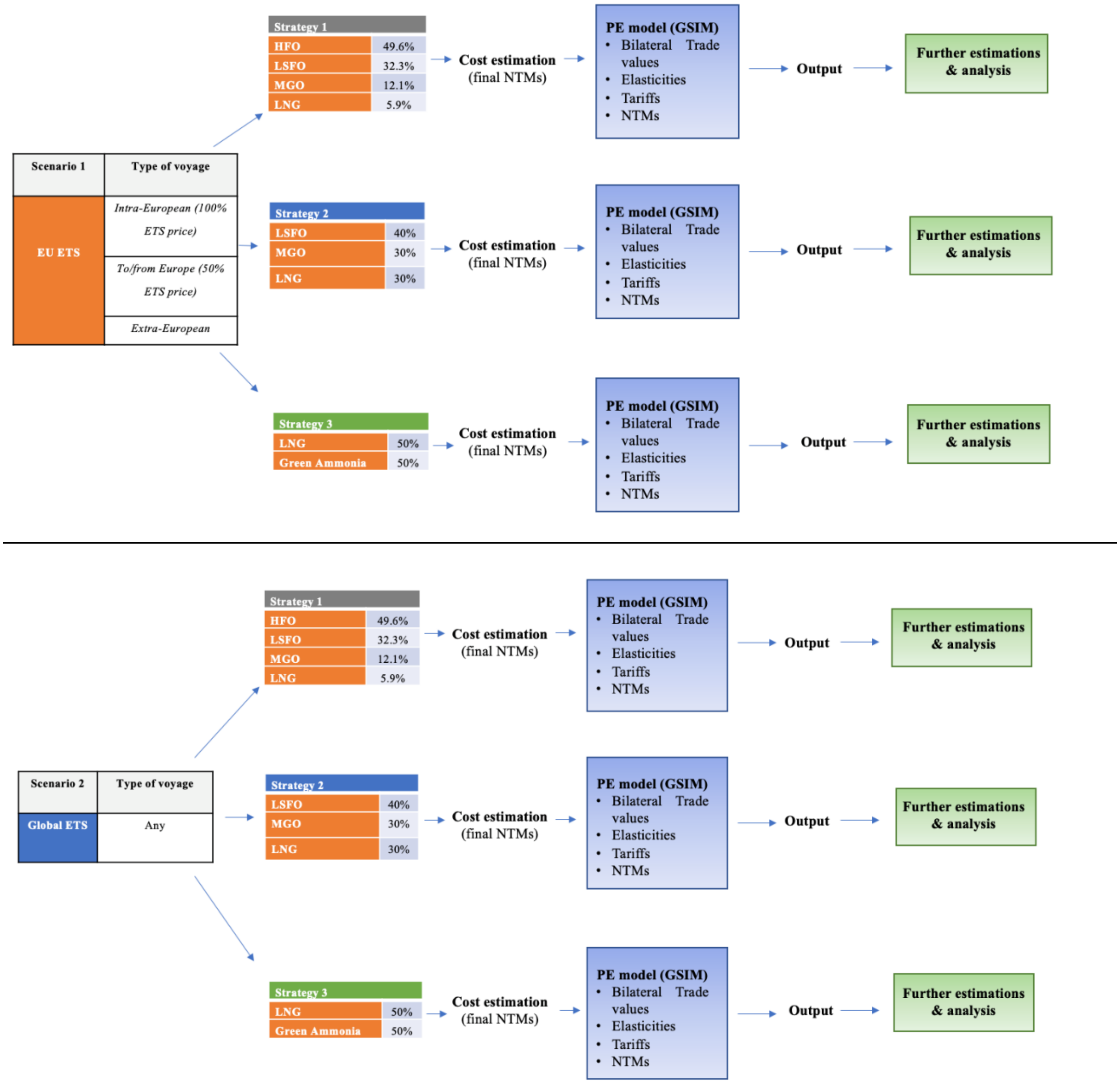
Strategy 2: VLSFO + LNG	
LSFO (Light sulphur fuel oil)	40%
MGO (Marine Gasoil)	30%
LNG (Liquid Natural Gas)	30%

Strategy 3: LNG + Green Ammonia	
LNG	50%
Green Ammonia	50%

Table 6. *Summary of fuel mix for each strategy considered. Author's own compilation.*

Scenario	**Type of voyage**	**ETS price per ton of CO2 emission equivalent (€)**
1. EU ETS	*Intra-European (100% ETS price)*	67.00
	To/from Europe (50% ETS price)	35.50
	Extra-European (0% ETS price)	0.00
2. Global ETS	*Any*	50.25

Table 7. *Summary of selected scenarios and associated ETS price per ton of CO2 emission equivalent. Author's own compilation.*



Map 1. *Conceptual map of research methodological network flow. Author's own compilation.*

5.4.6 Final NTMs

Final NTMs are estimated based on calculations of several strategies and scenarios detailed in the previous section. This is the input which is affected by the ETS implementation.

General method

In Section 5.4.4, we presented the calculations for the estimation of the initial NTMs. We need now to model two distinct shocks or scenarios: one arising from the introduction of the EU ETS (*Scenario 1*); the second in which a global ETS is implemented (*Scenario* 2). For both scenarios we modelled 3 different plausible strategies – see Section 5.4.5 and **Chapter 4** for a detailed explanation – which differ in terms of fuel mix adopted by the world fleet. These strategies are characterised by the following fuel mix typologies or strategies: current fuel mix[12] (*Strategy 1*); VLSFO[13] and LNG[14] (*Strategy 2*); and LNG and Green Ammonia (*Strategy 3*). The fuel mix for each strategy is specified in **Table 6**. Note that *Strategies* 2 and 3 are hypothetical future scenarios which nonetheless reflect likely outcomes in the near-to-mid future. Since the ETS imposes a tax on the amount of CO2-equivalent emissions, modelling different current and future fuel mix is of not only particularly interesting but it is also crucially relevant to make more comprehensive forecasts.

For now, it suffices to say that each fuel mix entails different bunkering costs, CO2-equivalent emissions, cost impact of the ETS, as well as different capital costs (CAPEX) that arise from investing in vessels propelled by a different fuel. The estimations for all these variables will be analysed and explained in detail in the next section. At this stage, we limit ourselves to provide an example of how the cost impact of these variables on NTMs TCE. Following Anderson and Wincoop (2004), in the case of the USA exporting containerised goods to TEUMME[15] in the current fuel mix strategy (*Strategy 1*) after the implementation of the EU ETS, the final NTM (TCE) can be estimated in the following way:

$$[1.44 - (1.018 - 1)] \times 1.55 \times \{[0.21 \times (1 + 0.037)] + 1\} = 2.6835$$

Equation 19

in which, the expression inside the first pair of square brackets represents border costs adjusted for the actual tariff costs (see **Equation 18**), 1.55 stands for regional supply chain costs, and the expression within the curly brackets indicates the estimated transport costs after the implementation of the EU ETS, that is, after an increase in fuel cost. In fact, we can consider the additional costs (i.e., 0.0358 or 3.58%) arising from the introduction of the EU ETS to be directly linked to fuel costs as emissions are tied to fuel mix itself. Again, the calculations necessary to estimate the increase in transportation costs for each shock and scenario will be presented in the following paragraphs. Note that in the above example there is no variation in CAPEX as there is no change in the composition of the world fleet (i.e., current scenario).

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[12] Current fuel mix of the world containership fleet.

[13] Very Light Sulphur Fuel Oil.

[14] Liquified Natural Gas.

[15] Top EU Mediterranen Economies.

Finally, comparing the initial NTM with the final NTM for this specific example (see **Table 8**), we note that TCE has increased (+1.65%) as a consequence of the EU ETS implementation:

Scenario 1 (Strategy 1): USA exports to TEUMME	
Initial NTM (TCE)	Final NTM (TCE)
2.667 (or 166.7%)	2.6835 (or 168.4%)

Table 8. *USA-to-TEUMME initial and final TCE under Scenario 1 and Strategy 1. Author's own compilation.*

Below, we explain in detail how we estimated and converted the cost impact of each strategy for both scenarios researched into NTMs.

Strategy 1: use of current fuel mix

Strategy 1 represents an approximation of the present state of the art in terms of fuel mix adopted by the world container fleet (Lloyd's List, 2021; Placek, 2021). As reported also in **Table 9** and explained in Section 4.1, the current fuel mix strategy can be summarised as follows:

Fuel type	**% Share**	**Tons of CO2-emissions equivalent[16] per ton of fuel consumed**	**Tons of CO2-emissions equivalent[17] per ton of fuel consumed weighted as a % share of fuel type**
HFO	49.6%	3.682	1.826
LSFO	32.3%	3.548	1.146
MGO	12.1%	3.394	0.411
LNG	5.9%	2.794	0.165
Weighted Average	100%		**3.548**

Table 9. *Strategy 1: Summary CO2-emissions eq. for each fuel type and weighted average. Author's own compilation based on Comer and Osipova (2021).*

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[16] Tank-to-wake.

[17] Tank-to-wake.

In the current strategy, no response is taken by shipowners to mitigate the effects of the ETS. Therefore, CAPEX remains unvaried, and the only cost impact is the pure effect of the ETS, which only impacts operating expenses (OPEX). In fact, the cost impact of the ETS is dependent upon the volume of CO2-emissions equivalent per ton of fuel consumed, and this is ultimately determined by the type of fuel. For this reason, the additional costs arising from the ETS implementation are here allocated and treated as additional fuel expenses which determine rising vessel OPEX and therefore higher transportation costs. In order to estimate the average CO2-emissions equivalent per ton of fuel consumed for *Strategy 1*, it is necessary to know the fuel mix composition of the world's fleet, and the volume of CO2-emissions equivalent associated with each type of fuel (see **Table 9**). With these data, it was possible to calculate the volume of CO2-emissions equivalent per ton of fuel consumed weighted as a percentage share of fuel type – this is necessary to ultimately estimate the total weighted average – simply by multiplying the share of each fuel type as a percentage of the fuel mix adopted by the world's container fleet by the volume of CO2-emissions equivalent per ton of fuel consumed of the same type. We provide an example for HFO to show the calculations:

$3.682 \times 49.6\% = 1.826$ tons of CO2-emissions eq. per ton of HFO consumed

Equation 20

By adding the volume of CO2-emissions equivalent per ton of fuel consumed weighted as a percentage share of each fuel type we estimated the weighted average for the entire fuel mix:

$1.826 + 1.146 + 0.411 + 0.165 = 3.548$ tons of CO2-emissions eq. per ton of fuel consumed

Equation 21

We finally calculated the cost impact of the ETS implementation under *Strategy 1* for both scenarios multiplying the expected cost of the ETS per ton CO2-emission equivalent by the average tons of CO2-emission eq. per ton of fuel consumed (i.e., **Equation 21**). We provide an example for all possible cases:

	Voyage type	Average CO2-em. eq. per ton of fuel consumed	ETS price (€) per ton of CO2-em. Eq. [18]	ETS cost impact (€)
EU ETS (*Scenario 1*)	*Intra-European (100% ETS price)*	3.548	67.00	**237.72**
	To/from Europe (50% ETS price)	3.548	33.50	**118.86**
	Extra-European	3.548	0	**0**
Global ETS (*Scenario 2*)	*Any*	3.548	50.25	**178.23**

Table 10. *Strategy 1: Extra fuel cost per ton after EU ETS and global ETS implementation. Author's own compilation.*

Now, we know that the EU ETS implementation leads to an increase of €237.72 and €118.86 in extra fuel costs per ton of fuel consumed for *intra-European* and *to/from Europe* voyages respectively in *scenario 1;* and that a global ETS is estimated to increase fuel expenses by €178.23 for each ton of fuel consumed. In order to calculate the impact of the ETS in terms of TCE (trade costs equivalent) with Anderson's and Wincoop's (2004) method, we need to calculate the percentage differential between the initial average fuel price per ton and the new price per ton inclusive of the extra costs arising from the ETS implementation (see **Table 10**). To do this, we collected the price per ton of each fuel considered in the current fuel mix situation (*Strategy 1*) to calculate the average fuel cost for this strategy (see **Table 11**). Again, we calculated the weighted average of fuel price for *Strategy 1* with the same method as per **Equation 20** and **21** (see **Table 11**).

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[18] Based on Faber et al. (2022).

Fuel type	% Share	Fuel price[19] (€/ton)	Fuel price (€/ton) weighted as a % share of fuel type
HFO	49.6%	515.00	255.44
LSFO	32.3%	852.00	275.16
MGO	12.1%	1090.00	131.89
LNG	5.9%	353.00	20.83
Weighted Average	100%		**683.27**

Table 11. *Strategy 1: Summary of fuel price for each fuel type and weighted average. Author's own compilation.*

As we already explained, we treat the cost of the ETS as an additional fuel cost. Therefore, we added the average ETS cost impact per ton of fuel consumed (see **Table 10**) to the average fuel price for *Strategy 1* (see **Table 11**) for both scenarios and all routes. The results are reported below (**Table 12**).

EU ETS			Global ETS
Intra-European	*To/from Europe*	*Extra-European*	*Any*
€920.97	€802.12	€683.27	€861.55

Table 12. *Strategy 1: New average fuel price per ton after ETS implementation for both scenarios. Author's own compilation.*

We could now calculate the percentage increase of vessel total costs after the implementation of the ETS for both scenarios. Remember that OPEX represents 35% of total vessel expenses and fuel costs are approximately 70% of OPEX. We provide calculation examples for intra-European (**Equation 22**), to/from European (**Equation 23**), extra-European (**Equation 24**) voyages in the case of the EU ETS and for all voyages for the global ETS (**Equation 25**):

$\{[(920.97 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 8.52\%$ increase in vessel costs

Equation 22

$\{[(802.12 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 4.26\%$ increase in vessel costs

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[19] At 22/07/2022 for the Port of Rotterdam (Ship & Bunker, 2022).

Equation 23

$\{[(683.27 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 0.0\%$ increase in vessel costs

Equation 24

$\{[(861.55 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 6.39\%$ increase in vessel costs

Equation 25

Hence, as per **Equation II**, using Anderson's and Wincoop's (2004) method we estimated and calculated the increase of NTMs expressed as TCE for the implementation of the ETS. Here again we provide the example TEUMME[20] importing from the USA:

$$[1.44 - (1.018 - 1)] \times 1.55 \times \{[0.21 \times (1 + 0.0426)] + 1\} = 2.6867$$

Equation 19

Remember from Section 5.4.4 that transportation costs (costs of freight) – which include vessel expenses – represent 21% of total NTMs TCE (ibid.), thus the percentage increase of vessel expenses (i.e., 4.26% for USA-to- TEUMME) will be added to freight costs (i.e., 21% of total NTM TCE). All estimated NTMs TCE for all strategies and scenarios can be found in **Appendix 5**.

Strategy 2: 25% use of LSFO, 25% use of MGO, and 50% use of LNG

In *Strategy 2* we imagined that shipowners take action to mitigate global warming and the cost impact of the ETS by deploying a less polluting fuel mix. In particular, *Strategy 2* is characterised by the half of the world fleet being propelled by VLSFO and the other half by LNG. In the case of *Strategy 2* we will have three effects, two of which will affect OPEX and a distinct one that will impact CAPEX:

OPEX:

a) *a shock arising from the cost impact of ETS on fuel expenses*

b) *a variation of bunker price arising from the new fuel mix as compared to the current one (i.e., Strategy 1)*

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[20] Top EU Mediterranen Economies.

CAPEX:

c) an increase in capital expenses due to the costs incurred by shipowners to install LNG propulsion

a) Cost impact of ETS on fuel expenses (OPEX)

First, as we did for *Strategy 1*, we proceed with estimating the variation in OPEX due to the new fuel mix by calculating its (weighted) average CO2-emissions equivalent per ton of fuel consumed for *Strategy 2*. **Table 13** provides a summary of results while **Equation 26** illustrates the calculations.

Fuel type	% Share	Tons of CO2-emissions equivalent[21] per ton of fuel consumed	Tons of CO2-emissions equivalent[22] per ton of fuel consumed weighted as a % share of fuel type
LSFO	40%	3.548	1.419
MGO	30%	3.394	1.018
LNG	30%	2.794	0.838
Weighted Average	100%		**3.276**

Table 13. *Strategy 2: Summary of CO2-emissions eq. for each fuel type and weighted average. Author's own compilation based on Comer and Osipova (2021).*

$(3.548 \times 50\%) + (3.394 \times 35\%) + (2.794 \times 15\%) = 3.381$ tons of CO2-emissions eq. per ton of fuel consumed

Equation 26

Again, we calculated the cost impact of the ETS on fuel costs under *Strategy 2* for both scenarios multiplying the expected cost of the ETS per ton CO2-emission equivalent by the average tons of CO2-emission eq. per ton of fuel consumed (i.e., **Equation 26**). We provide an example for all possible cases:

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[21] Tank-to-wake.

[22] Tank-to-wake.

	Voyage type	**Average CO2-em. eq. per ton of fuel consumed**	**ETS price (€) per ton of CO2-em. Eq.**	**ETS cost impact (€)**
EU ETS (*Scenario 1*)	*Intra-European (100% ETS price)*	3.276	67.00	**219.47**
	To/from Europe (50% ETS price)	3.276	33.50	**109.73**
	Extra-European	3.276	0	**0**
Global ETS (*Scenario 2*)	*Any*	3.276	50.25	**164.60**

Table 14. *Strategy 2: Extra fuel cost per ton after EU ETS and global ETS implementation. Author's own compilation.*

As illustrated by **Table 14**, we estimate that the EU ETS implementation results in a €219.47 and €109.73 increase in extra fuel costs per ton of fuel consumed for *intra-European* and *to/from Europe* voyages respectively in *Scenario 1;* and that the introduction of a global ETS (*Scenario 2*) adds €164.60 for each ton of fuel consumed.

b) Bunker price differential arising from the new fuel mix adopted (OPEX)

Now that the cost impact of ETS on fuel expenses has been estimated, we calculated the percentage differential between the initial average fuel cost per ton in *Strategy 1* (current mix) and the new fuel expense per ton inclusive of the extra costs arising from the ETS implementation (see **Table 10**). To do this, we collected the price per ton of each fuel considered in *Strategy 2* to calculate the average fuel cost for this strategy (see **Table 11**). Again, we calculated the weighted average of fuel price for *Strategy 2* with the same mathematical rationale as per **Equation 26** (see **Table 15**).

Fuel type	% Share	Fuel price[23] (€/ton)	Fuel price (€/ton) weighted as a % share of fuel type
LSFO	40%	852.00	340.70
MGO	30%	1090.00	327.00
LNG	30%	353.00	105.90
Weighted Average (*Strategy 2*)	100%		**773.60**
Weighted Average (*Strategy 1*)	100%		**683.27**

Table 15. *Strategy 2: Summary of fuel price for each fuel type and weighted average compared to Strategy 1. Author's own compilation.*

Comparing the weighted average of fuel price for *Strategy 2* with the one for *Strategy 1*, we see that the new fuel mix leads to an increase (+13.22%) in average fuel price:

$$(773.60 - 683.27) \div 683.27 = +13.22\% \text{ change in avg. fuel price compared to } \textit{Strategy 1}$$

Equation 27

Since we treat the effect of the ETS as an extra fuel cost, we summed the average ETS cost impact per ton of fuel consumed (see **Table 14**) to the average fuel price for *Strategy 2* (see **Table 15**) for both scenarios and all routes. **Table 16** summarises and compares the results of *Strategy 1* and *2*.

	EU ETS			Global ETS
	Intra-European	*To/from Europe*	*Extra-European*	*Any*
Strategy 1	€920.97	€802.12	€683.27	€861.55
Strategy 2	€993.07	€883.33	€773.60	€938.20

Table 16. *Strategy 2: New average fuel price per ton after ETS implementation for both scenarios compared to Strategy 1. Author's own compilation.*

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[23] At 22/07/2022 for the Port of Rotterdam (Ship & Bunker, 2022).

We can now calculate the percentage variation of OPEX once the ETS has been implemented in both scenarios as compared to the current scenario (i.e., *Scenario 1* before the introduction of the ETS). Recalling that we hold fuel costs to be approximately 70% of OPEX, and OPEX to represents about 35% of vessel total costs, we provide calculation examples for intra-European (**Equation 28**), to/from European (**Equation 29**), extra-European (**Equation 30**) voyages in the case of the EU ETS and for all voyages for the global ETS (**Equation 31**) as we did for *Strategy 1*:

$$\{[(993.07 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 11.11\% \text{ change in total vessel costs}$$

Equation 28

$$\{[(883.33 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 7.17\% \text{ change in total vessel costs}$$

Equation 29

$$\{[(773.60 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 3.24\% \text{ change in total vessel costs}$$

Equation 30

$$\{[(938.20 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 9.14\% \text{ change in total vessel costs}$$

Equation 31

c) Impact of Strategy 2 on CAPEX

While typically in order to use VLSFO vessels do not need to be retrofitted, installing an LNG plant or ordering a new LNG-propelled vessel has implications for CAPEX irrespective of voyage route selected. The cost of undertaking any of the two procedures has reduced significantly in recent years, however estimations still indicates that on average a shipowner will spend approximately €15 million to retrofit a ship for LNG use or about €18 million more (or an increase of about 22% in CAPEX) on average to buy an LNG-propelled vessel compared to a traditionally propelled ship (Sathe, 2019; Hellenic Shipping News, 2021). Undertaking calculations on a 10-year payback cycle, this results in approximately €1.5 million and €1.8 million in fixed CAPEX per year during the payback period in the case of retrofitting and newbuild respectively. To include both strategies without prioritising one over the other, in this paper we took the average between the two estimated fixed costs. Hence, we held €1.65 million to be the average fixed yearly CAPEX to for LNG transition. If – as per Stopford's (2009) assumptions – we take total average cost of a typical 68.000 Dwt vessel to be €8.1 million, and

CAPEX to represents 39% of a vessel's total costs, we can calculate the average annual percentage increase in total costs required for transitioning to LNG:

$(1.65 \div 8.1) \times 39\% = 7.94\%$ cost impact of CAPEX on total vessel costs (non-adjusted)

Equation 32

This would be the result if the entirety of the world fleet would transition to LNG and currently there was no share of operating LNG containership. However, we need to adjust for the fact that currently it is estimated that approximately 5% of the world fleet is composed by LNG vessels (see *Strategy 1* and Section 3.6.1) as well as for the fact that in *Strategy 2* only 50% of the world containership fleet is propelled by LNG. Henceforth, we adjust to include these two considerations as follows:

$[7.94\% \times (1 - 5\%)] \times 50\% = 3.74\%$ cost impact of CAPEX on total vessel costs (adjusted)

Equation 33

Results for the calculated variations in total vessel costs arising from the impact of both ETS and shipowners' decision-making on OPEX and CAPEX are summarised in **Table 17**.

	Voyage type	% Impact of final OPEX on total vessel costs	% Impact of final CAPEX on total vessel costs	Total final % impact on total vessel costs
EU ETS (*Scenario 1*)	*Intra-European (100% ETS price)*	11.11%	3.74%	**14.85%**
	To/from Europe (50% ETS price)	7.17%	3.74%	**10.91%**
	Extra-European	3.24%	3.74%	**6.98%**
Global ETS (*Scenario 2*)	*Any*	9.14%	3.74%	**12.88%**

Table 17. *Strategy 2: variations in total vessel costs arising from variations in OPEX and CAPEX combined. Author's own compilation.*

Adding these results in the freight costs (i.e., transportation costs) variable in Anderson's and Wincoop's (2004) equation and adjusting to exclude tariff costs from TCE (see **Equation 18**), we estimated and calculated the variation of NTMs expressed as TCE for the implementation of the ETS for *Strategy 2.* Once again, we provide the example of the USA exporting to TEUMME[24] for *Scenario 1* and *Strategy 2*:

$$[1.44 - (1.018 - 1)] \times 1.55 \times \{[0.21 \times (1 + 0.1091)] + 1\} = 2.7175$$

Equation 34

Note that we adjusted freight costs for an increase in TCE of 0.0505 (or 5.05%)[25] as USA-to-TEUMME is an international voyage *to Europe* considered under *Scenario 1* (see **Table 17**). All final NTMs TCE can be found in **Appendix 5**.

Strategy 3: 100% use of green Ammonia

Strategy 3 represents a scenario in which green fuel technology has evolved to such an extent in which shipowners mitigate the effects of global warming by investing in green ammonia powered containerships. Therefore, in *Strategy 3* half of the global container fleet runs on green ammonia – hence on clean CO2-equivalent neutral fuel – and the other half on LNG. The ETS is here considered a main driver for transitioning to green ammonia. To be more precise, while the ETS does not directly affect ownership costs *per se* with regards to green ammonia, the shift toward clean fuel significantly impacts both OPEX and CAPEX. For what it concerns LNG, we use the same approach adopted in *Strategy 2*. In *Strategy 3* we have three distinct however interrelated effects that we encountered in *Strategy 2*:

OPEX:

a) *a shock arising from the cost impact of ETS on fuel expenses*

b) *a variation of bunker price arising from the new fuel mix as compared to the current one (i.e., Strategy 1)*

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[24] Top EU Mediterranen Economies.

[25] Initial NTMs – Final NTMs (i.e., 2.7175 – 2.6670 = 5.05%.

CAPEX:

c) an increase in capital expenses due to the costs incurred by shipowners to buy green ammonia-powered vessels

a) Cost impact of ETS on fuel expenses (OPEX)

Once more we estimate the change in OPEX starting by calculating the (weighted) average CO2-emissions equivalent per ton of fuel consumed for the fuel mix of *Strategy 3*. Results are summarised in **Table 18** and **Equation 35** clarifies the calculations.

Fuel type	% Share	Tons of CO2-emissions equivalent[26] per ton of fuel consumed	Tons of CO2-emissions equivalent[27] per ton of fuel consumed weighted as a % share of fuel type
Green ammonia	50%	0	0
LNG	50%	2.794	1.397
Weighted Average	100%		**1.397**

Table 18. *Strategy 3: Summary of CO2-emissions eq. for each fuel type and weighted average. Source: Comer and Osipova (2021).*

$$(0.000 \times 50\%) + (2.794 \times 50\%) = 1.397 \text{ tons of CO2-emissions eq. per ton of fuel consumed}$$

Equation 35

We then derived the cost impact of the ETS on fuel expenses for *Strategy 3* in both scenarios by multiplying the expected cost of the ETS per ton CO2-emission equivalent for the average tons of CO2-emission eq. per ton of fuel consumed (i.e., **Equation 35**). **Table 19** reports examples for all categories of voyages examined:

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[26] Tank-to-wake.

[27] Tank-to-wake.

	Voyage type	Average CO2-em. eq. per ton of fuel consumed	ETS price (€) per ton of CO2-em. Eq. [28]	ETS cost impact (€)
EU ETS (*Scenario 1*)	*Intra-European (100% ETS price)*	1.397	67.00	**93.60**
	To/from Europe (50% ETS price)	1.397	33.50	**46.80**
	Extra-European	1.397	0	**0**
Global ETS (*Scenario 2*)	*Any*	1.397	50.25	**70.12**

Table 19. *Strategy 3: Extra fuel cost per ton after EU ETS and global ETS implementation. Author's own compilation.*

Therefore, we estimate that the EU ETS implementation results in a €93.60 and €46.80 increase in extra fuel costs per ton of fuel consumed for *intra-European* and *to/from Europe* voyages respectively in *Scenario 1;* and that the introduction of a global ETS (*Scenario 2*) adds €70.12 for each ton of fuel consumed.

b) Bunker price differential arising from the new fuel mix adopted (OPEX)

We now calculated the percentage differential between the initial average fuel cost per ton in *Strategy 1* (current mix) and the new fuel expense per ton under *Strategy 3*. Hence, we collected and estimated the price per ton of green ammonia to calculate the average fuel cost for this strategy (see **Table 20**).

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[28] Based on Faber et al. (2022).

Fuel type	**% Share**	**Fuel price[29] (€/ton)**	**Fuel price (€/ton) weighted as a % share of fuel type**
Green ammonia	50%	1347.17	673.59
LNG	50%	353.00	176.50
Weighted Average (*Strategy 3*)	100%		**850.09**
Weighted Average (*Strategy 2*)	100%		**773.60**
Weighted Average (*Strategy 1*)	100%		**683.27**

Table 20. *Strategy 3: Summary of fuel price for each fuel type and weighted average compared to Strategy 1 and 2. Author's own compilation.*

Comparing the weighted average of fuel price for *Strategy 3* with the one for *Strategy 1,* we note that the new fuel mix leads to a significant increase (+24.41%) in average fuel price:

$(1951.09 - 1190.63) \div (1190.63) = 63.87\%$ change in avg. fuel price compared to *Strategy 1*

Equation 36

Since we treat the effect of the ETS as an extra fuel cost, we summed the average ETS cost impact per ton of fuel consumed (see **Table 19**) to the average fuel price for *Strategy 3* (see **Table 20**) for both scenarios and all routes. **Table 21** summarises and compares the results of *Strategy 1, 2, and 3.*

	EU ETS			**Global ETS**
	Intra-European	*To/from Europe*	*Extra-European*	*Any*
Strategy 1	€920.97	€802.12	€683.27	€861.55
Strategy 2	€993.07	€883.33	€773.60	€938.20
Strategy 3	€943.68	€896.88	€850.09	€920.28

Table 21. *Strategy 3: New average fuel price per ton after ETS implementation for both scenarios compared to Strategy 1 and 2. Author's own compilation.*

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[29] At 22/07/2022 for the Port of Rotterdam (Ship & Bunker, 2022).

We can now calculate the percentage variation of OPEX once the ETS has been implemented in both scenarios as compared to the current scenario (i.e., *Scenario 1* before the introduction of the ETS). Recalling that we hold fuel costs to be approximately 70% of OPEX, and OPEX to represents about 35% of vessel total costs, we provide calculation examples for intra-European (**Equation 37**), to/from European (**Equation 38**), extra-European (**Equation 39**) voyages in the case of the EU ETS and for all voyages for the global ETS (**Equation 40**) as we did for *Strategy 1 and 2*:

$$\{[(943.68 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 9.34\% \text{ change in total vessel costs}$$

Equation 37

$$\{[(896.88 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 7.66\% \text{ change in total vessel costs}$$

Equation 38

$$\{[(850.09 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 5.98\% \text{ change in total vessel costs}$$

Equation 39

$$\{[(920.28 - 683.27) \div 683.27] \times 70\%\} \times 35\% = 8.50\% \text{ change in total vessel costs}$$

Equation 40

c) *Impact of Strategy 3 on CAPEX*

As it was the case for LNG, retrofitting a vessel for green ammonia use bears significant capital expenses. While we estimated that on a 10-year payback cycle it would cost an average of €1.65 million in CAPEX a year for transitioning to LNG, considering the same payback cycle in the case of ammonia we calculated an average annual fixed cost of €2.2 million (Bockmann, 2022). We hence took the average yearly CAPEX between the two types of transition. Again, because we take total average cost of a typical 68.000 Dwt vessel to be €8.1 million, CAPEX to represents 39% of a vessel's total costs, and we consider that already 5.9% of the world container fleet is characterised by LNG vessels, we calculate average yearly CAPEX for *Strategy 3* as follows:

$\{[(2.2 \div 8.1) + (1.65 \div 8.1) \times 94.1\%] \div 2\} \times 39\% = 9.03\%$ cost impact of CAPEX on total vessel costs

Equation 41

Results for the calculated variations in total vessel costs arising from OPEX and CAPEX as a result of *Strategy 3* are summarised in **Table 22**.

	Voyage type	% Impact of final OPEX on total vessel costs	% Impact of final CAPEX on total vessel costs	Total final % impact on total vessel costs
EU ETS (*Scenario 1*)	*Intra-European (100% ETS price)*	9.34%	9.03%	**18.37%**
	To/from Europe (50% ETS price)	7.66%	9.03%	**16.69%**
	Extra-European	5.98%	9.03%	**15.01%**
Global ETS (*Scenario 2*)	*Any*	8.50%	9.03%	**17.53%**

Table 22. *Strategy 3: variations in total vessel costs arising from variations in OPEX and CAPEX combined. Author's own compilation.*

Adding these results in the freight costs (i.e., transportation costs) variable in Anderson's and Wincoop's (2004) equation and adjusting to exclude tariff costs from TCE (see **Equation 18**), we estimated and calculated the variation of NTMs expressed as TCE for the implementation of the ETS for *Strategy 3*. Once again, we provide the example of the USA exporting to TEUMME[30] for *Scenario 1* and *Strategy 3*:

$$[1.44 - (1.018 - 1)] \times 1.55 \times \{[0.21 \times (1 + 0.1669)] + 1\} = 2.7442$$

Equation 42

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[30] Top EU Mediterranen Economies.

Note that we adjusted freight costs for an increase of 0.0773 (or 7.73%)[31] in TCE as USA-to-TEUMME is an international voyage *to Europe* considered under *Scenario 1* (see **Table 18**). All final NTMs TCE can be found in **Appendix 5**.

5.4.7 Supply and demand elasticities of the container segment

Demand and supply elasticities are economic concepts that indicates the degree to which demand and supply change as a result of the variation of a commodity price. For instance, if as a consequence of a significant change in price we observe an insignificant, or relatively small, variation in demand and/or supply, we can term this an inelastic good; whereas, if a small variation in price is followed by a significant change in demand and/or supply, we are dealing with an elastic commodity. In economics, whenever we refer to a good as inelastic, this corresponds to a small number (typically in the range between |0| and |1|), while the elasticity value of a so-called *elastic* commodity normally translates into a number greater than |1|. The elastic or inelastic characteristic of a commodity is dependent on several factors, among which its destined use, necessity, availability, socio-political and/or geographical barriers, legislation, logistics and many others.

The econometric model deployed in this research paper (i.e., GSIM model) considers supply, demand, and substitution elasticities of commodities – or group of commodities – to calculate variations in trade and economic dynamics after a shock has been modelled starting from the base scenario. Therefore, to address the research question of the thesis we should take into account the demand and supply elasticity of the shipping segment – or group of commodities – under examination, that is, containerised goods. Estimating the elasticities of containerised goods is particularly difficult as the category is very diversified and includes both elastic and inelastic commodities. For this reason, it is reasonable to consider the goods transported on container vessels to reflect the combined elasticities of international trade more generally. This is also the case since small volumes of both dry and liquid bulk are also transported on containerships. Thus, the elasticities of the container segment were estimated from an international trade standpoint following Berden's (2015) and Francois' (2003) considerations. For a complete overview of the estimated elasticities see **Appendix 6**.

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[31] Initial NTMs – Final NTMs (i.e., 2.7442 – 2.6670 = 7.73%.

5.4.8 Substitution elasticities

For what it concerns substitution elasticity, in this case its value needs to be estimated to encompass not only the substitution elasticity of containerised goods but also the degree of substitution between the different modes of transport considered. This way, the model will be used to determine variations in the transport mix after the shock has been modelled for the various scenarios as well. This is key in order to be able to measure the percentage variation of CO2 emissions equivalent as compared to the initial (or base) scenario, and thus answer the research question. We estimated substation elasticity combining substitution elasticity from a global perspective – as per Francois (2003), Berden (2015), and Sathe (2019) – with estimations regarding the degree of substitution elasticity between modes of freight transports based on extensive literature review on modal split (ITF, 2022) – see **Appendix 6**.

5.5 Sensitivity analysis

Sensitivity analysis consists of stress testing the model by altering one or more variables to assess the consistency of the economic model used. The sensitivity study involved altering substitution elasticity for all strategies and scenarios. We chose to alter substitution elasticity as this is the only economic variable that was estimated precisely for this study and thus considered the most critical. Two tests were carried out for all simulations. The first included running the model with substitution elasticity increased by 25%, while the second evaluated the model with the same variable reduced by 25%. We then compared results obtained in terms of net welfare effect and average variation in trade values with the original results obtained utilising the primary elasticity of the research. For all tests, we found no significant variation (<0.0001%). As a result, we can confidently infer that the model is consistent and that the modelled inputs for the simulations are accurate and work properly. Results from sensitivity analysis can be found in **Appendix 10** to **15**.

5.6 Chapter summary

Chapter 5 treated the methodology adopted in the present thesis. To motivate the rationale behind the choice of the PE model for this research paper, in Section 5.1 we described and compared three econometric models – Gravity, General Equilibrium (GE), and Partial Equilibrium (PE) models – with particular attention to the differences of application between the GE and PE model. Section 5.2 was devoted to the explanation of the theoretical functioning of the GSIM model together with its main assumptions, strengths, and limitations. In Section 5.3, we dived into the mathematical formalisation and calculations at the foundation of the GSIM model following Francois' and Hall's (2002) framework. Finally, In Sections 5.4 and 5.5, we explained in detail the inputs requirement of the GSIM model, with their associate collection and estimation methods, as well as the estimation methods adopted for tackling and answering the main research question. the following chapter, results for all simulation run using the GSIM model are presented and analysed in order to ultimately assess the ***economic, trade, transport and carbon emission impact of the introduction of and EU carbon border tax on container shipping in different scenarios***.

Chapter 6 – Results and Analysis

In this chapter, we present the empirical results from the research and provide an analysis of the main outputs to answer the main research question. More precisely, we will analyse and compare the changes in economic, trade, transport, and CO2-emission equivalent parameters resulting from the simulation of each strategy and scenario.

6.1 Welfare effects

Total welfare impacts assess the entire economic impact of the policy shock. It is calculated as the sum of the changes in consumer surplus, producer surplus and tariff revenue. In this section, we present our findings in terms of changes in total welfare effects after the introduction of the ETS both at a European (*Scenario 1*) and global level (*Scenario 2*) for each *Strategy*.

6.1.1 Welfare effects for Strategy 1

By simulating the introduction of the ETS for *Strategy 1* both at a European and global level we found an overall decrease in terms of net welfare effects, respectively -€10.2bn and -€28.5bn. From an international economic perspective, we estimate that the introduction of a global ETS would negatively affect the global economy three times more than implementing the policy at a European level. We also observed that while the EU ETS will negatively impact European countries the most, the introduction of the global ETS would conversely result in a higher loss for extra-EU countries and in particular for TAME. This is consistent with Mohindru's and Li's (2021) expectations about the marked decrease of consumer surplus in the Eurozone.

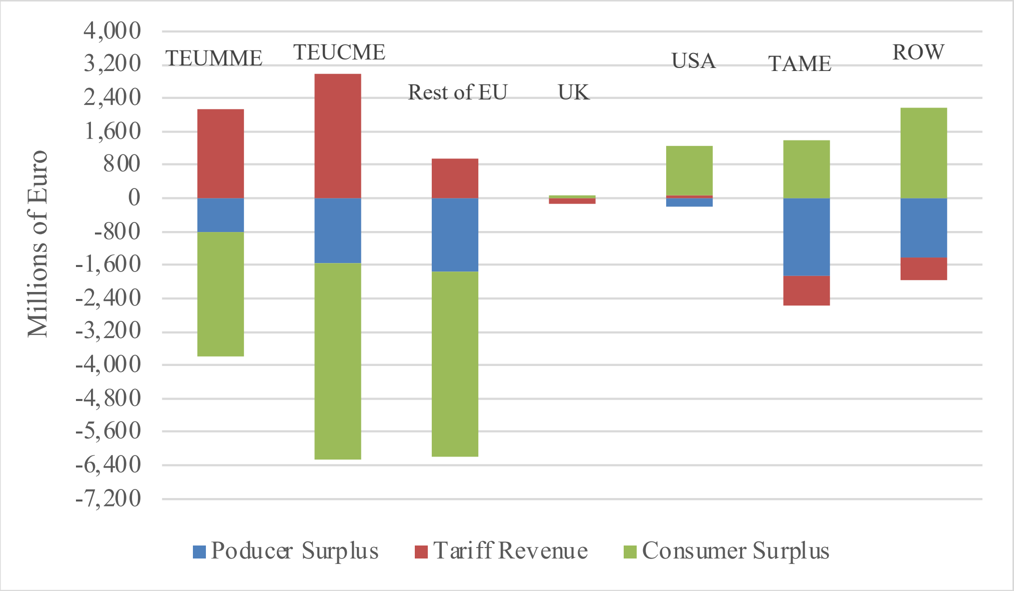

Figure 9. *Strategy 1; Scenario 1 (EU ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

In the case of *Scenario 1* (see **Figure 9**), although European countries experience a sharp increase in tariff revenue thanks to the application of the EU ETS (+€6.1bn combined), they nevertheless register the highest decrease in net welfare (-€10.2bn) and particular of consumer surplus (-€12.2bn) precisely because of decreasing seaborne trade resulting from the ETS introduction. This is consistent with expectations, since the estimated increase in freight costs resulting from the implementation of the EU ETS will negatively impact EU countries the most. In particular, while Rest of EU registers the most significant impact in terms of net welfare effects (-€5.2bn), followed by a loss of €3.3bn for TEUCME and a €1.7bn decrease for TEUMME, TEUCME is associated with the highest absolute loss of consumer surplus (-€4.7bn). By contrast, all other countries except for the UK show an increase in consumer surplus because of the policy shock. Unsurprisingly, extra-EU regions are associated with a decrease in tariff revenue because comparatively to the Eurozone they are only mildly affected by the EU ETS (only 50% on voyages to and from EU). Moreover, we found that USA and ROW are both positively impacted registering an overall increase in net welfare effects of €1.1bn and €0.2bn respectively. The highest loss in producer surplus is showed by TAME (-€1.8bn) and Rest of EU (-€1.7bn).

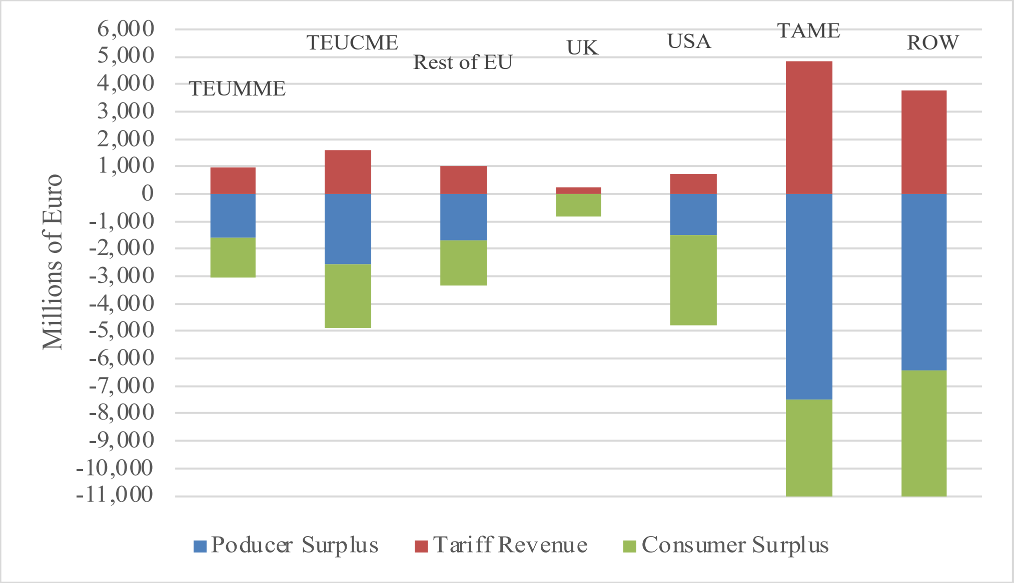

Figure 10. *Strategy 1; Scenario 2 (Global ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

As illustrated by **Figure 10**, once the policy is globally applied (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, results show a marked shift toward extra-EU countries compared to *Scenario 1* with regards to the loss of net welfare and consumer surplus. In fact, we found ROW, TAME, and the USA to experience the highest absolute decrease in net welfare effects and consumer surplus registering a loss of total net welfare of €9.7bn, €6.5bn, and €4.1bn respectively. This is followed by TEUCME (-€3.3bn), Rest of EU (-€2.3bn), and TEUMME (-€2.0bn). While in this case ROW (-€6.4bn) and TAME (-€7.5bn) are associated also with the most significant loss in producer surplus, EU countries combined experience a much higher negative impact (-€5.9bn) in terms of producer surplus when compared to the USA (-€1.5bn). Interestingly, in this case we found an increase in tariff revenue for all regions (+€13.2bn in total), with the Eurozone registering +€3.6bn and extra-EU countries +€9.6bn when combined. This is consistent with the fact that the ETS has been implemented globally for *Scenario 2.*

6.1.2 Welfare effects for Strategy 2

Simulating the introduction of the ETS for *Strategy 2* both at a European and global level we found an overall decrease in terms of net welfare effects, respectively -€55.1bn and -€57.5bn which represent a 440% and 101% decrease compared to the same scenarios simulated under *Strategy 1.* Hence, while under *Strategy 1* the difference between the impact of the two scenarios was almost 300%, for *Strategy 2* the gap between the scenarios has comparatively reduced to a difference of only 4.6%. Therefore, we conclude that from an international perspective the introduction of a either a global or EU ETS under *Scenario 2* would not make a significantly different impact in terms of welfare effects.

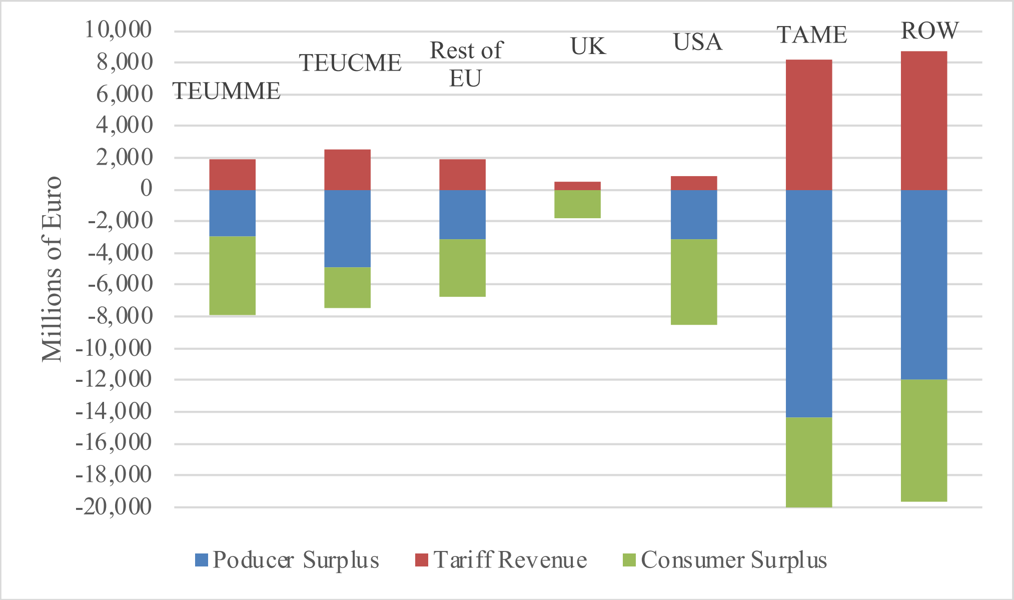

Figure 11. *Strategy 2; Scenario 1 (EU ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

In the case of *Scenario 1* (see **Figure 11**), TAME experience the highest decrease in net welfare (-€19.4bn) as well as the highest loss in terms of consumer (-€7.7bn) and producer surplus (-€12.0bn) precisely because of decreasing seaborne trade. This contrasts expectations according to which an increase in freight costs resulting from the implementation of the EU ETS will negatively impact EU countries the most. In fact, although TEUCME register a higher decrease of producer surplus compared to the USA, we also observe that ROW (-€10.9bn) and the USA (-€7.7bn) are associated with a higher loss of total net welfare compared to the Eurozone. The only exception is the UK which registers the lowest total net welfare loss (-€1.3bn). We also found that all countries experience an increase in tariff revenue (+€24.7bn in total) despite the ETS is introduced at an EU level. However, this is not counterintuitive considering that, while it is true that extra-EU regions are only mildly affected by the pure ETS shock, they are nevertheless impacted by the increase in NTMs resulting both from the change in fuel mix (i.e., surge in OPEX) and from the partial change in the fleet mix (i.e., surge in CAPEX as a consequence of a higher proportion of LNG vessels in the world container fleet).

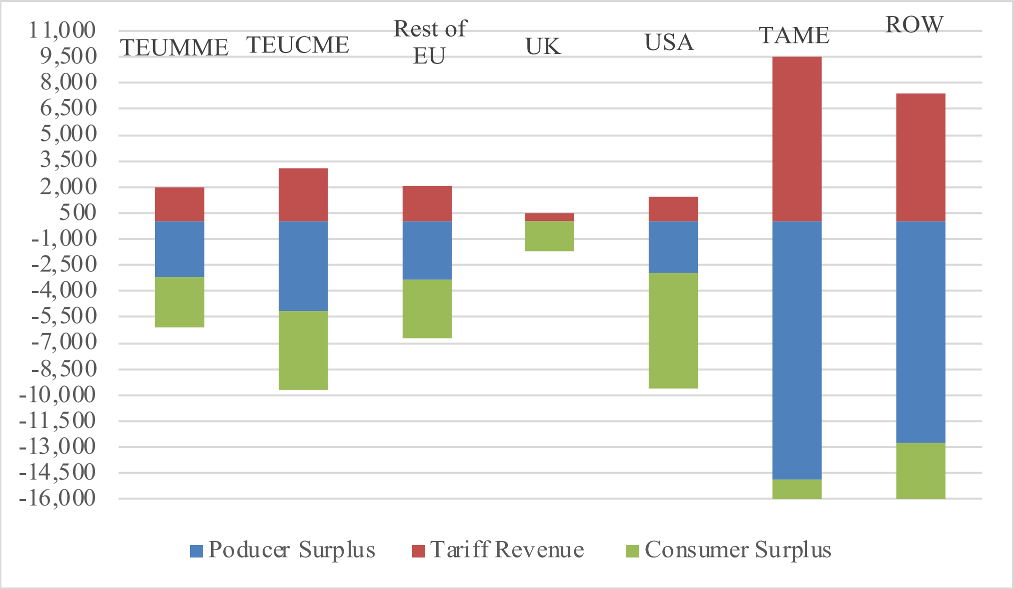

Figure 12. *Strategy 2; Scenario 2 (Global ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

As illustrated by **Figure 12**, once the policy is globally applied (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, the results still show a higher decrease of net welfare on the part of extra-EU countries compared to European ones with the only exception of the UK. In fact, we observe that ROW and TAME experience a decrease in net welfare of -€19.4bn and -€13.2bn respectively. While the USA is estimated to be the third most affected region by net welfare loss (-€8.2bn), it is however less negatively impacted from a producer surplus perspective (-€3.0bn) when compared to the less affected European region represented by TEUMME (-€3.2bn). In particular, in Europe the highest loss in terms of net welfare is registered by TEUCME (-€6.6bn) followed by Rest of EU (-€4.7bn) and TEUMME (-€4.1bn). Again, we found that tariff revenue increases for all regions, with EU registering +7.1bn and other countries +18.8bn. combined This result has multiple explanations: (1) the ETS was introduced at a global level; (2) extra-EU regions are impacted by the increase in NTMs as a result of the change in fuel mix (i.e., surge in OPEX) and the partial change in the fleet mix (i.e., surge in CAPEX as a consequence of a higher proportion of LNG vessels in the world container fleet).

6.1.3 Welfare effects for Strategy 3

By implementing the ETS for *Strategy 3* both at a European and global level we found again an overall decrease in terms of net welfare effects, respectively -€77.2bn and -€78.4bn which represent a 40.1% and 36.3% decrease compared to the same scenarios simulated under *Strategy 2*. This is consistent with the fact that the price-impact gap between *Strategy 2* and *Strategy 3* as a result of the ETS introduction is significantly smaller than the that between *Strategy 1* and *2*.

Moreover, we notice that the gap between the net welfare effects associated with both scenarios in the case of *Strategy 3* has further reduced (1.6%) compared to *Strategy 2* (4.6%). This seems logical considering that the difference between the impact of ETS across both scenarios simulated under *Strategy 3* is less marked. The reason is that the deployment of green Ammonia does not lead to increased OPEX but only to a mild increase in CAPEX. Similarly to *Strategy 2,* we conclude that from an international perspective the introduction of a either a global or EU ETS under *Scenario 3* would not make a significantly different impact in terms of welfare effects.

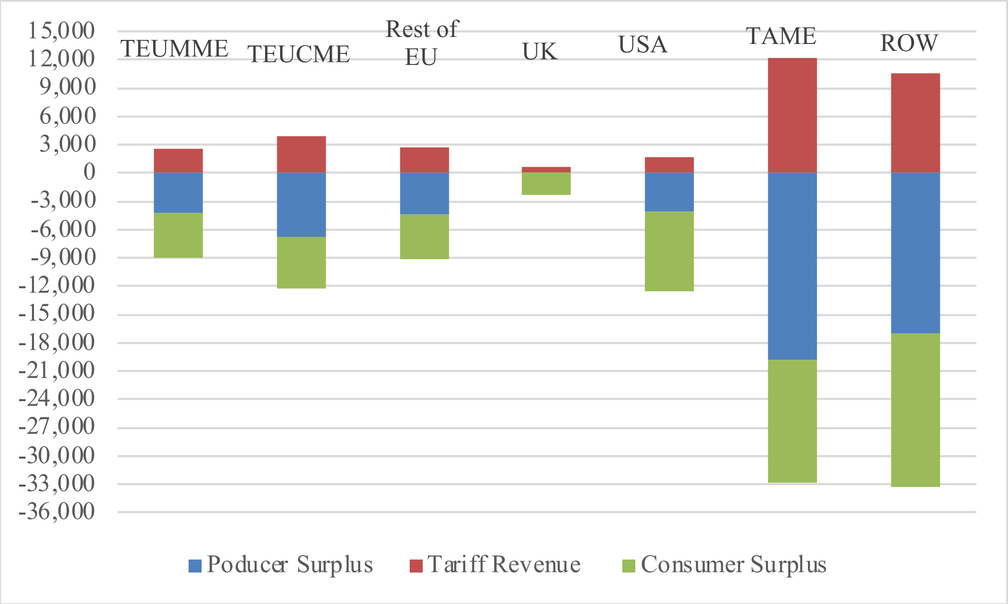

Figure 13. *Strategy 3; Scenario 1 (EU ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

In the case of *Scenario 1* (see **Figure 13**), ROW experiences the highest decrease in net welfare effects (-€22.8bn) as well as the highest loss in terms of consumer surplus (-€16.4bn) followed by TAME (-€20.6bn; -€16.4bn). Again, this contrasts expectations according to which an increase in freight costs resulting from the implementation of the EU ETS will negatively impact EU countries the most. In fact, although all the three European regions considered register a higher decrease of producer surplus compared to the USA, results show that the USA (-€11.0bn) is associated with a higher loss of total net welfare. Again, we found that all countries experience an increase in tariff revenue (+€34.2bn in total) despite the ETS is introduced at an EU level, with a surge of €9.2bn associated with the Eurozone and a combined increase of €25.0bn for other countries. This is consistent with the fact that that extra-EU regions are also impacted by the increase in NTMs resulting both from the change in fuel mix (i.e., surge in OPEX) and from the partial change in the fleet mix (i.e., surge in CAPEX as a consequence of a higher proportion of LNG and Ammonia-powered vessels in the world container fleet).

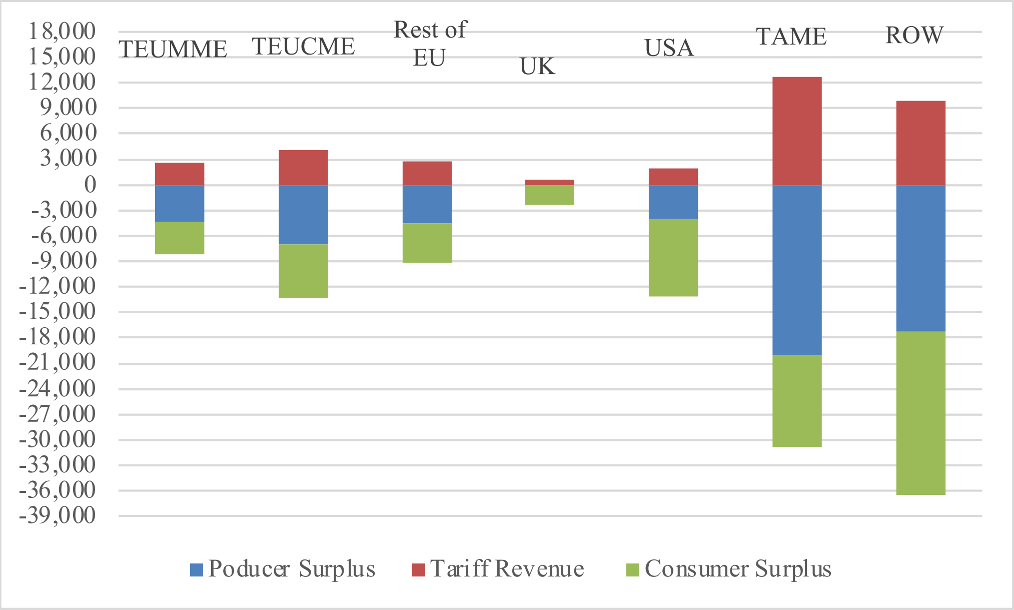

Figure 14. *Strategy 3; Scenario 2 (Global ETS): aggregated and disaggregated Total Net Welfare Effects. Author's own illustration.*

As shown in **Figure 14**, when the policy is globally implemented (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, the results still show a higher decrease of net welfare on the part of extra-EU countries compared to European ones with the only exception of the UK. In fact, we observe that ROW, TAME, and the USA experience a decrease in net welfare of -€26.5bn, -€18.0bn, and -€11.2bn respectively. However, the USA is estimated to be less negatively impacted from a producer surplus perspective (-€4.0bn) when compared to any of the European regions considered. Similarly to the same scenario in *Strategy 2*, the highest loss in terms of net welfare in Europe is registered by TEUCME (-€6.9bn) followed by Rest of EU (-€4.5bn) and TEUMME (-€4.3bn). Once more, we found that tariff revenue increases for all regions (+€34.8bn), with EU registering +9.5bn and other countries +25.3bn. combine. This result has the same multiple explanations as in the case of *Strategy 2 (Scenario 2)*: (1) the ETS was introduced at a global level; (2) extra-EU regions are impacted by the increase in NTMs as a result of the change in fuel mix (i.e., surge in OPEX) and the partial change in the fleet mix (i.e., surge in CAPEX as a consequence of a higher proportion of LNG and Ammonia-powered vessels in the world container fleet).

6.2 Trade impact

In this section, we present our findings in terms of changes in imports and exports of containerised goods resulting from the implementation of the ETS both at a European (*Scenario 1*) and global level (*Scenario 2*) for each *Strategy*.

6.2.1 Trade impact for Strategy 1

By simulating the introduction of the ETS for *Strategy 1* both at a European and global level we found an overall decrease in terms of trade[32], respectively -€31.0bn and -€86.3bn. Therefore, it appears that from an international trade perspective the introduction of a global ETS would negatively affect the global trade almost three times more (-278.4%) than implementing the policy at a European level. Furthermore, for both *Scenario 1* and *Scenario 2* results show miniscule (<0.0001% and 1.1% respectively) thus negligible difference between variations in imports and exports. Interestingly, we only found variations in seaborne trade, meaning that other modes of transport were not subjected to any significant change worth capturing and analysing.

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[32] Imports and exports combined.

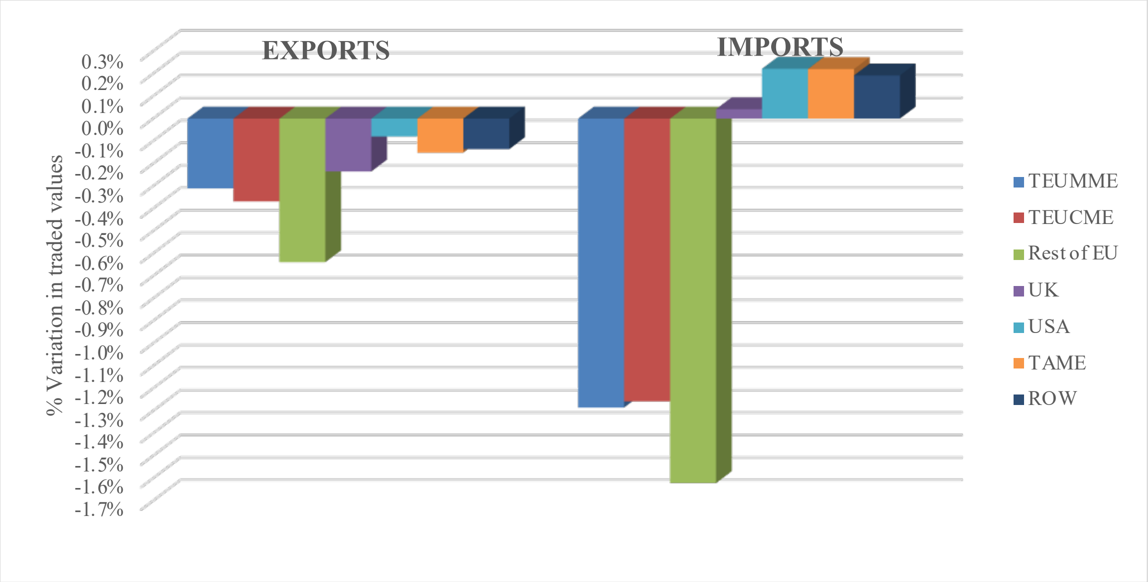

Figure 15. *Strategy 1; Scenario 1 (EU ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

In particular, **Figure 15** illustrates the results from the implementation of the EU ETS (*Scenario 1*). We notice that the Rest of EU is the most negatively impacted region (-0.64% exports; -1.62% imports) followed by TEUCME (-0.37%) in the case of exports and by TEUMME (-1.29%) with regards to imports. In fact, we observe that extra-EU regions are relatively less impacted by the EU ETS and that their imports slightly increase as a result. This is in line with Parry's et al.'s (2018), Marrewijk's et al.'s (2012), and our expectations both about Europe being the most negatively impacted by the EU ETS and regarding the possibility of resulting trade diversion effects. Interestingly, the UK being the closest country to the Eurozone appears to be the experience the highest trade loss in exports (-0.24%) and the smallest gain in exports (+0.04%) compared to other extra-EU regions. We estimate that ROW (+€1.7bn) and the USA (+€2.1bn) are the only countries to register an overall increase in trade.

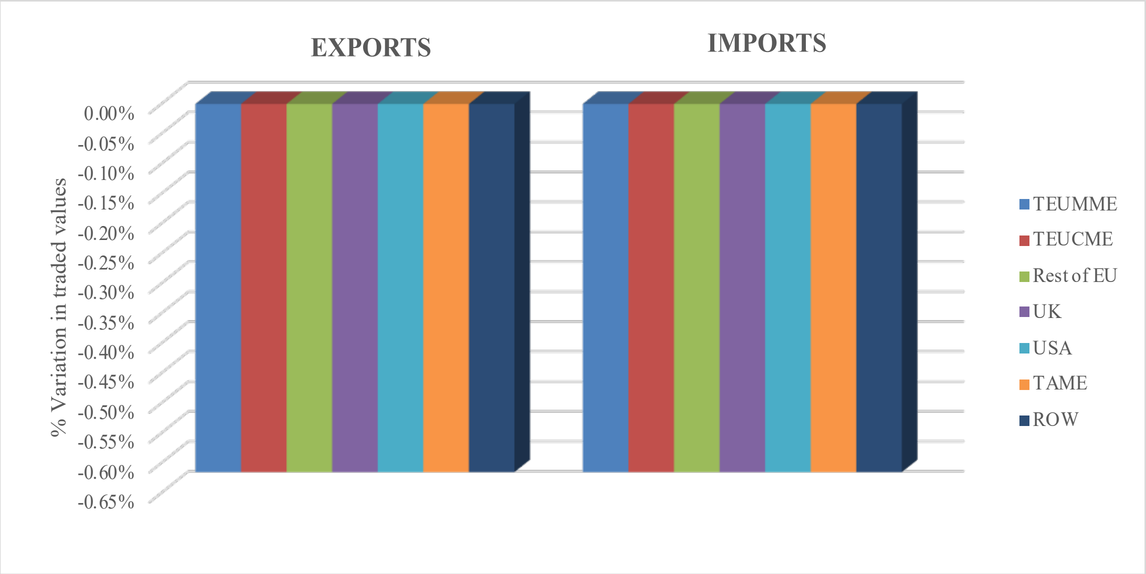

Figure 16. *Strategy 1; Scenario 2 (Global ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

As shown in **Figure 16**, when the policy is globally implemented (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, we find that all countries experience trade loss. However, variation between regions is minimal and thus not particularly significant.

6.2.2 Trade impact for Strategy 2

By simulating the introduction of the ETS for *Strategy 2* both at a European and global level we found an overall decrease in terms of trade[33], respectively -€164.7bn and -€173.3bn which represent a 431.3% and 99.7% decrease compared to the same scenarios simulated under *Strategy 1*. Thus, while under *Strategy 1* the difference between the impact of the two scenarios was almost 280%, for *Strategy 2* the gap between the scenarios has comparatively reduced to a difference of only 5.2%. Therefore, in line with results for net welfare effects we argue that from an international perspective the introduction of a either a global or EU ETS under *Scenario 2* would not make a significantly different impact in terms of traded values. Again, we only found variations in seaborne trade, meaning that other modes of transport were not subjected to any significant change worth capturing and analysing. Furthermore, similarly to *Strategy 1,* for both *Scenario 1* and *Scenario 2* results show miniscule (0.2% and <0.0001% respectively) thus negligible difference between variations in imports and exports.

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[33] Imports and exports combined.

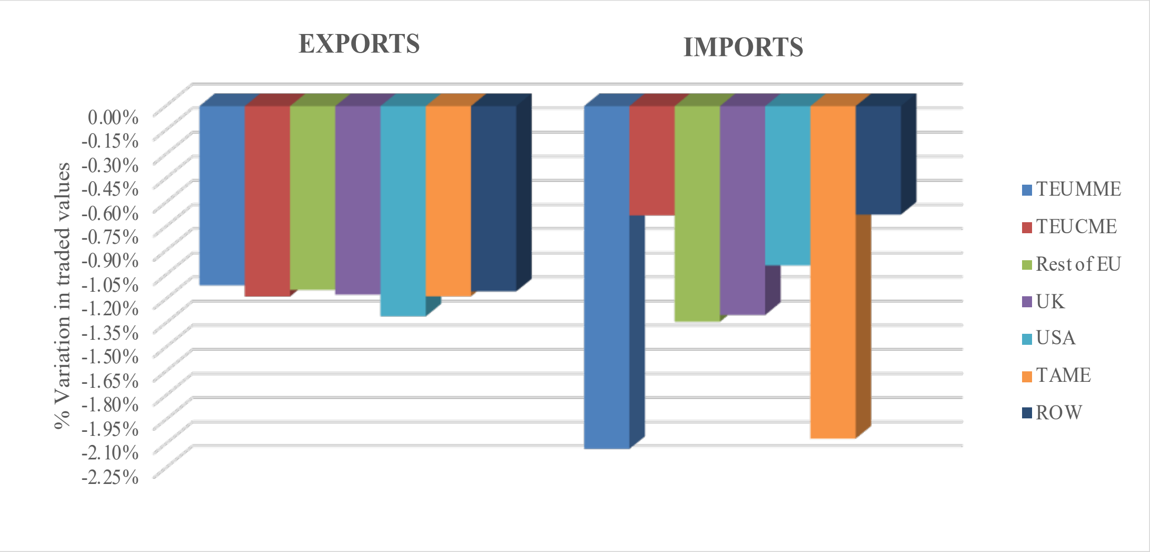

Figure 17. *Strategy 2; Scenario 1 (EU ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

Figure 17 illustrates the results from the implementation of the EU ETS (*Scenario 1*). We notice no significant difference in relative export variation among regions. The largest relative difference in exports observed is between the USA (-1.3%; -€6.3bn) and TEUMME (-1.1%; -€5.9bn). Surprisingly and against expectations, we also found no marked difference in import variation between EU and extra-EU countries. The largest relative loss in imports is suffered by TEUMME and TAME (-2.1%) followed by the Rest of EU and the UK (-1.3%), while TEUCME and ROW registered the smallest relative negative impact (-0.7%).

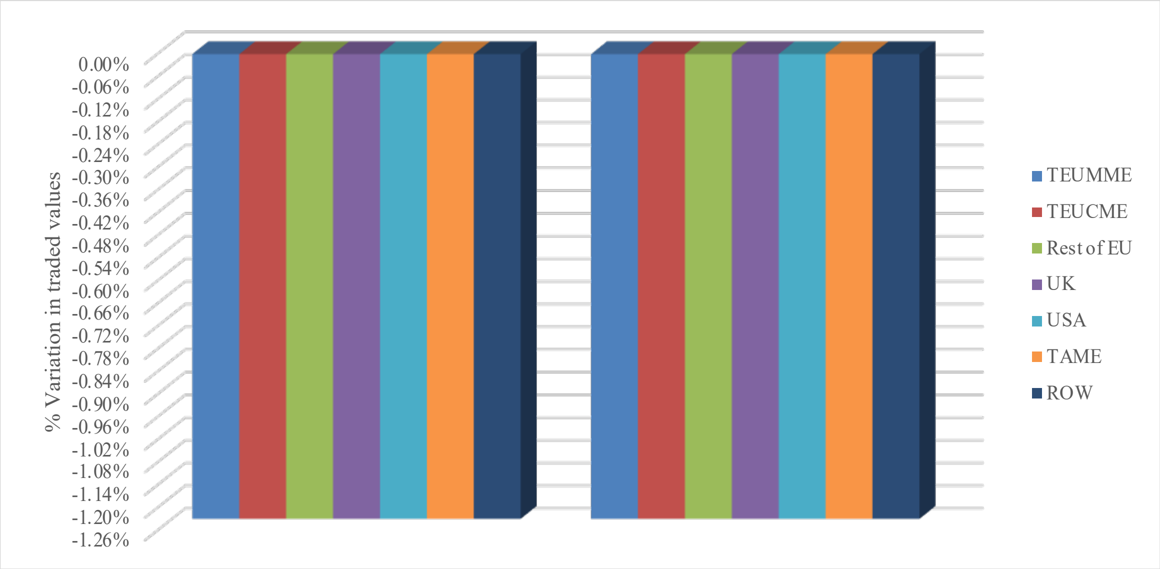

Figure 18. *Strategy 2; Scenario 2 (Global ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

As shown in **Figure 18**, when the policy is globally implemented (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, we find that all countries experience trade loss (-1.2% on average) with only minimal relative difference. The overall relative variation is so small to be considered insignificant.

6.2.3 Trade impact for Strategy 3

Introducing the ETS for *Strategy 3* both at a European and global level we found an overall decrease in terms of trade[34], respectively -€230.0bn and -€233.6bn which represent a 39.6% and 35.0% decrease compared to the same scenarios simulated under *Strategy 2.* Again, this is consistent with the fact that the price-impact gap between *Strategy 2* and *Strategy 3* as a result of the ETS introduction is significantly smaller than the that between *Strategy 1* and *2.*

Moreover, we notice that the gap between trade associated with both scenarios in the case of *Strategy 3* has further reduced (1.6%) compared to *Strategy 2* (5.2%). This seems logical considering that the difference between the impact of ETS across both scenarios simulated under *Strategy 3* is less marked. The reason is that the deployment of green Ammonia does not lead to increased OPEX but only to a mild increase in CAPEX. Similarly to our conclusions for *Strategy 2,* we argue that from an international perspective the introduction of a either a global or EU ETS under *Scenario 3* would not make a significantly different impact in terms of trade impact.

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[34] Imports and exports combined.

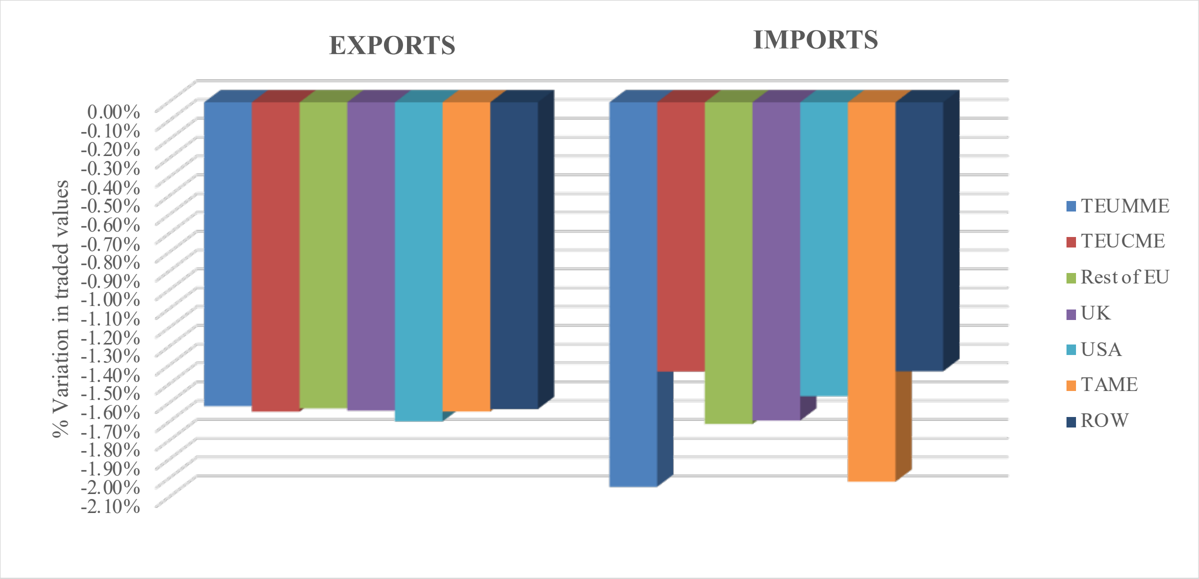

Figure 19. *Strategy 3; Scenario 1 (EU ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

Figure 19 shows the results from the implementation of the EU ETS (*Scenario 1*). We observe no significant difference in relative export variation among regions. Also, we notice proportional changes between regions to resemble outputs for the same scenario under *Strategy 2*. For instance, again the largest relative difference in exports observed is between the USA (-1.7%; -€8.2bn) and TEUMME (-1.6%; -€8.5bn). Surprisingly, we also found no marked difference in import variation between EU and extra-EU countries. The largest relative loss in imports is suffered by TEUMME and TAME (-2.0%) followed by the Rest of EU and the UK (-1.7%), while TEUCME and ROW registered the smallest relative negative impact (-1.4%) which nevertheless has doubled compared to the same scenario associated with *Strategy 2.* We conclude that TEUMME and TAME are the only two regions to be less negatively impacted (-2.0%) when it compares to variations in imports under *Strategy 2* (-2.1%).

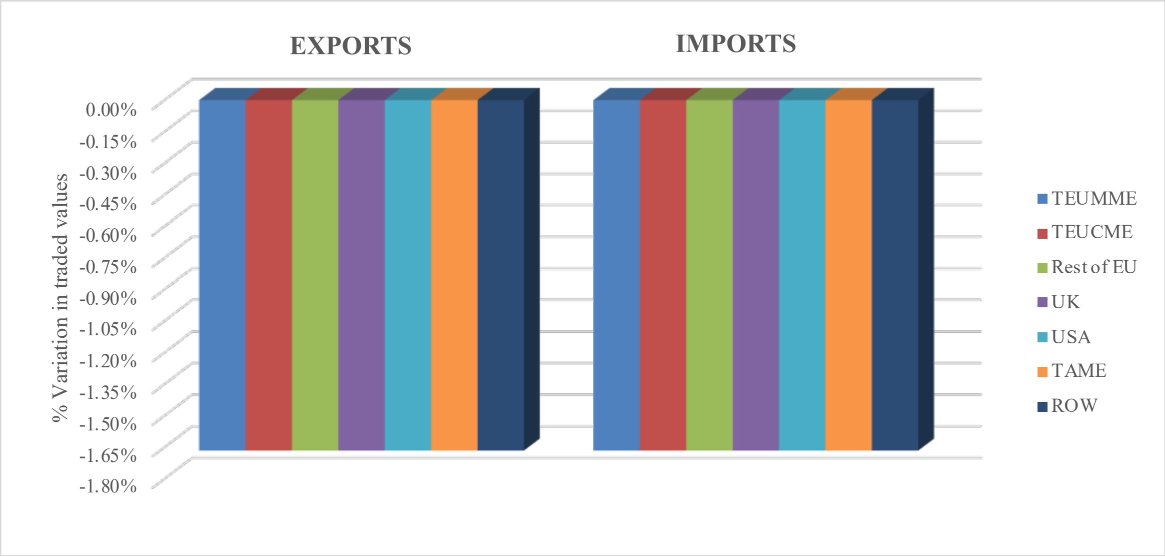

Figure 20. *Strategy 3; Scenario 2 (Global ETS): percentage variation in traded values of containerised goods. Author's own illustration.*

As illustrated in **Figure 20**, when the policy is globally implemented (*Scenario 3*)[35], we find that all countries experience trade loss (-1.7% on average) with only minimal relative difference. The overall relative variation is so small to be considered negligible.

6.3 Logistics and transport impact

In this section, we present our findings in terms of changes in logistics and transport of containerised goods resulting from the implementation of the ETS both at a European (*Scenario 1*) and global level (*Scenario 2*) for each *Strategy*. It is important to understand that since logistics flows are directly estimated from variations in trade figures, the magnitude of changes in logistics and transport dynamics closely match the trade figures analysed in Section 6.2. However, before diving into the results, **Worked Example 1a** together with **Table 23** and **Table 24** illustrate the estimation method deployed for estimating variations in the number of TEUs transported and transport vehicles[36]. Assuming – according to researched literature – that on average a full TEU container carries approximately 13 tonnes[37], and knowing the average number of TEUs carried by each mode of transport (**E**), and the traded volumes between countries (**B**; **I**), it is easy to estimate the container flow between these (**D**; **J**) and thus calculate

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[35] Same price per ton of CO2-emission equivalent across countries.
[36] The data in example is only for illustration purposes regarding the calculation process and does not refer to any specific empirical outcome of the present paper.
[37] Estimation based on Laursen (2015) and Stopford (2009).

the approximate number of vehicles deployed on each route (**F**; **K**). Having information about both initial trade values (**A**) and volumes (**B**) enables also to quickly calculate the volume-value ratio (**C**) for each route and each mode of transport. We can then calculate the new container flow between selected countries (**J**) simply multiplying the new (final) trade values (**H**) by the volume-value ratios (**C**) and dividing the results by 13 (i.e., average tonnes carried per TEU). Now, we can calculate the new approximate number of vehicles deployed on each route after the ETS implementation (**L**) simply dividing the number of TEUs transported (**J**) by the average number of TEUs carried by each mode of transport[38] (**E**).

Worked Example 1a (Container ship trade):

- **Initial traded volumes (B)** = Sourced from Eurostat
- **13** = Sourced from literature
- **Initial Number of TEUs transported (D1)** = B1 / 13 = 3373599 / 13 = 259508 TEUs
- **Initial Number of vehicles deployed (F1)** = D1 / E1 = 259508 / 8000 = 32.4 Container ships
- **Initial total number of TEUs transported by all modes (D6)** = SUM (D1:D5) = 274062 TEUs
- **Initial share per mode (G1**) = D1 / D6 = 259508 / 274062 = 0.9469 = 94.69%
- **Volume/value ratio (C1)** = B1 / A1 = 3373599 / 12744.63 = 264.71 (ton/€)
- **Final traded values (H)** = Generated by the GSIM output
- **Final traded volumes (I1)** = H1 * C1 = 12744.63 * 264.71 = 3036268 tons
- **Final number of TEUs transported (J1)** = I1 / 13 = 3036268 / 13 = 233559 TEUs
- **Final number of vehicles deployed (K1)** = J1 / E1 = 233559 / 8000 = 29.2 Container ships
- **Variation in number of vehicles deployed** = F1 – K1 = 19.5 – 32.4 = -12.9 Container ships

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[38] Based on literature – e.g., Nagurney (2021); Murray (2021); Shintani et al. (2020); Intermodal Group (2022); Container FAQs (2021); Nice (2021).

		A	B	C	D	E	F	G
	Pre-ETS	**Initial traded values (millions of €)**	**Initial traded volumes (tons)**	**Volume/ value ratio (ton/€)**	**Number of TEUs transported**	**Average transport capacity (n of TEUs)**	**Number of vehicles deployed**	**Initial % share per mode (TEUs transported)**
1	**Cont. ship**	12744.63	3373599	264.71	259508	12000	32.4	94.69%
2	**Rail**	1.49	1678	1126.17	129	90	1.6	0.05%
3	**Truck**	866.99	97409	112.35	7493	1.2	6244.2	2.73%
4	**Barge**	27.80	51395	1848.74	3953	150	22.0	1.44%
5	**Plane**	16779.83	38733	2.31	2979	8	372.4	1.09%
6	**Total**	30420.74	3562814	//	274062	//	6672.6	100%

Table 23. *Summary of (pre-ETS) data requirements for calculating the logistics and transport impact of the ETS implementation. Compiled by the author.*

		H	I	J	K
	Post-ETS	**Final traded values (millions of €)**	**Final traded volumes (tons)**	**Number of TEUs transported**	**Number of vehicles deployed**
1	**Cont. ship**	12744.63	3036268	233559	19.5
2	**Rail**	1.49	1762	136	1.5
3	**Truck**	866.99	116888	8991	7492.5
4	**Barge**	27.80	54993	4230	28.2
5	**Plane**	16779.83	41087	3161	395.1
6	**Total**	30420.74	3250997	250077	7936.0

Table 24. *Summary of (post-ETS) data requirements for calculating the logistics and transport impact of the ETS implementation. Compiled by the author.*

6.3.1 Logistics and transport impact for Strategy 1

Simulating the implementation of the ETS for *Strategy 1* both at a European and global level, we found an overall decrease in terms of TEUs traffic, respectively -957,270 TEUs and -2.1 million TEUs which translates into -80 and -179 container ships' visits considering an average capacity of 12,000 TEUs. Therefore, it appears that from an international trade perspective the introduction of a global ETS would negatively affect global trade over two times more (219.4%) than implementing the policy at a European level. Nevertheless, the impact can still be considered quite insignificant at a global level. Interestingly, in contrast to Parry et al., 2018; Marrewijk et al., 2012, we only found variations in seaborne trade, meaning that other modes of transport were not subjected to any significant change worth capturing and analysing.

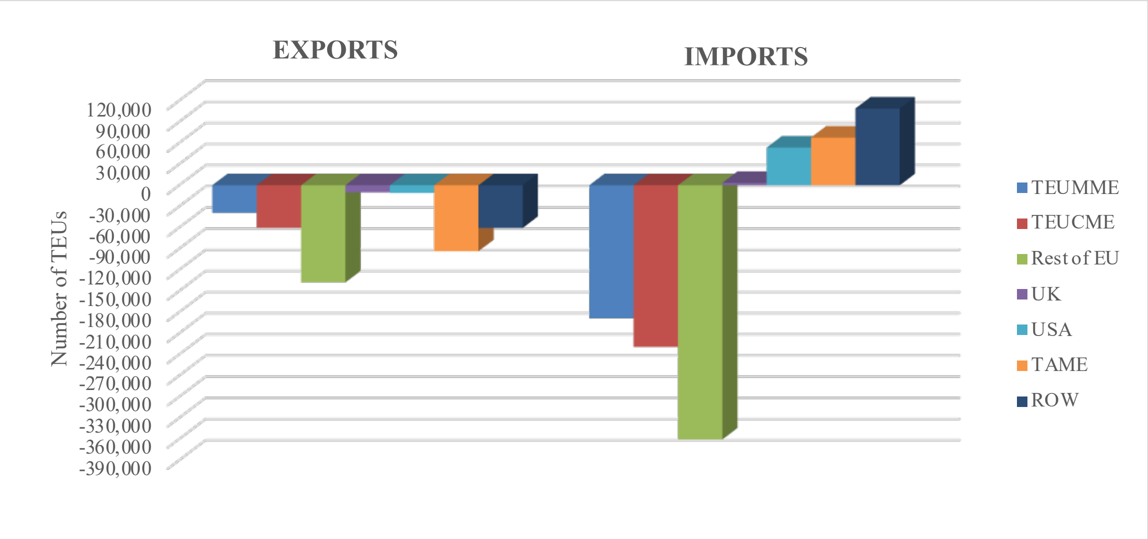

Figure 21. *Strategy 1; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

In particular, **Figure 21** illustrates the results from the implementation of the EU ETS (*Scenario 1*). We notice that the Rest of EU is the most negatively impacted region also in absolute terms (-137,683 TEUs exports; -360,442 TEUs imports) followed by TEUCME (-229,254 TEUs) in the case of imports and by TEUMME (-93,625 TEUs) with regards to exports. At a general level, we observe that extra-EU regions are less negatively impacted by the EU ETS and even that their imports slightly increase as a result. This is in line with Parry's et al.'s (2018), Marrewijk's et al.'s (2012), and our expectations both about Europe being the most negatively impacted by the EU ETS and regarding the possibility of resulting trade diversion effects. It is also consistent with results from Faber et al. (2022) that indicates how the implementation of the EU ETS for shipping could negatively impact the throughput of European container terminals. We estimate that ROW (+48,437 TEUs) and the USA (+42,555 TEUs) are the only regions to register an overall increase in TEUs transported.

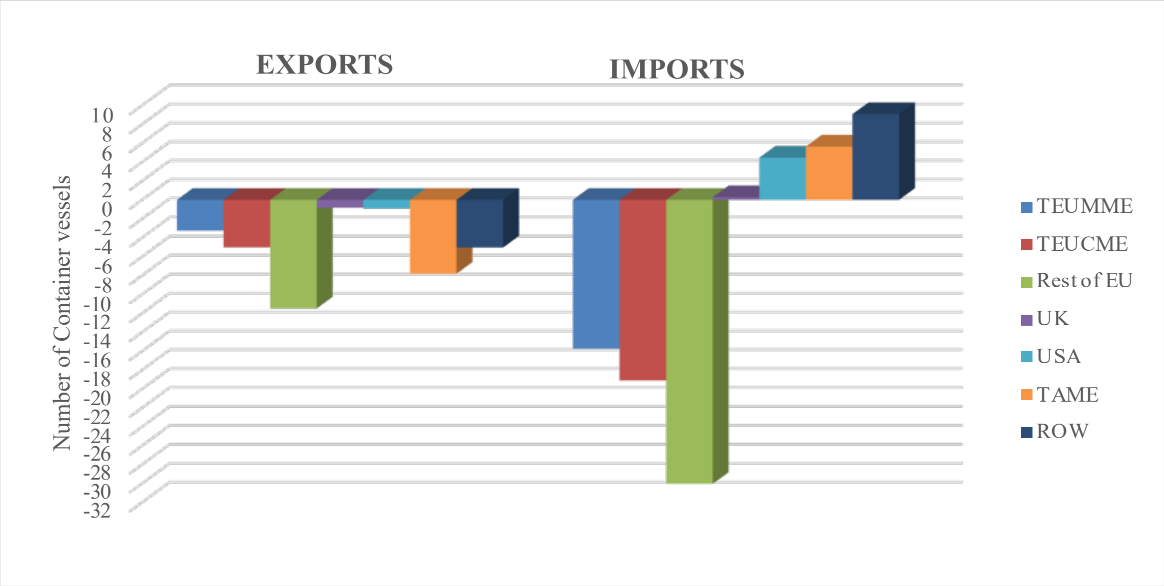

Figure 22. *Strategy 1; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

Results about changes in the number of container ships illustrated by **Figure 22** closely mirror the same dynamics of **Figure 21** since they have been directly worked out starting from those data. In fact, also in this case Rest of EU (-12 container ships) and TAME (-8 container ships) suffer the greatest loss in terms of container ships export flow. Again, ROW (+4 container ships) and the USA (+4 container ships) are the only regions to register an overall increase in TEUs transported.

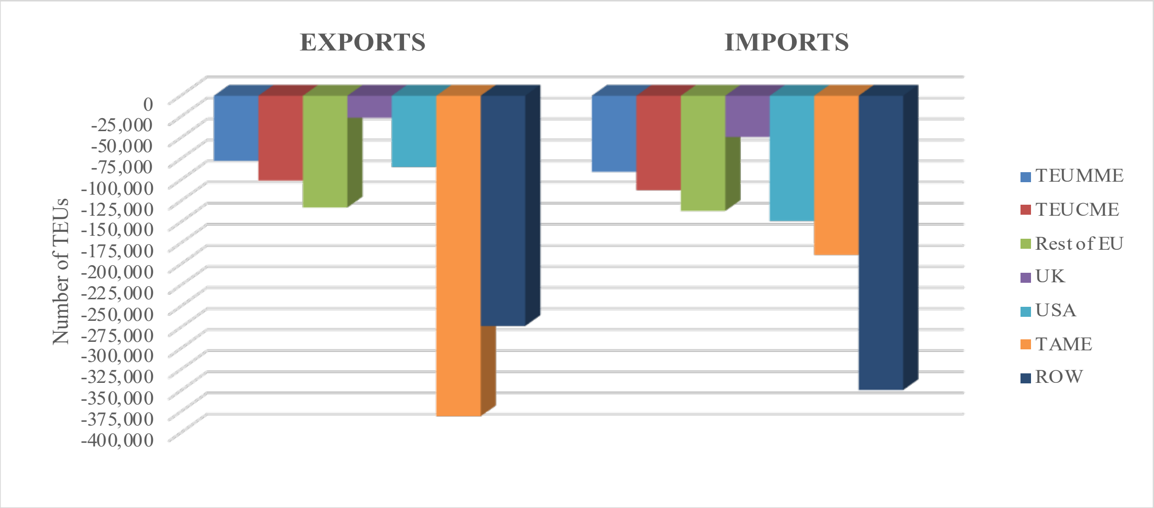

Figure 23. *Strategy 1; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

As illustrated by **Figure 23**, once the policy is globally applied (*Scenario 2*) with the same price per ton of CO2-emission equivalent across countries, the results show a marked shift toward extra-EU countries compared to *Scenario 1* with regards to the loss of TEUs transported. In fact, we found ROW and TAME to experience the highest absolute decrease registering -622,539 TEUs and -569,200 TEUs respectively when considering imports and exports combined. This translates into approximately -51.9 and -47.4 container vessels' visits a year (see **Figure 24**). This is followed by Rest of EU (-269,389 TEUs; -22.4 container ships), the USA (-233,312 TEUs; -19.4 container ships) and TEUCME (-212,824 TEUs; -17.7 container ships).

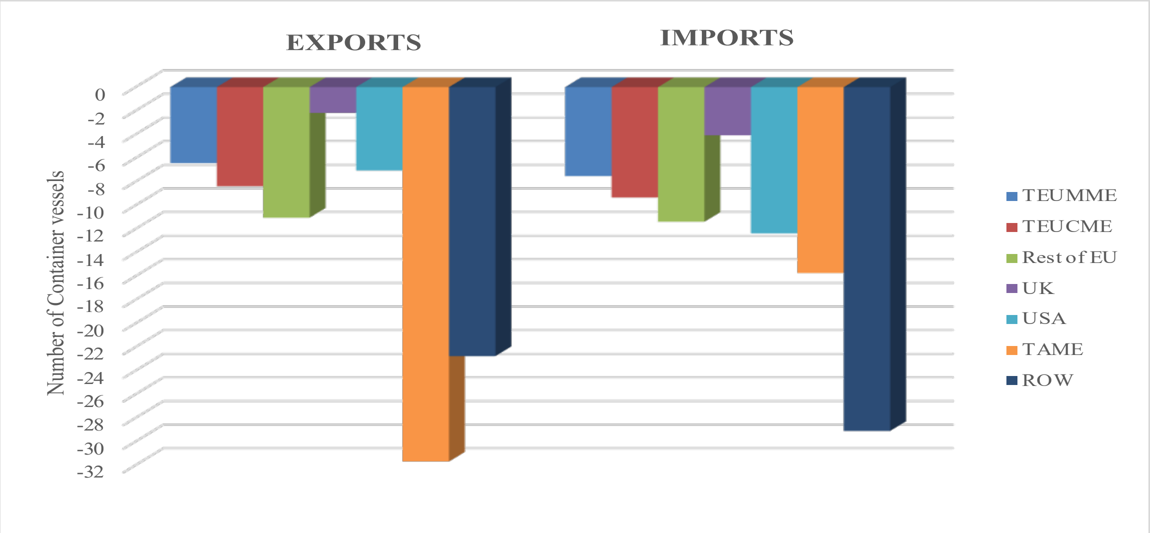

Figure 24. *Strategy 1; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

6.3.2 Logistics and transport impact for Strategy 2

By simulating the introduction of the ETS for *Strategy 2* both at a European and global level we found an overall decrease of TEUs traffic, respectively -4.2 TEUs and -4.3 million TEUs which translates into -346 and -358 container ships' visits considering an average capacity of 12,000 TEUs. This represents a 332.5% and 10.0% decrease in container ships' visits and a 337.5% and 104.8% decrease in terms of TEUs traffic compared to the same scenarios simulated under *Strategy 1.* Thus, while under *Strategy 1* the difference between the impact of the two scenarios was 219.4% in terms of TEUs traffic and 124.0% with regards to container ships' visits, for *Strategy 2* the gap between the scenarios has comparatively reduced to a difference of only 2.4% and 3.5% respectively. Therefore, in line with results for net welfare effects and trade values, we argue that from an international perspective the introduction of a either a global or EU ETS under *Scenario 2* would not make a significantly different impact in terms of traded values. Moreover, the impact can still be considered quite insignificant at a global level.

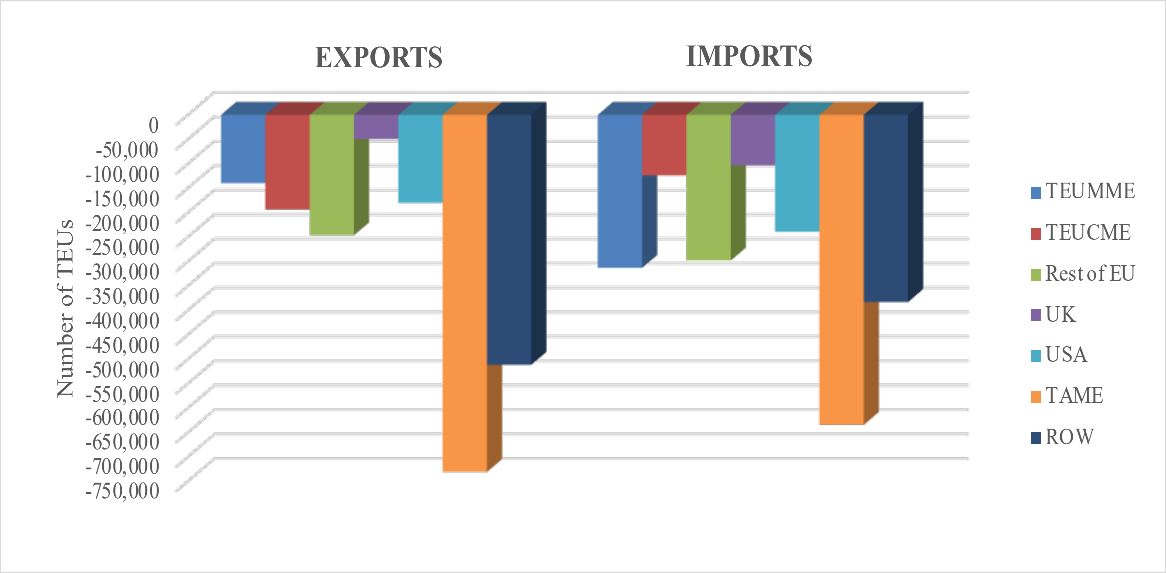

Figure 25. *Strategy 2; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

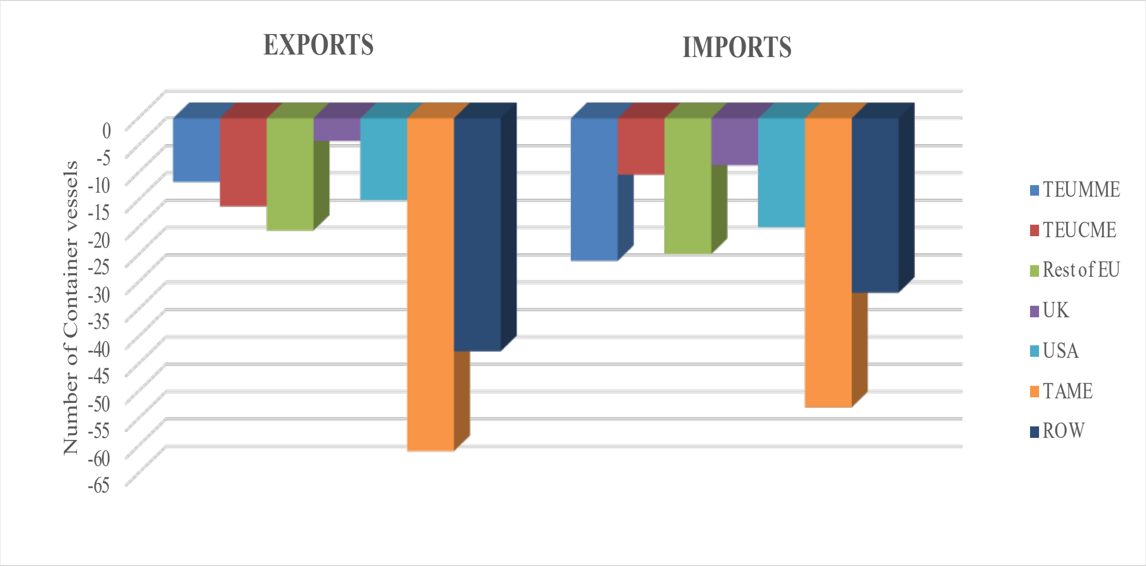

Figure 26. *Strategy 2; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

In the case of *Scenario 1* (see **Figure 25** and **26**), TAME and ROW experience the highest absolute decrease in TEUs traffic (-1.4 million TEUs; -894,664 TEUs) and container vessels' visits (-114; -75) when considering both aggregated (exports + imports) results. In relative terms we found no considerable differences in the variation of export logistics flows between the regions considered (see Section 6.2.2). However, when it comes to relative variations, results are again in line with Faber et al. (2022) being the Eurozone the most negatively affected region (see Section 6.2.2).

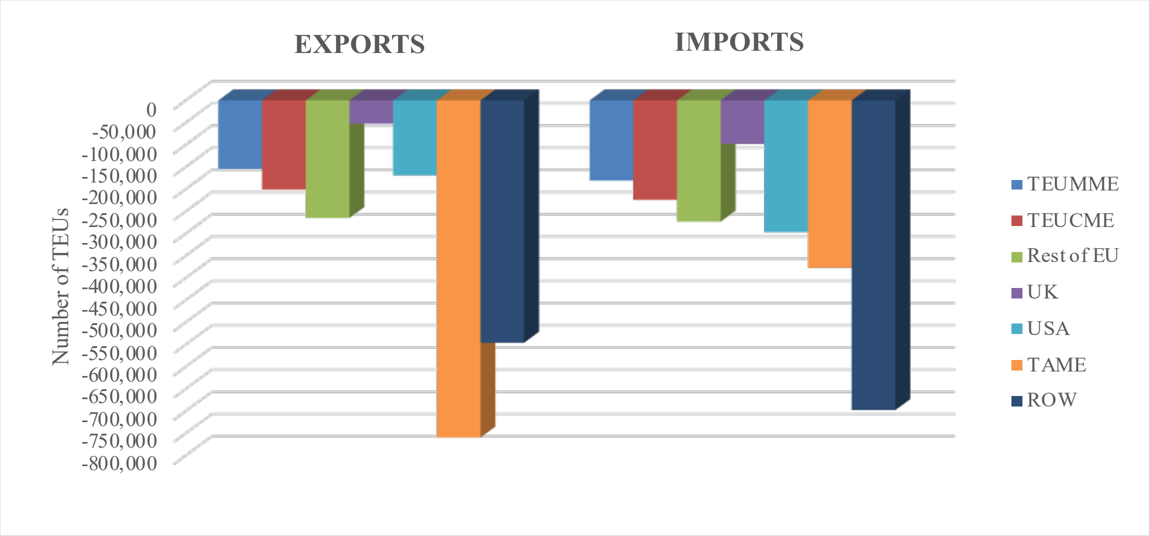

Figure 27. *Strategy 2; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

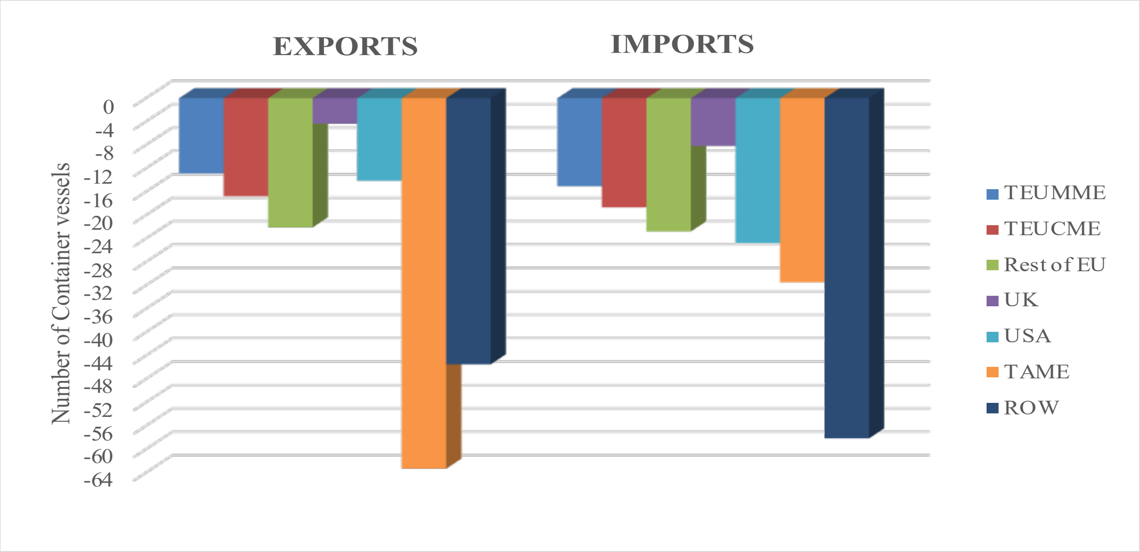

Figure 28. *Strategy 2; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

When we simulate the implementation of the ETS policy at a global level (*Scenario 2*), we found no significant relative variations between the regions considered. However, in absolute terms, **Figures 27** and **28** show that ROW (-1.2 million TEUs; -104 container ships' visits) and TAME (-1.1 million TEUs; -95 container ships' visits) are the most negatively impacted regions while the UK (-150,111 TEUs; -13 container ships' visits) is the least affected both when considering exports and imports combined. In Europe, the most impacted is Rest of EU (-538,055 TEUs; -45 container ships' visits) followed by TEUCME (-425,077 TEUs; -35 container ships' visits) and TEUMME (-334,668 TEUs; -28 container ships' visits) both in the case of imports and exports.

6.3.3 Logistics and transport impact for Strategy 3

Simulating the implementation of the ETS for *Strategy 3* both at a European and global level we found an overall decrease of TEUs traffic, respectively -5.7 TEUs and -5.8 million TEUs which translates into -479 and -485 container ships' visits considering an average capacity of 12,000 TEUs. This represents a 38.4% and 35.5% decrease in container ships' visits and a 35.7% and 34.9% in terms of TEUs traffic compared to the same scenarios simulated under *Strategy 2*. Thus, while under *Strategy 2* the difference between the impact of the two scenarios was 2.4% in terms of TEUs traffic and 3.5% with regards to container ships' visits, for *Strategy*

3 the gap between the scenarios has comparatively further reduced to a difference of only 0.8% and 2.9% respectively. Again, this is consistent with the fact that the price-impact gap between *Strategy 2* and *Strategy 3* as a result of the ETS introduction is significantly smaller than the that between *Strategy 1* and *2*. This seems logical considering that the difference between the impact of ETS across both scenarios simulated under *Strategy 3* is less marked. The reason is that the deployment of green Ammonia does not lead to increased OPEX but only to a mild increase in CAPEX. Similarly to our conclusions for *Strategy 2,* we argue that from an international perspective the introduction of a either a global or EU ETS under *Scenario 3* would not make a significantly different impact in terms of trade impact.

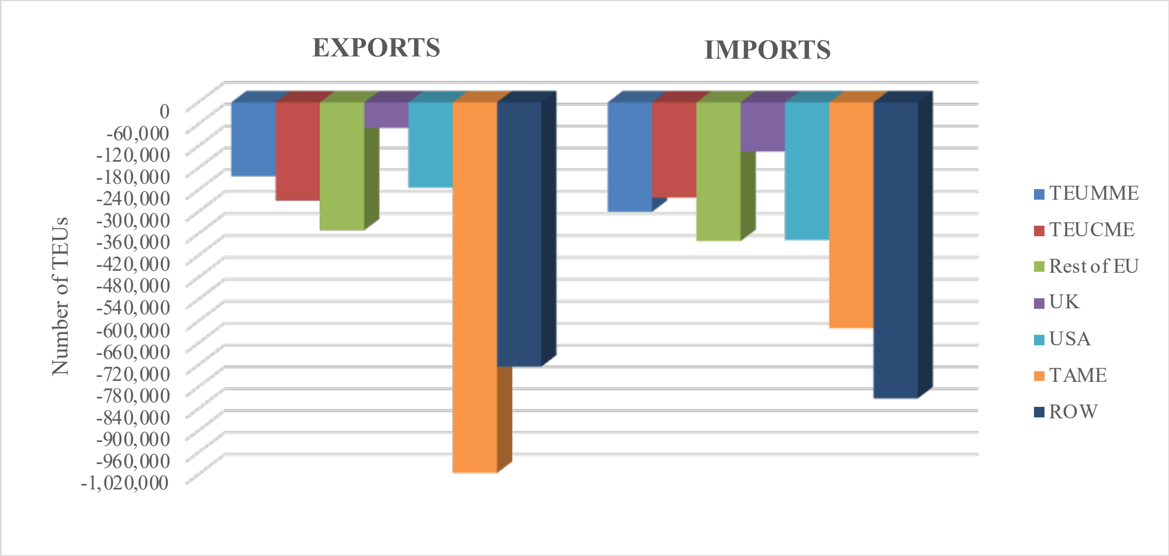

Figure 29. *Strategy 3; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

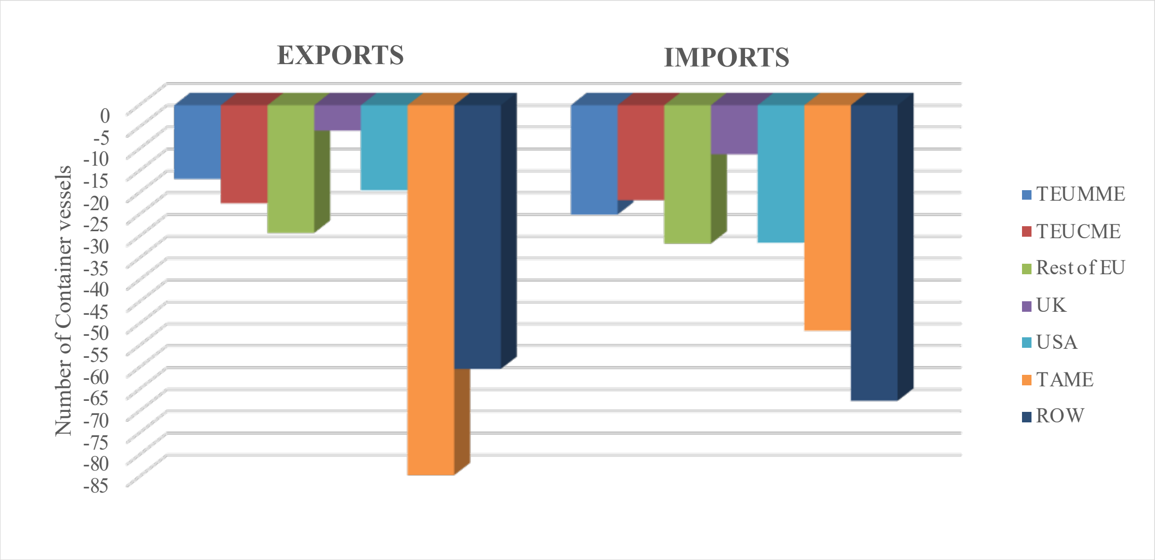

Figure 30. *Strategy 3; Scenario 1 (EU ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

In the case of *Scenario 1* (see **Figure 29** and **30**), TAME and ROW experience the highest absolute decrease in TEUs traffic (-1.6 million TEUs; -1.5 TEUs) and container vessels' visits (-136; -128) when considering both aggregated (exports + imports) results. The UK registers the smallest negative impact for both imports and exports (-204,387 TEUs; -17 container ships' visits). In relative terms, we found no considerable differences in the variation of export logistics flows between the regions considered with the only exceptions of TEUMME and TAME, both of which record a 3.0% decrease more compared to average loss in imports (see also Section 6.2.2).

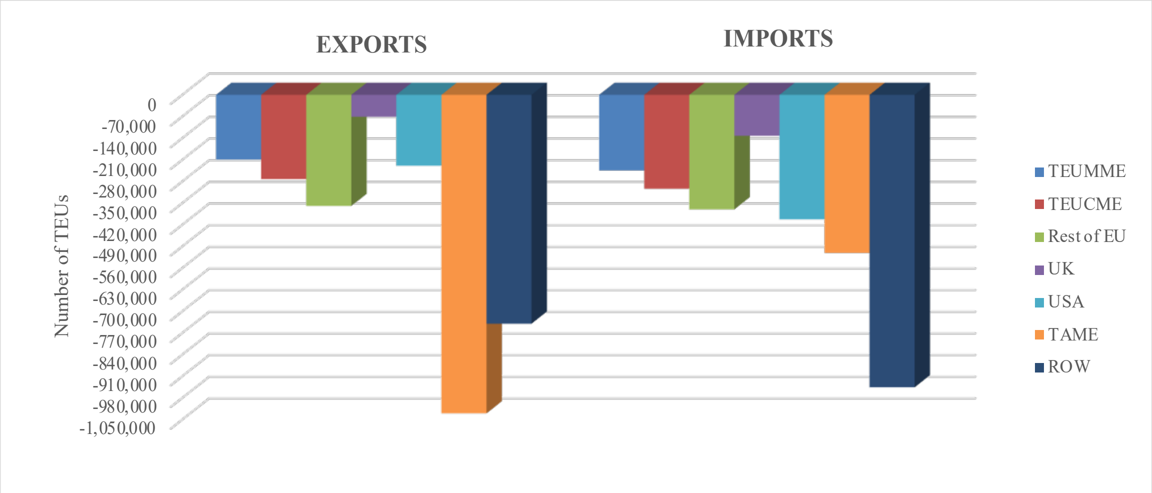

Figure 31. *Strategy 3; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of TEUs traded. Author's own illustration.*

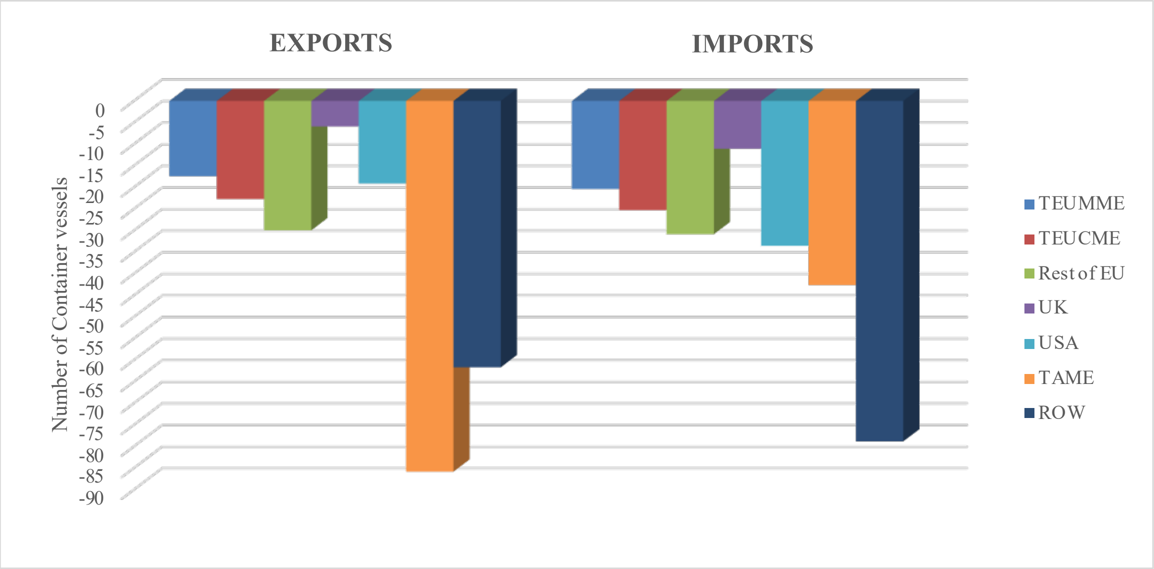

Figure 32. *Strategy 3; Scenario 2 (global ETS): logistics impact measured in terms of variation of number of container vessels deployed for trade. Author's own illustration.*

When we simulate the implementation of the ETS policy at a global level (*Scenario 2*), we found no significant relative variations between the regions considered. However, similarly to *Strategy 2,* in absolute terms **Figures 31** and **32** show that ROW (-1.7 million TEUs; -141 container ships' visits) and TAME (-1.5 million TEUs; -128 container ships' visits) are the most negatively impacted regions while the UK (-203,506 TEUs; -17 container ships' visits) is the least affected both when considering exports and imports combined. In Europe, the most impacted is Rest of EU (-729,443 TEUs; -61 container ships' visits) followed by TEUCME (-576,278 TEUs; -48 container ships' visits) and TEUMME (-453,710 TEUs; -38 container ships' visits) both in the case of imports and exports.

6.4 CO2-emission equivalent impact

In this section, we present our findings in terms of changes in CO2-equivalent emissions resulting from the implementation of the ETS both at a European (*Scenario 1*) and global level (*Scenario 2*) for each *Strategy*. Before going into details, we briefly outline the estimation method deployed for estimating variations in CO2-equivalent emissions. Please refer to **Worked Example 1b** and to **Table 25** and **26**[39]. Knowing initial trade volumes (see column

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[39] The data in example is only for illustration purposes regarding the calculation process and does not refer to any specific empirical outcome of the present paper.

B) between countries and the proportion of average carbon emission between selected modes of transport (**M**), with few assumptions it is possible to derive figures about the percentage variation of transport-related carbon emissions (**N**) following the ETS implementation from the GSIM outputs. In fact, knowing the proportion of average carbon emission between selected modes of transport[40] (**M**) we can easily estimate the percentage increase/decrease of transport-related carbon emission compared to the initial situation (**N**) using the weighted average method, this way measuring the carbon emission impact of the ETS implementation – i.e., multiply the proportion of average carbon emission between selected modes of transport by the initial and final % mode share respectively, calculate their ratio (final/initial) , and subtract 1 from the obtained value.

Worked Example 1b (Container ship trade):

- **Final total number of TEUs transported by all modes (J6)** = SUM (J1:J5) = 250077 TEUs

- **Final share per mode (L1)** = J1 / J6 = 233559 / 250077 = 0.8522 = 85.22%

- **Proportion of CO2 emission equivalent share between modes (M)** = Estimation based on Shell (2022), Unifeeder (2022), and CEFIC (2021).

- **CO2 emissions compared to pre-ETS (N1)** = (L1 * M1) – (G1 * M1) = (85.22% * 2.17%) – (94.69% * 2.17%) = 1.85% – 2.06%% = **– 0.21%**

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[40] Estimation based on Shell (2022), Unifeeder (2022), and CEFIC (2021).

		G
	Pre-ETS	**Initial % share per mode (TEUs transported)**
1	**Cont. ship**	94.69%
2	**Rail**	0.05%
3	**Truck**	2.73%
4	**Barge**	1.44%
5	**Plane**	1.09%
6	**Total**	100%

Table 25. *Summary of (pre-ETS) data requirements for calculating the carbon emission impact of the ETS implementation. Compiled by the author.*

		H	I	J	K	L	M	N
	Post-ETS	**Final traded values (millions of €)**	**Final traded volumes (tons)**	**Number of TEUs transported**	**Number of vehicles deployed**	**Final % share per mode (TEUs transported)**	**Proportion of CO2 emission share**	**CO2 emission equivalent compared to pre-ETS**
1	**Cont. ship**	12744.63	3036268	233559	19.5	85.22%	2.17%	**-0.21%**
2	**Rail**	1.49	1762	136	1.5	0.05%	2.99%	**+0.00%**
3	**Truck**	866.99	116888	8991	7492.5	3.28%	8.42%	**+0.05%**
4	**Barge**	27.80	54993	4230	28.2	1.54%	4.68%	**+0.01%**
5	**Plane**	16779.83	41087	3161	395.1	1.15%	81.74%	**+0.05%**
6	**Total**	30420.74	3250997	250077	7936.0	100%	100%	**-0.10%**

Table 26. *Summary of (post-ETS) data requirements for calculating the carbon emission impact of the ETS implementation. Example by the author.*

6.4.1 CO2-emission equivalent impact for Strategy 1

Simulating the introduction of the ETS for *Strategy 1* both at a European and global level we found an overall decrease in terms of CO2-emission equivalent amounting to 0.011%. However, the changes are too minuscule to be considered particularly significant.

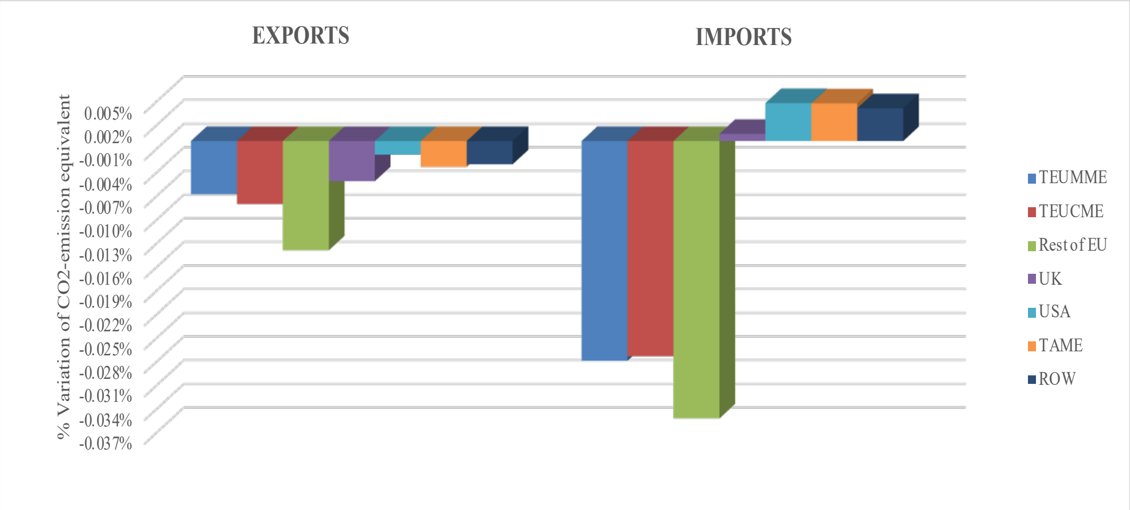

Figure 33. *Strategy 1; Scenario 1 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

Figure 33 illustrates the results from the implementation of the EU ETS (*Scenario 1*). We notice that the Rest of EU experiences the greatest decrease of CO2-emission equivalent (-0.014% exports; -0.035% imports) followed by TEUCME (-0.084%) in the case of exports and by TEUMME (-0.028%) with regards to imports. In fact, we observe that extra-EU regions are relatively less impacted by the EU ETS and that their CO2-emission equivalent associated with imports slightly increase as a result. Once more, this is in line with Parry's et al.'s (2018), Marrewijk's et al.'s (2012), and our expectations both about Europe being the most negatively impacted by the EU ETS and regarding the possibility of resulting trade diversion effects. We estimate that ROW (+0.001%), TAME (+0.002%) and the USA (+0.003%) are the only countries to register an overall increase in terms of CO2-emission equivalent.

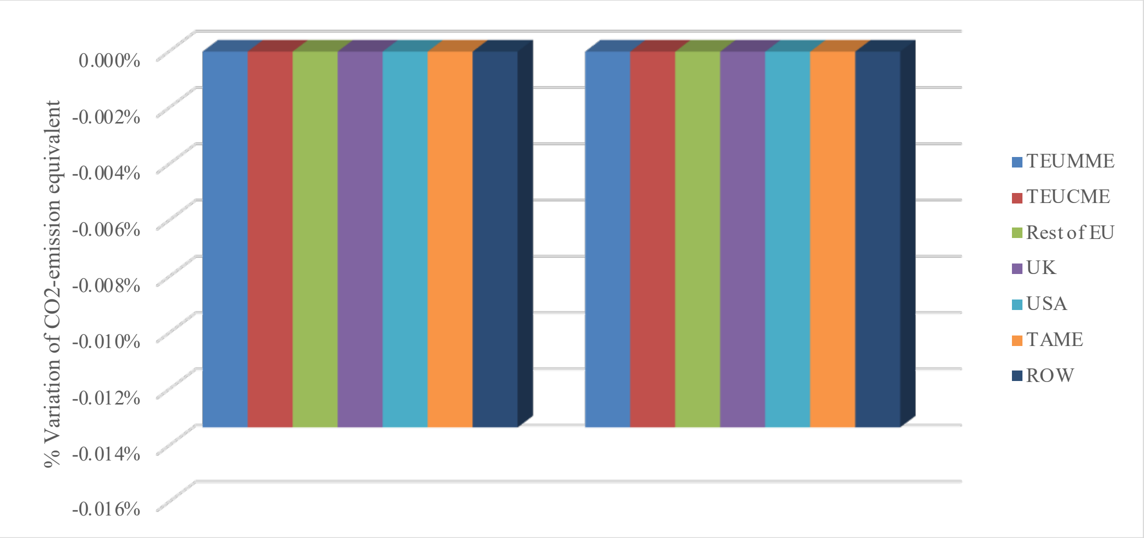

Figure 34. *Strategy 1; Scenario 2 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

As shown in **Figure 34**, when the policy is globally implemented (*Scenario 2*), we find that all countries experience approximately the same decrease of CO2-emission equivalent (-0.013%). The variation between regions is minimal and thus not significant.

6.4.2 CO2-emission equivalent impact for Strategy 2

By simulating the introduction of the ETS for *Strategy 2* both at a European and global level, we found an average decrease in terms of CO2-emission equivalent of -0.027% with only a 0.004% difference between imports and exports registered for *Scenario 1*. Therefore, results show that implementing the ETS either at a global or European level will not make a difference from a global emission standpoint nor a significant one from a regional perspective. We estimate that implementing *Strategy 2* will cause a 352% decrease in CO2-emission equivalent relatively to *Strategy 1* on average.

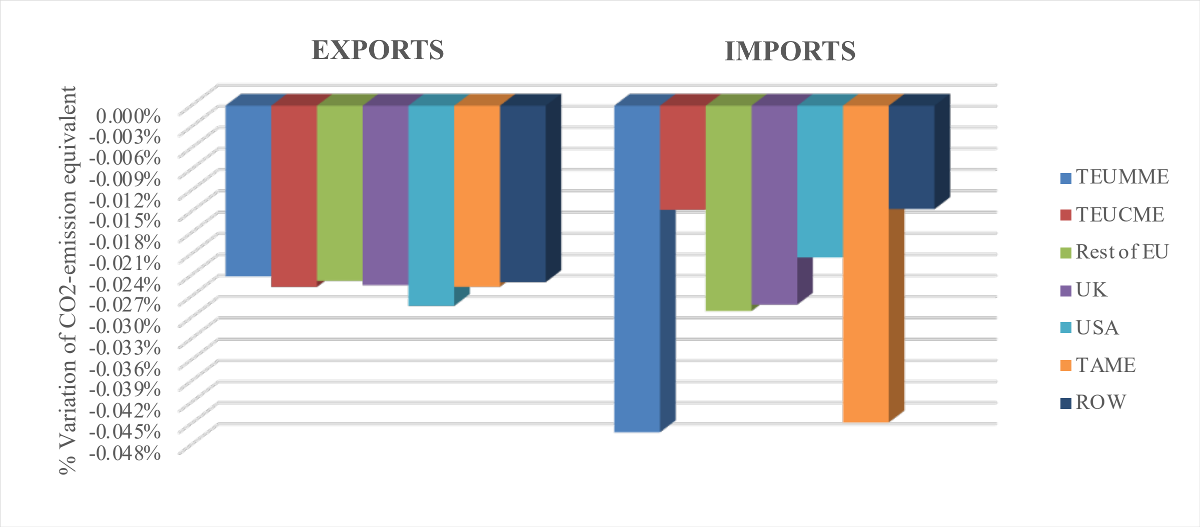

Figure 35. *Strategy 2; Scenario 1 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

Figure 35 illustrates the results from the implementation of the EU ETS (*Scenario 1*). We notice no significant difference in relative variation of CO2-emission equivalent associated with exports regions. The largest relative difference in exports observed is between the USA (-0.028%) and TEUMME (-0.024%). Surprisingly and against expectations, we also found no marked difference in the variation of CO2-emission equivalent associated with imports between EU and extra-EU countries. The largest relative decrease in CO2-emission equivalent linked to imports is represented by TEUMME (-0.05%) and TAME (-0.04%) followed by the Rest of EU and the UK (-0.03%), while TEUCME and ROW registered the smallest relative impact (-0.01%).

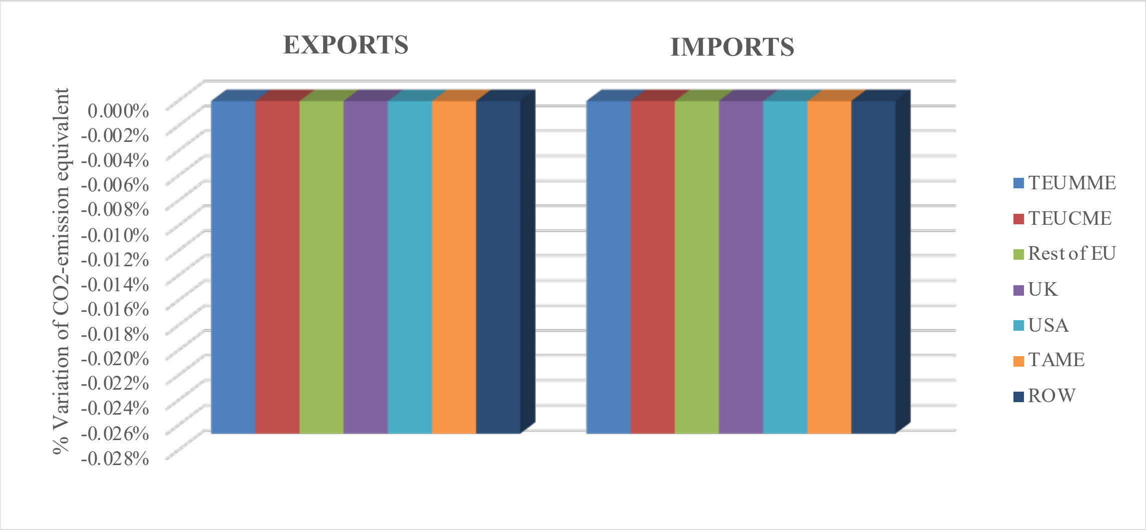

Figure 36. *Strategy 2; Scenario 2 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

As shown in **Figure 36**, when the policy is globally implemented (*Scenario 2*), we find that all countries experience approximately the same decrease of CO2-emission equivalent (-0.027%). The variation between regions is minimal and thus not significant.

6.4.3 CO2-emission equivalent impact for Strategy 3

Simulating the introduction of the ETS for *Strategy 3* both at a European and global level, we found an average decrease in terms of CO2-emission equivalent of -0.036% with only a 0.001% difference between imports and exports registered for *Scenario 1*. Therefore, results show that implementing the ETS either at a global or European level will not make a difference from a global emission standpoint nor a significant one from a regional perspective. We estimate that implementing *Strategy 3* will cause a 33.3% decrease in CO2-emission equivalent relatively to *Strategy 2* on average.

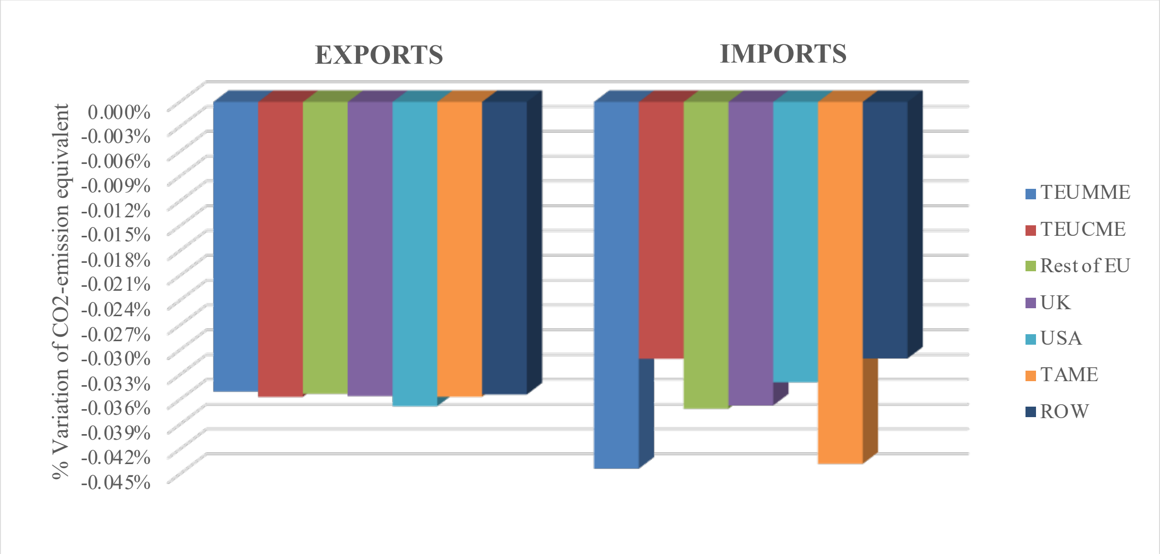

Figure 37. *Strategy 3; Scenario 1 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

Figure 37 shows the results from the implementation of the EU ETS (*Scenario 1*). We observe no significant difference in relative export variation among regions. Also, we notice proportional changes between regions to resemble outputs for the same scenario under *Strategy 2*. For instance, the largest relative difference in CO2-emission equivalent (exports) observed is again associated with the USA (-0.037%). Surprisingly, we also found no marked difference in import variation between EU and extra-EU countries. The largest relative loss in imports is suffered by TEUMME and TAME (-0.044%) followed by the Rest of EU and the UK (-0.037%), while TEUCME and ROW registered the smallest relative negative impact (-0.031%) which nevertheless has triplicated compared to the same scenario associated with *Strategy 2* (-0.01%). Therefore, we observe no clear pattern with regards to expectations about the diminished competitiveness of the EU as a consequence of the EU ETS implementation.

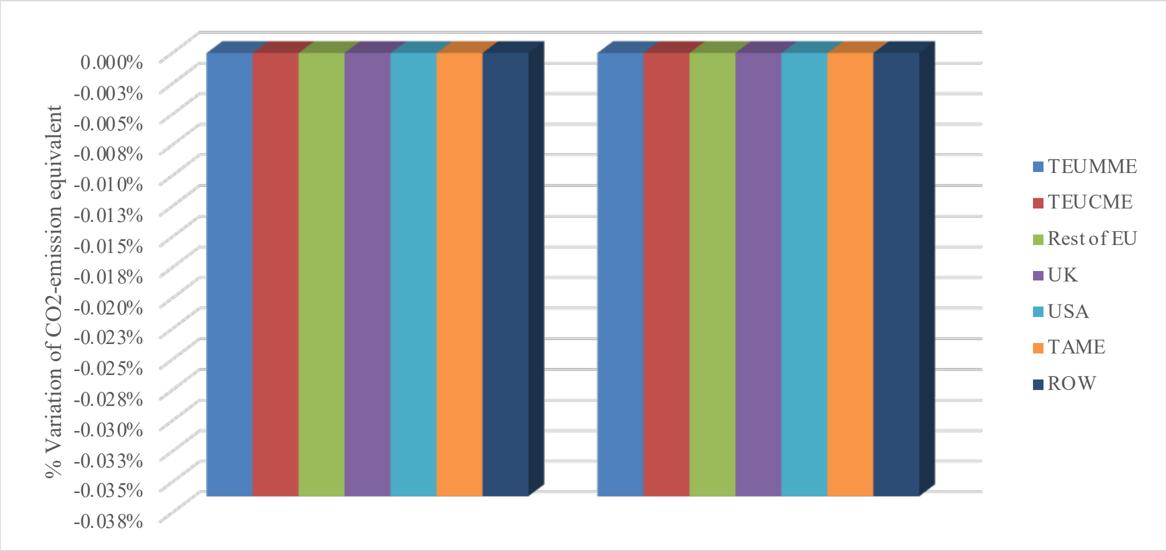

Figure 38. *Strategy 3; Scenario 2 (EU ETS): emission impact measure as variation in CO2-emission equivalent. Author's own illustration.*

As illustrated in **Figure 38**, when the policy is globally implemented (*Scenario 3*)[41], we find that CO2-emission equivalent decreases all regions (-0.036% on average) with only minimal relative difference (<0.0001). The overall variation is so small to be considered negligible.

6.5 Summary of results

In the light of these research outcomes, we conclude that the ETS policy is at best ineffective in reducing carbon emissions and that it would cause a – despite mild and limited – negative economic and trade impact from both a European and global perspective.

To summarise, we found that regardless of the strategy and scenario considered, the implementation of the ETS would to a greater or lesser extent negatively impact global net welfare, trade, and logistics and transport volumes generating only a marginal reduction in

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[41] Same price per ton of CO2-emission equivalent across countries.

CO2-misison equivalent. On a general level, we discovered a steady drop in all metrics as we progressed from *Strategy 1* to *Strategies 2* and *3*. The finding is not surprising given that the simulated strategies include a gradual increase in NTMs. For all figures, the largest result difference has been noted between *Strategies 1* and *2,* as the greatest trade barrier shock difference occurs when the increased trade barriers from higher OPEX and CAPEX adds to the pure policy shock which characterised *Strategy 1.*

There can be multiple reasons for these outcomes. The main explanation regards the positive relationship between trade, welfare and logistics that is expressed in economic theory. In fact, an increase in trade barriers tends to hamper bilateral trade flows between countries as now both consumer and producer surplus are negatively impacted by surging trading costs. Particularly, we expect to observe a drop in welfare effect when the sum of tariff revenue resulting from the increase in trade barriers is offset by the decrease in producer and consumer surplus combined. Because the strategies considered are progressively associated with an increase in trade barriers, due to rising trade costs resulting from the combination of the policy shock and the mitigating strategies adopted, we observe increasingly negative impacts for these parameters as we move from *Strategy 1* to *3.* It is not a case that the only positive trade impacts registered are associated with some extra-EU regions for *Strategy 1* since this strategy comprise only a pure policy shock with no widespread increase in OPEX and CAPEX (except for the EU). The same holds true for CO2 emissions. In fact, as we observe bilateral trade flows decreasing as tariff barriers increase, we also notice CO2 emissions dropping because of decreased logistics flows combined with a progressively less polluting world container fleet.

For the reasons explained above, the greatest negative effect considering the impact on all parameters has been observed in the case of *Strategy 3* (*Scenario 1)* which shows a total worldwide loss of €77.2 in net welfare, an average trade loss of -1.7%, -5.7 million TEUs traffic and -480 container ships' visits. The same strategy and scenario are also associated with the highest decrease in CO2-emission equivalent (-0.036%) linked to container shipping. By contrast, the milder policy impact has been recorded for *Strategy 1* (*Scenario 2*). In this case, results show a total global loss of €28.5 in net welfare, an average trade loss of (-0.6%), -2.1 million TEUs traffic and -179 container ships' visits. The same strategy and scenario are also associated with the lowest decrease in CO2-emission equivalent (-0.013%) linked to container shipping. Therefore, from a general perspective these results confirm the strong positive correlation between net welfare, trade, logistics flows, and carbon emissions.

We also noticed that the gap between scenarios for all strategies narrows progressively from *Strategy 1* to *3*. In fact, we argued that there would be only a minimal difference between scenarios of the same strategy for *Strategy 2* and *3*. Again, it is not surprising since the effect of the ETS on NTMs proportionally reduces as we move from *Strategy 1* to *Strategy 3*.

By contrast to expectations by Parry et al. (2018), Marrewijk et al., (2012), results also show that in none of the simulations trade is transferred from container vessels to other modes of transport in any significant way. It is likely that this outcome reflects the relatively elastic nature of ocean shipping. In fact, in reality the largest containerised traded volumes are shipped by container vessels as there are both substantial volume capacity and costs constraints for all other modes of transport. Hence, the model seems to suggest that sea shipping is still by far the most economically feasible modal trading solution despite the increasing shipping costs generated by the policy shock. In this sense, it appears that the introduction of the ETS policy does not risk causing the undesired effect of leading to surges in CO2 emissions due to carbon leakages arising from the increased deployment of more polluting transport modes. However, the model also shows that this might occur at an expense of reduced global welfare, trade, and container terminals' throughputs.

Chapter 7 – Conclusions

7.1 Key takeaways

This paper analysed the ***trade, transport and carbon-emission impact of the introduction of an EU carbon border tax (EU ETS) on container shipping***. Being the most ambitious and large-scale attempt to reduce CO2 emissions from shipping ever advanced by a legislative organ, assessing the impact of the ETS is important for informing future decisions regarding the development of policies targeting green transition in shipping. The ETS will mean that shipowners must buy from the EU (or from other shipowners) emission allowances – 1 ton of CO2 equals 1 allowance – to be able to operate in European waters and berth in European ports (European Parliament, 2021). On the 22nd of June 2022, the European Council voted in favour of the application of the ETS for shipping starting from the 1st of January 2024 (European Council, 2022). European legislators have argued that the eventual application of this proposed mechanism will ideally disincentivise shipowners to use traditional fuels thus leading to a decrease in CO2-emission equivalent (ibid.).

On the other hand, many in the shipping industry fear that taxation will make freight costs too expensive, it will reduce the already low profitability of many liners and discourage new builds, hence leading to an undesired outcome (Mohindru and Li, 2021). In fact, a preliminary analysis of the impact avoidance on the competitiveness of EU ports conducted by Faber et al. (2022) suggests that the implementation of the EU ETS for shipping could negatively impact the throughput of container terminals. Furthermore, prior studies have argued that the increased expenses potentially associated with this market-based carbon tax might lead to trade diversion from Europe and/or to CO2 leakages arising from switching to alternative, more polluting, modes of transports such as: airplane, train and trucks (Parry et al., 2018; Marrewijk et al., 2012). For these reasons, many in the maritime community (e.g., shippers; freight forwarders) operating in Europe have stressed that the ETS should instead be implemented at a global level through IMO regulations, so that also the incurring costs can be both distributed more evenly and mitigated by means of a reduced allowance price (Mohindru and Li, 2021).

In order to address these issues and add to the debate with quantitative insights, using a Partial Equilibrium model we ran different simulations modelling both the introduction of the ETS at a European (*Scenario 1*) and global level (*Scenario 2*) according to different mitigating strategies that reflects likely development in the green transition for shipping. In particular, the simulations took into account the increase in NTMs as a consequence of the ETS implementation.

Only when introducing the ETS at a European level (*Scenario 1*) at the current state of the art (*Strategy 1*) we found evidence that the policy would negatively and significantly impact Europe the most in economic and logistics terms as anticipated by Faber et al., (2022). Moreover, the same simulation is also the only one that shows trade diversion associated with imports from the Eurozone to extra-EU countries. Although considered as a mild impact, results confirm Faber's et al.'s (2022) suggestions regarding the possible harmful effect of the EU ETS for European container terminals (-1.0 million TEUs) in terms of competitive advantage (extra-EU countries registered +58,339 TEUs). Not surprisingly, only for *Scenario 1* of *Strategy 1* we measured an increase in trade and net welfare effect which was associated with the USA and ROW. In this sense, the results partially confirm expectations by Parry et al. (2018) and Marrewijk et al., (2012). Being *Strategy 1* (*Scenario 1*) the most plausible state of the art for when the policy will come into effect in 2024, these results raise doubts on whether an average reduction of ~0.02% in CO2-emission equivalent linked to shipping is worth a net welfare decrease of -€10.2 bn in the Eurozone. The issue becomes more doubtful if we consider that a decrease of ~0.02% in CO2-emission equivalent from container ships represents only a 0.0004% reduction of total emissions. In the light of these outcomes, we argue that the European Commission should further assess the extent to which the trade-off between carbon emissions and net welfare can be considered successful from a policy standpoint.

By contrast, implementing the ETS at a global level (*Scenario 2*) under *Strategy 1* we found that all countries experience a similar degree of trade loss (-0.6% on average) and that, surprisingly, extra-EU countries are the most negatively impacted in absolute terms from a net welfare perspective (-€20.9bn in total). Comparatively to *Scenario 1, Scenario 2* is more effective in terms of reducing carbon emissions (-0.013%<0.008%). Therefore, for *Strategy 1* we conclude that implementing the ETS at a global level will lead to a greater, however more evenly spread, negative economic and trade impact and to a higher reduction of carbon emissions. This is however not true for *Strategy 2* and *Strategy 3* in which *Scenario 2* causes a higher negative impact in economic and trade terms compared to *Scenario 1* while showing same figures for changes in carbon emissions. Therefore, for what it concerns *Strategy 3,* considering that there is no significant difference in relative economic and trade loss between

EU and extra-EU countries across the two scenarios, we argue that implementing the ETS at a European level (*Scenario 1)* would lead to the best outcome for all regions considered – that is, to the best trade-off between economic loss and carbon emission reduction. By contrast, in the case of *Strategy 2* the most desired impact from a European standpoint would be to implement the ETS at a global level (*Scenario 2*) since we observe a slight imbalance in average economic and trade loss between EU (-1.3%) and extra-EU regions (-1.2%) associated with *Scenario 1*.

At a more general level, we found a progressive decrease for all parameters as we move from *Strategy 1* to *Strategy 2* and *3*. The outcome is not surprising considering that the strategies simulated entails a progressive increase in NTMs. Comparatively, the greatest difference in results have been observed between *Strategy 1* and *2* for all figures. Similarly, we also noticed that the gap between scenarios for all strategies reduces progressively from *Strategy 1* to *3*. In fact, we argued that there would be only a marginal difference between scenarios of the same strategy for *Strategy 2* and *3*. Again, it is not surprising since the effect of the ETS on NTMs proportionally reduces as we move from *Strategy 1* to *Strategy 3*.

The greatest negative effect considering the impact on all parameters has been registered in the case of *Strategy 3* (*Scenario 1)* which shows a total global loss of €77.2 in net welfare, an average trade loss of -1.7%, -5.7 million TEUs traffic and -480 container ships' visits. The same strategy and scenario are also associated with the highest decrease in CO2-emission equivalent (-0.036%) linked to container shipping. By contrast, the milder policy impact has been recorded for *Strategy 1* (*Scenario 2*). In this case, results show a total global loss of €28.5 in net welfare, an average trade loss of (-0.6%), -2.1 million TEUs traffic and -179 container ships' visits. The same strategy and scenario are also associated with the lowest decrease in CO2-emission equivalent (-0.013%) linked to container shipping. Therefore, from a general perspective these results confirm the strong positive correlation between net welfare, trade, logistics flows, and carbon emissions.

To summarise, we found that regardless of the strategy and scenario considered, the implementation of the ETS would to a greater or lesser extent negatively impact global net welfare, trade, and logistics and transport volumes generating only a marginal reduction in CO2-misison equivalent. By contrast to expectations by Parry et al. (2018), Marrewijk et al., (2012), results also show that in none of the simulations trade is transferred from container vessels to other modes of transport in any significant way. It is likely that this outcome reflects the relatively elastic nature of ocean shipping. In fact, in reality the largest containerised traded volumes are shipped by container vessels as there are both substantial volume capacity and costs constraints for all other modes of transport. Hence, the model seems to suggest that sea shipping is still by far the most economically feasible modal trading solution despite the increasing shipping costs generated by the policy shock. In this sense, it appears that the introduction of the ETS policy does not risk causing the undesired effect of leading to surges in CO2 emissions due to carbon leakages arising from the increased deployment of more polluting transport modes. However, this comes at an expense of reduced global welfare, trade, and container terminals' throughputs.

In the light of these research outcomes, we conclude that the ETS policy is at best ineffective in reducing carbon emissions and that it would cause a – despite mild and limited – negative economic and trade impact from both a European and global perspective. Again, we argue that the European Commission should reassess the potential benefits and drawbacks of implementing such a policy especially considering that results suggest that the EU would suffer a comparatively higher negative economic impact on average compared to extra-EU countries. At the very least, the results of the present research should raise questions regarding what is deemed to be successful from a policy standpoint and what are the implications of the costs associated with it.

In order to mitigate the negative trade impact, we suggest that the ETS should be complemented with other policies that incentivise the purchasing of goods associated with a lower transportation carbon footprint. Moreover, we also suggest that the implementation of the ETS should come into effect together with policies that consent cheaper finance with regards to green transition in shipping.

7.2 Limitations and directions for further research

One important limitation of our research is that the partial equilibrium model deployed does not include the effects of the global value chain. In fact, the GSIM does not take into account the possible positive economic effects of developing a supply chain needed for green transition in shipping (e.g., alternative fuels). Furthermore, because the GSIM model does not incorporate time as a variable, it is impossible to forecast when changes in output will occur. This is significant when assessing the ETS policy since its pledge to reduce carbon emissions spans almost 30 years. Moreover, the present research has not taken into consideration possible ETS associated with other modes of transport nor modelled the degree to which customers are willing to pay for more sustainable shipping.

Further research should be conducted with the aim to find a carbon pricing that allows for a more optimal and effective trade-off between economic and trade loss and reduction of carbon emissions. Different strategies and scenarios could be also simulated including other shipping segments to have a more comprehensive understanding of the implications of the ETS. New research should also incorporate other variables such as time and effects of the global value chain as well as consider other possible market-based carbon measures and green development associated with other modes of transport. Most importantly, further research should include customer willingness to pay for more sustainable shipping into account. For instance, customer willingness to pay could be modelled and incorporated into the demand elasticity, thus providing further insights with regards to the economic, trade and emission effects resulting from the policy shock.

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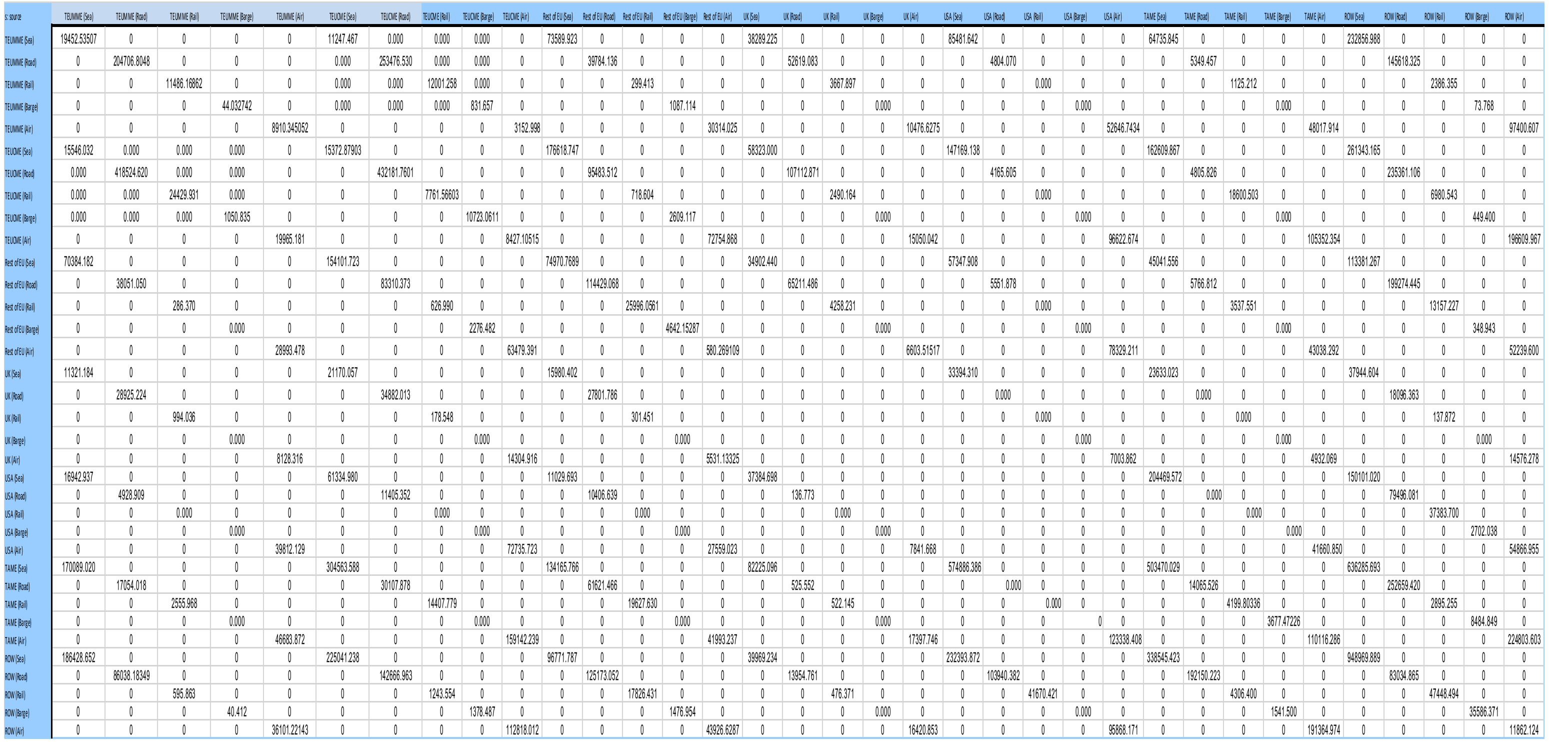
Appendix 1

Bilateral trade values in millions of Euros for containerised goods per mode of transport between selected countries. Author’s own compilation.



s: source	TEUMME (Sea)	TEUMME (Road)	TEUMME (Rail)	TEUMME (Barge)	TEUMME (Air)	TEUCME (Sea)	TEUCME (Road)	TEUCME (Rail)	TEUCME (Barge)	TEUCME (Air)	Rest of EU (Sea)	Rest of EU (Road)	Rest of EU (Rail)	Rest of EU (Barge)	Rest of EU (Air)	UK (Sea)	UK (Road)	UK (Rail)	UK (Barge)	UK (Air)	USA (Sea)	USA (Road)	USA (Rail)	USA (Barge)	USA (Air)	TAME (Sea)	TAME (Road)	TAME (Rail)	TAME (Barge)	TAME (Air)	ROW (Sea)	ROW (Road)	ROW (Rail)	ROW (Barge)	ROW (Air)
TEUMME (Sea)	19452.53507	0	0	0	0	11247.467	0.000	0.000	0.000	0	73589.923	0	0	0	0	38289.225	0	0	0	0	85481.642	0	0	0	0	64735.845	0	0	0	0	232856.988	0	0	0	0
TEUMME (Road)	0	204706.8048	0	0	0	0.000	253476.530	0.000	0.000	0	0	39784.136	0	0	0	0	52619.083	0	0	0	0	4804.070	0	0	0	0	5349.457	0	0	0	0	145618.325	0	0	0
TEUMME (Rail)	0	0	11486.16862	0	0	0.000	0.000	12001.258	0.000	0	0	0	299.413	0	0	0	0	3667.897	0	0	0	0	0.000	0	0	0	0	1125.212	0	0	0	0	2386.355	0	0
TEUMME (Barge)	0	0	0	44.032742	0	0.000	0.000	0.000	831.657	0	0	0	0	1087.114	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	73.768	0
TEUMME (Air)	0	0	0	0	8910.345052	0	0	0	0	3152.998	0	0	0	0	30314.025	0	0	0	0	10476.6275	0	0	0	0	52646.7434	0	0	0	0	48017.914	0	0	0	0	97400.607
TEUCME (Sea)	15546.032	0.000	0.000	0.000	0	15372.87903	0	0	0	0	176618.747	0	0	0	0	58323.000	0	0	0	0	147169.138	0	0	0	0	162609.867	0	0	0	0	261343.165	0	0	0	0
TEUCME (Road)	0.000	418524.620	0.000	0.000	0	0	432181.7601	0	0	0	0	95483.512	0	0	0	0	107112.871	0	0	0	0	4165.605	0	0	0	0	4805.826	0	0	0	0	235361.106	0	0	0
TEUCME (Rail)	0.000	0.000	24429.931	0.000	0	0	0	7761.56603	0	0	0	0	718.604	0	0	0	0	2490.164	0	0	0	0	0.000	0	0	0	0	18600.503	0	0	0	0	6980.543	0	0
TEUCME (Barge)	0.000	0.000	0.000	1050.835	0	0	0	0	10723.0611	0	0	0	0	2609.117	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	449.400	0
TEUCME (Air)	0	0	0	0	19965.181	0	0	0	0	8427.10515	0	0	0	0	72754.868	0	0	0	0	15050.042	0	0	0	0	96622.674	0	0	0	0	105352.354	0	0	0	0	196609.967
Rest of EU (Sea)	70384.182	0	0	0	0	154101.723	0	0	0	0	74970.7689	0	0	0	0	34902.440	0	0	0	0	57347.908	0	0	0	0	45041.556	0	0	0	0	113381.267	0	0	0	0
Rest of EU (Road)	0	38051.050	0	0	0	0	83310.373	0	0	0	0	114429.068	0	0	0	0	65211.486	0	0	0	0	5551.878	0	0	0	0	5766.812	0	0	0	0	199274.445	0	0	0
Rest of EU (Rail)	0	0	286.370	0	0	0	0	626.990	0	0	0	0	25996.0561	0	0	0	0	4258.231	0	0	0	0	0.000	0	0	0	0	3537.551	0	0	0	0	13157.227	0	0
Rest of EU (Barge)	0	0	0	0.000	0	0	0	0	2276.482	0	0	0	0	4642.15287	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	348.943	0
Rest of EU (Air)	0	0	0	0	28993.478	0	0	0	0	63479.391	0	0	0	0	580.269109	0	0	0	0	6603.51517	0	0	0	0	78329.211	0	0	0	0	43038.292	0	0	0	0	52239.600
UK (Sea)	11321.184	0	0	0	0	21170.057	0	0	0	0	15980.402	0	0	0	0	0	0	0	0	0	33394.310	0	0	0	0	23633.023	0	0	0	0	37944.604	0	0	0	0
UK (Road)	0	28925.224	0	0	0	0	34882.013	0	0	0	0	27801.786	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	18096.363	0	0	0
UK (Rail)	0	0	994.036	0	0	0	0	178.548	0	0	0	0	301.451	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	137.872	0	0
UK (Barge)	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0
UK (Air)	0	0	0	0	8128.316	0	0	0	0	14304.916	0	0	0	0	5531.13325	0	0	0	0	0	0	0	0	0	7003.862	0	0	0	0	4932.069	0	0	0	0	14576.278
USA (Sea)	16942.937	0	0	0	0	61334.980	0	0	0	0	11029.693	0	0	0	0	37384.698	0	0	0	0	0	0	0	0	0	204469.572	0	0	0	0	150101.020	0	0	0	0
USA (Road)	0	4928.909	0	0	0	0	11405.352	0	0	0	0	10406.639	0	0	0	0	136.773	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	79496.081	0	0	0
USA (Rail)	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	37383.700	0	0
USA (Barge)	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	2702.038	0
USA (Air)	0	0	0	0	39812.129	0	0	0	0	72735.723	0	0	0	0	27559.023	0	0	0	0	7841.668	0	0	0	0	0	0	0	0	0	41660.850	0	0	0	0	54866.955
TAME (Sea)	170089.020	0	0	0	0	304563.588	0	0	0	0	134165.766	0	0	0	0	82225.096	0	0	0	0	574886.386	0	0	0	0	503470.029	0	0	0	0	636285.693	0	0	0	0
TAME (Road)	0	17054.018	0	0	0	0	30107.878	0	0	0	0	61621.466	0	0	0	0	525.552	0	0	0	0	0.000	0	0	0	0	14065.526	0	0	0	0	252659.420	0	0	0
TAME (Rail)	0	0	2555.968	0	0	0	0	14407.779	0	0	0	0	19627.630	0	0	0	0	522.145	0	0	0	0	0.000	0	0	0	0	4199.80336	0	0	0	0	2895.255	0	0
TAME (Barge)	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	3677.47226	0	0	0	0	8484.849	0
TAME (Air)	0	0	0	0	46683.872	0	0	0	0	159142.239	0	0	0	0	41993.237	0	0	0	0	17397.746	0	0	0	0	123338.408	0	0	0	0	110116.286	0	0	0	0	224803.603
ROW (Sea)	186428.652	0	0	0	0	225041.238	0	0	0	0	96771.787	0	0	0	0	39969.234	0	0	0	0	232393.872	0	0	0	0	338545.423	0	0	0	0	948969.889	0	0	0	0
ROW (Road)	0	86038.18349	0	0	0	0	142666.963	0	0	0	0	125173.052	0	0	0	0	13954.761	0	0	0	0	103940.382	0	0	0	0	192150.223	0	0	0	0	83034.865	0	0	0
ROW (Rail)	0	0	595.863	0	0	0	0	1243.554	0	0	0	0	17826.431	0	0	0	0	476.371	0	0	0	0	41670.421	0	0	0	0	4306.400	0	0	0	0	47448.494	0	0
ROW (Barge)	0	0	0	40.412	0	0	0	0	1378.487	0	0	0	0	1476.954	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	1541.500	0	0	0	0	35586.371	0
ROW (Air)	0	0	0	0	36101.22143	0	0	0	0	112818.012	0	0	0	0	43926.6287	0	0	0	0	16420.853	0	0	0	0	95868.171	0	0	0	0	191364.974	0	0	0	0	11862.124

Appendix 2

Bilateral trade volumes (tons) of containerised goods per mode of transport between selected countries. Author's own compilation.

s: source	TEUMME (Sea)	TEUMME (Road)	TEUMME (Rail)	TEUMME (Barge)	TEUMME (Air)	TEUCME (Sea)	TEUCME (Road)	TEUCME (Rail)	TEUCME (Barge)	TEUCME (Air)	Rest of EU (Sea)	Rest of EU (Road)	Rest of EU (Rail)	Rest of EU (Barge)	Rest of EU (Air)	UK (Sea)	UK (Road)	UK (Rail)	UK (Barge)	UK (Air)	USA (Sea)	USA (Road)	USA (Rail)	USA (Barge)	USA (Air)	TAME (Sea)	TAME (Road)	TAME (Rail)	TAME (Barge)	TAME (Air)	ROW (Sea)	ROW (Road)	ROW (Rail)	ROW (Barge)	ROW (Air)
TEUMME (Sea)	9169316	0	0	0	0	5403255.000	0.000	0.000	0.000	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0
TEUMME (Road)	0	60554719	0	0	0	0.000	70234612.000	0.000	0.000	0	0	6453915.000	0	0	0	0	#########	0	0	0	0	305897.000	0	0	0	0	388001.748	0	0	0	0	#########	0	0	0
TEUMME (Rail)	0	0	2243168	0	0	0.000	0.000	5071561.000	0.000	0	0	0	122731.000	0	0	0	0	1329559.000	0	0	0	0	0.000	0	0	0	0	97262.886	0	0	0	0	1512219.114	0	0
TEUMME (Barge)	0	0	0	16342	0	0.000	0.000	0.000	1351740.000	0	0	0	0	554090.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	40428.000	0
TEUMME (Air)	0	0	0	0	38896	0	0	0	0	36997.000	0	0	0	0	336014.000	0	0	0	0	84686	0	0	0	0	286869	0	0	0	0	417074.365	0	0	0	0	871862.635
TEUCME (Sea)	7874552.000	0.000	0.000	0.000	0	10355966	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0
TEUCME (Road)	0.000	142465999.000	0.000	0.000	0	0	138191944	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	335414.000	0	0	0	0	465239.177	0	0	0	0	#########	0	0	0
TEUCME (Rail)	0.000	0.000	6138956.000	0.000	0	0	0	4123491	0	0	0	0	294558.000	0	0	0	0	735723.000	0	0	0	0	0.000	0	0	0	0	993578.318	0	0	0	0	2450071.682	0	0
TEUCME (Barge)	0.000	0.000	0.000	1415422.000	0	0	0	0	20279174	0	0	0	0	1329836.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	512024.000	0
TEUCME (Air)	0	0	0	0	163029.000	0	0	0	0	102857	0	0	0	0	806444.000	0	0	0	0	179813.000	0	0	0	0	1343919.000	0	0	0	0	1105331.67	0	0	0	0	1837740.333
Rest of EU (Sea)	27429369.000	0	0	0	0	60054872.000	0	0	0	0	114203129	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0
Rest of EU (Road)	0	7782195.000	0	0	0	0	13514887.000	0	0	0	0	168835228	0	0	0	0	#########	0	0	0	0	456491.000	0	0	0	0	482430.854	0	0	0	0	#########	0	0	0
Rest of EU (Rail)	0	0	147990.000	0	0	0	0	257005.000	0	0	0	0	51424609.2	0	0	0	0	458353.000	0	0	0	0	0.000	0	0	0	0	471362.414	0	0	0	0	5412821.586	0	0
Rest of EU (Barge)	0	0	0	529951.000	0	0	0	0	1160296.000	0	0	0	0	16434571.1	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	515100.000	0
Rest of EU (Air)	0	0	0	0	321376.000	0	0	0	0	703632.000	0	0	0	0	19287.6721	0	0	0	0	70358	0	0	0	0	301655.000	0	0	0	0	321076.453	0	0	0	0	540591.547
UK (Sea)	3099837.000	0	0	0	0	8547690.000	0	0	0	0	6655758.000	0	0	0	0	0	0	0	0	0	#########	0	0	0	0	8760928.289	0	0	0	0	#########	0	0	0	0
UK (Road)	0	5829687.000	0	0	0	0	4772092.000	0	0	0	0	6622928.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	2960464.716	0	0	0
UK (Rail)	0	0	297892.000	0	0	0	0	31995.000	0	0	0	0	69906.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	69926.043	0	0
UK (Barge)	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0
UK (Air)	0	0	0	0	32301.000	0	0	0	0	147155.000	0	0	0	0	40888	0	0	0	0	0	0	0	0	0	74031.000	0	0	0	0	52852.664	0	0	0	0	163386.336
USA (Sea)	9841424.000	0	0	0	0	14943157.000	0	0	0	0	2968502.000	0	0	0	0	#########	0	0	0	0	0	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0
USA (Road)	0	654739.000	0	0	0	0	963592.000	0	0	0	0	268423.000	0	0	0	0	22188.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	#########	0	0	0
USA (Rail)	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	37836.344	0	0
USA (Barge)	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	0.000	0	0	0	0	2702.038	0
USA (Air)	0	0	0	0	172089.000	0	0	0	0	1043771.000	0	0	0	0	145329.000	0	0	0	0	82877.000	0	0	0	0	0	0	0	0	0	449449.966	0	0	0	0	627997.034
TAME (Sea)	39768565.970	0	0	0	0	51529130.777	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	176481186	0	0	0	0	#########	0	0	0	0
TAME (Road)	0	4089836.890	0	0	0	0	4266996.958	0	0	0	0	3379724.583	0	0	0	0	103354.508	0	0	0	0	0.000	0	0	0	0	3266142.27	0	0	0	0	#########	0	0	0
TAME (Rail)	0	0	345329.058	0	0	0	0	1101975.789	0	0	0	0	2147708.213	0	0	0	0	204422.881	0	0	0	0	0.000	0	0	0	0	1199020.08	0	0	0	0	1282946.000	0	0
TAME (Barge)	0	0	0	579.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	0	0	0	0	0	1874364	0	0	0	0	4515959.000	0
TAME (Air)	0	0	0	0	634310.000	0	0	0	0	1891979.334	0	0	0	0	579007.873	0	0	0	0	186059.945	0	0	0	0	1343513.709	0	0	0	0	1321519.74	0	0	0	0	2577115.000
ROW (Sea)	93777990.030	0	0	0	0	86074657.223	0	0	0	0	#########	0	0	0	0	7205727.626	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0
ROW (Road)	0	15073182.11	0	0	0	0	19855730.042	0	0	0	0	#########	0	0	0	0	2232389.492	0	0	0	0	#########	0	0	0	0	#########	0	0	0	0	#########	0	0	0
ROW (Rail)	0	0	629721.942	0	0	0	0	442936.211	0	0	0	0	#########	0	0	0	0	148860.119	0	0	0	0	772598.727	0	0	0	0	2187557.916	0	0	0	0	6410621.376	0	0
ROW (Barge)	0	0	0	28939.000	0	0	0	0	1465717.000	0	0	0	0	3737487.000	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0	0	164913.000	0	0	0	0	4982091.919	0
ROW (Air)	0	0	0	0	618443	0	0	0	0	1406646.666	0	0	0	0	278079.127	0	0	0	0	127830.055	0	0	0	0	601529.291	0	0	0	0	1690851.259	0	0	0	0	165964.962

Appendix 3

Tariff rates for containerised goods between selected countries. Author's own compilation.

s: source	TEUMME (Sea	TEUMME (Roa	TEUMME (Rai	TEUMME (Bar	TEUMME (Air)	TEUCME (Sea	TEUCME (Roa	TEUCME (Rail	TEUCME (Bar	TEUCME (Air)	Rest of EU (S	Rest of EU (R	Rest of EU (R	Rest of EU (B	Rest of EU (Ai	UK (Sea)	UK (Road)	UK (Rail)	UK (Barge)	UK (Air)	USA (Sea)	USA (Road)	USA (Rail)	USA (Barge)	USA (Air)	TAME (Sea)	TAME (Road)	TAME (Rail)	TAME (Barge)	TAME (Air)	ROW (Sea)	ROW (Road)	ROW (Rail)	ROW (Barge)	ROW (Air)
TEUMME (Sea)	1	1	1	1	1	1.000	1	1	1	1	1.000	1	1	1	1	1.020	1.02	1.02	1.02	1.02	1.025	1.0249	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.024	1.0238	1.0238	1.0238	1.0238
TEUMME (Road)	1	1	1	1	1	1	1.000	1	1	1	1	1.000	1	1	1	1.02	1.020	1.02	1.02	1.02	1.0249	1.025	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.024	1.0238	1.0238	1.0238
TEUMME (Rail)	1	1	1	1	1	1	1	1.000	1	1	1	1	1.000	1	1	1.02	1.02	1.020	1.02	1.02	1.0249	1.0249	1.025	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.024	1.0238	1.0238
TEUMME (Barge)	1	1	1	1	1	1	1	1	1.000	1	1	1	1	1.000	1	1.02	1.02	1.02	1.020	1.02	1.0249	1.0249	1.0249	1.025	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.024	1.0238
TEUMME (Air)	1	1	1	1	1	1	1	1	1	1.000	1	1	1	1	1.000	1.02	1.02	1.02	1.02	1.020	1.0249	1.0249	1.0249	1.0249	1.025	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.0238	1.024
TEUCME (Sea)	1	1	1	1	1	1	1	1	1	1	1.000	1	1	1	1	1.020	1.02	1.02	1.02	1.02	1.025	1.0249	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.024	1.0238	1.0238	1.0238	1.0238
TEUCME (Road)	1	1	1	1	1	1	1	1	1	1	1	1.000	1	1	1	1.02	1.020	1.02	1.02	1.02	1.0249	1.025	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.024	1.0238	1.0238	1.0238
TEUCME (Rail)	1	1	1	1	1	1	1	1	1	1	1	1	1.000	1	1	1.02	1.02	1.020	1.02	1.02	1.0249	1.0249	1.025	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.024	1.0238	1.0238
TEUCME (Barge)	1	1	1	1	1	1	1	1	1	1	1	1	1	1.000	1	1.02	1.02	1.02	1.020	1.02	1.0249	1.0249	1.0249	1.025	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.024	1.0238
TEUCME (Air)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.000	1.02	1.02	1.02	1.02	1.020	1.0249	1.0249	1.0249	1.0249	1.025	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.0238	1.024
Rest of EU (Sea)	1	1	1	1	1	1.000	1	1	1	1	1	1	1	1	1	1.020	1.02	1.02	1.02	1.02	1.025	1.0249	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.024	1.0238	1.0238	1.0238	1.0238
Rest of EU (Road)	1	1	1	1	1	1	1.000	1	1	1	1	1	1	1	1	1.02	1.020	1.02	1.02	1.02	1.0249	1.025	1.0249	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.024	1.0238	1.0238	1.0238
Rest of EU (Rail)	1	1	1	1	1	1	1	1.000	1	1	1	1	1	1	1	1.02	1.02	1.020	1.02	1.02	1.0249	1.0249	1.025	1.0249	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.024	1.0238	1.0238
Rest of EU (Barge)	1	1	1	1	1	1	1	1	1.000	1	1	1	1	1	1	1.02	1.02	1.02	1.020	1.02	1.0249	1.0249	1.0249	1.025	1.0249	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.024	1.0238
Rest of EU (Air)	1	1	1	1	1	1	1	1	1	1.000	1	1	1	1	1	1.02	1.02	1.02	1.02	1.020	1.0249	1.0249	1.0249	1.0249	1.025	1.051	1.051	1.051	1.051	1.051	1.0238	1.0238	1.0238	1.0238	1.024
UK (Sea)	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1	1	1	1	1	1.031	1.0307	1.0307	1.0307	1.0307	1.044	1.0441	1.0441	1.0441	1.0441	1.031	1.031	1.031	1.031	1.031
UK (Road)	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1	1	1	1	1	1.0307	1.031	1.0307	1.0307	1.0307	1.0441	1.044	1.0441	1.0441	1.0441	1.031	1.031	1.031	1.031	1.031
UK (Rail)	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1	1	1	1	1	1.0307	1.0307	1.031	1.0307	1.0307	1.0441	1.0441	1.044	1.0441	1.0441	1.031	1.031	1.031	1.031	1.031
UK (Barge)	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1	1	1	1	1	1.0307	1.0307	1.0307	1.031	1.0307	1.0441	1.0441	1.0441	1.044	1.0441	1.031	1.031	1.031	1.031	1.031
UK (Air)	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1.02	1.02	1.02	1.02	1.020	1	1	1	1	1	1.0307	1.0307	1.0307	1.0307	1.031	1.0441	1.0441	1.0441	1.0441	1.044	1.031	1.031	1.031	1.031	1.031
USA (Sea)	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.013	1.0125	1.0125	1.0125	1.0125	1	1	1	1	1	1.0398	1.0398	1.0398	1.0398	1.0398	1.026	1.0256	1.0256	1.0256	1.0256
USA (Road)	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.0125	1.013	1.0125	1.0125	1.0125	1	1	1	1	1	1.0398	1.0398	1.0398	1.0398	1.0398	1.0256	1.026	1.0256	1.0256	1.0256
USA (Rail)	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.0125	1.0125	1.013	1.0125	1.0125	1	1	1	1	1	1.0398	1.0398	1.0398	1.0398	1.0398	1.0256	1.0256	1.026	1.0256	1.0256
USA (Barge)	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.0125	1.0125	1.0125	1.013	1.0125	1	1	1	1	1	1.0398	1.0398	1.0398	1.0398	1.0398	1.0256	1.0256	1.0256	1.026	1.0256
USA (Air)	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.0125	1.0125	1.0125	1.0125	1.013	1	1	1	1	1	1.0398	1.0398	1.0398	1.0398	1.0398	1.0256	1.0256	1.0256	1.0256	1.026
TAME (Sea)	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.036	1.0355	1.0355	1.0355	1.0355	1.0331	1.0331	1.0331	1.0331	1.0331	1	1	1	1	1	1.058	1.0581	1.0581	1.0581	1.0581
TAME (Road)	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0355	1.036	1.0355	1.0355	1.0355	1.0331	1.0331	1.0331	1.0331	1.0331	1	1	1	1	1	1.0581	1.058	1.0581	1.0581	1.0581
TAME (Rail)	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0355	1.0355	1.036	1.0355	1.0355	1.0331	1.0331	1.0331	1.0331	1.0331	1	1	1	1	1	1.0581	1.0581	1.058	1.0581	1.0581
TAME (Barge)	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0355	1.0355	1.0355	1.036	1.0355	1.0331	1.0331	1.0331	1.0331	1.0331	1	1	1	1	1	1.0581	1.0581	1.0581	1.058	1.0581
TAME (Air)	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0573	1.0573	1.0573	1.0573	1.057	1.0355	1.0355	1.0355	1.0355	1.036	1.0331	1.0331	1.0331	1.0331	1.0331	1	1	1	1	1	1.0581	1.0581	1.0581	1.0581	1.058
ROW (Sea)	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017	1.017	1.017	1.017	1.091	1.0912	1.0912	1.0912	1.0912	1.037	1.0366	1.0366	1.0366	1.0366	1.0446	1.0446	1.0446	1.0446	1.0446
ROW (Road)	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017	1.017	1.017	1.017	1.0912	1.091	1.0912	1.0912	1.0912	1.0366	1.037	1.0366	1.0366	1.0366	1.0446	1.0446	1.0446	1.0446	1.0446
ROW (Rail)	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017	1.017	1.017	1.017	1.0912	1.0912	1.091	1.0912	1.0912	1.0366	1.0366	1.037	1.0366	1.0366	1.0446	1.0446	1.0446	1.0446	1.0446
ROW (Barge)	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017	1.017	1.017	1.017	1.0912	1.0912	1.0912	1.091	1.0912	1.0366	1.0366	1.0366	1.037	1.0366	1.0446	1.0446	1.0446	1.0446	1.0446
ROW (Air)	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017	1.017	1.017	1.017	1.0912	1.0912	1.0912	1.0912	1.091	1.0366	1.0366	1.0366	1.0366	1.037	1.0446	1.0446	1.0446	1.0446	1.0446

Appendix 4

Initial NTMs Trade Costs Equivalent between selected countries. Author's own compilation.

s: source	TEUMME (Sea	TEUMME (Roa	TEUMME (Rail	TEUMME (Bar	TEUMME (Air)	TEUCME (Sea	TEUCME (Roa	TEUCME (Rail	TEUCME (Bar	TEUCME (Air)	Rest of EU (S	Rest of EU (R	Rest of EU (R	Rest of EU (B	Rest of EU (Ai	UK (Sea)	UK (Road)	UK (Rail)	UK (Barge)	UK (Air)	USA (Sea)	USA (Road)	USA (Rail)	USA (Barge)	USA (Air)	TAME (Sea)	TAME (Road)	TAME (Rail)	TAME (Barge)	TAME (Air)	ROW (Sea)	ROW (Road)	ROW (Rail)	ROW (Barge)	ROW (Air)
TEUMME (Sea)	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1	1
TEUMME (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
TEUMME (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
TEUMME (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
TEUMME (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
TEUCME (Sea)	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1	1
TEUCME (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
TEUCME (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
TEUCME (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
TEUCME (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
Rest of EU (Sea)	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1	1
Rest of EU (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
Rest of EU (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
Rest of EU (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
Rest of EU (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
UK (Sea)	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1	1	1
UK (Road)	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1	1
UK (Rail)	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1
UK (Barge)	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1
UK (Air)	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795
USA (Sea)	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1	1	1
USA (Road)	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1	1
USA (Rail)	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1
USA (Barge)	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1
USA (Air)	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072
TAME (Sea)	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1	1	1
TAME (Road)	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1	1
TAME (Rail)	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1
TAME (Barge)	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1
TAME (Air)	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345
ROW (Sea)	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1	1	1
ROW (Road)	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1	1
ROW (Rail)	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1
ROW (Barge)	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1
ROW (Air)	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727

Appendix 5

Final NTMs Trade Costs Equivalent between selected countries. Author’s own compilation.

s: source	TEUMME (Sea	TEUMME (Roa	TEUMME (Rail	TEUMME (Bar	TEUMME (Air)	TEUCME (Sea	TEUCME (Roa	TEUCME (Rail	TEUCME (Bar	TEUCME (Air)	Rest of EU (Se	Rest of EU (Ro	Rest of EU (Ra	Rest of EU (Ba	Rest of EU (Ai	UK (Sea)	UK (Road)	UK (Rail)	UK (Barge)	UK (Air)	USA (Sea)	USA (Road)	USA (Rail)	USA (Barge)	USA (Air)	TAME (Sea)	TAME (Road)	TAME (Rail)	TAME (Barge)	TAME (Air)	ROW (Sea)	ROW (Road)	ROW (Rail)	ROW (Barge)	ROW (Air)
TEUMME (Sea)	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.68290711	1	1	1	1	2.6736492	1	1	1	1	2.62433661	1	1	1	1	2.6757275	1	1	1	1
TEUMME (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
TEUMME (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
TEUMME (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
TEUMME (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
TEUCME (Sea)	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.68290711	1	1	1	1	2.6736492	1	1	1	1	2.62433661	1	1	1	1	2.6757275	1	1	1	1
TEUCME (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
TEUCME (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
TEUCME (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
TEUCME (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
Rest of EU (Sea)	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.74066945	1	1	1	1	2.68290711	1	1	1	1	2.6736492	1	1	1	1	2.62433661	1	1	1	1	2.6757275	1	1	1	1
Rest of EU (Road)	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1	1
Rest of EU (Rail)	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1	1
Rest of EU (Barge)	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831	1
Rest of EU (Air)	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.70072	1	1	1	1	2.66321	1	1	1	1	2.65402005	1	1	1	1	2.6050695	1	1	1	1	2.6560831
UK (Sea)	2.68290711	1	1	1	1	2.68290711	1	1	1	1	2.68290711	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1	1	1
UK (Road)	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1	1
UK (Rail)	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1	1
UK (Barge)	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795	1
UK (Air)	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.66321	1	1	1	1	2.70072	1	1	1	1	2.64314215	1	1	1	1	2.61801045	1	1	1	1	2.6425795
USA (Sea)	2.68668586	1	1	1	1	2.68668586	1	1	1	1	2.68668586	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1	1	1
USA (Road)	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1	1
USA (Rail)	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1	1
USA (Barge)	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072	1
USA (Air)	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.666961	1	1	1	1	2.67727625	1	1	1	1	2.70072	1	1	1	1	2.6260751	1	1	1	1	2.6527072
TAME (Sea)	2.61243357	1	1	1	1	2.61243357	1	1	1	1	2.61243357	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1	1	1
TAME (Road)	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1	1
TAME (Rail)	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1	1
TAME (Barge)	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345	1
TAME (Air)	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.59325385	1	1	1	1	2.63413975	1	1	1	1	2.63864095	1	1	1	1	2.70072	1	1	1	1	2.59175345
ROW (Sea)	2.69991146	1	1	1	1	2.69991146	1	1	1	1	2.69991146	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1	1	1
ROW (Road)	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1	1
ROW (Rail)	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1	1
ROW (Barge)	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727	1
ROW (Air)	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6800895	1	1	1	1	2.6688365	1	1	1	1	2.5296744	1	1	1	1	2.6320767	1	1	1	1	2.6170727

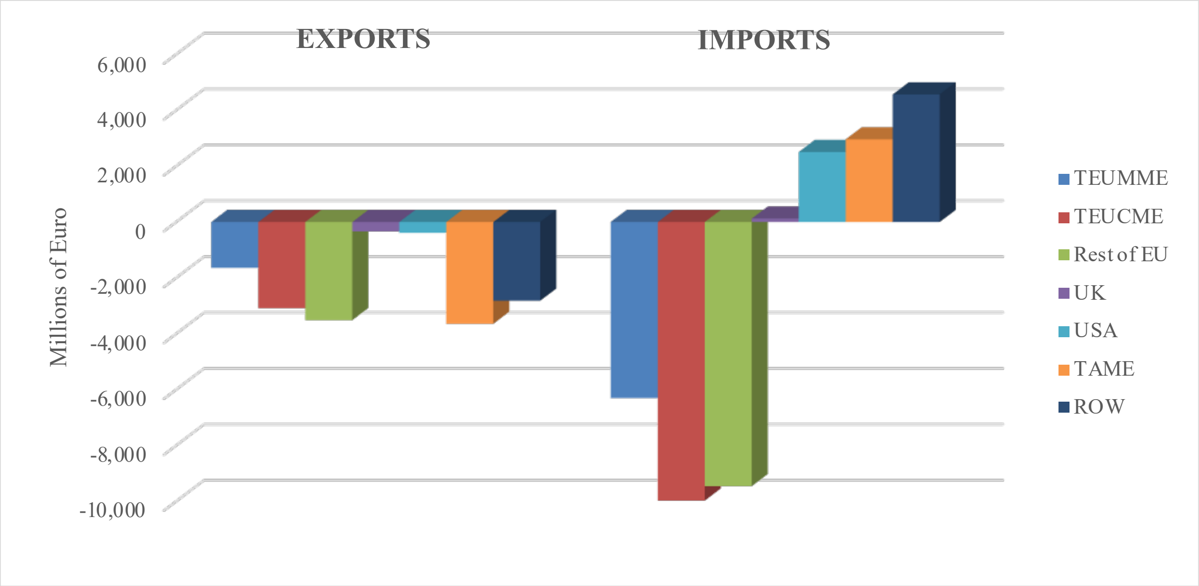
Appendix 6

Supply, Demand, and Substitution elasticities. Author's own compilation.

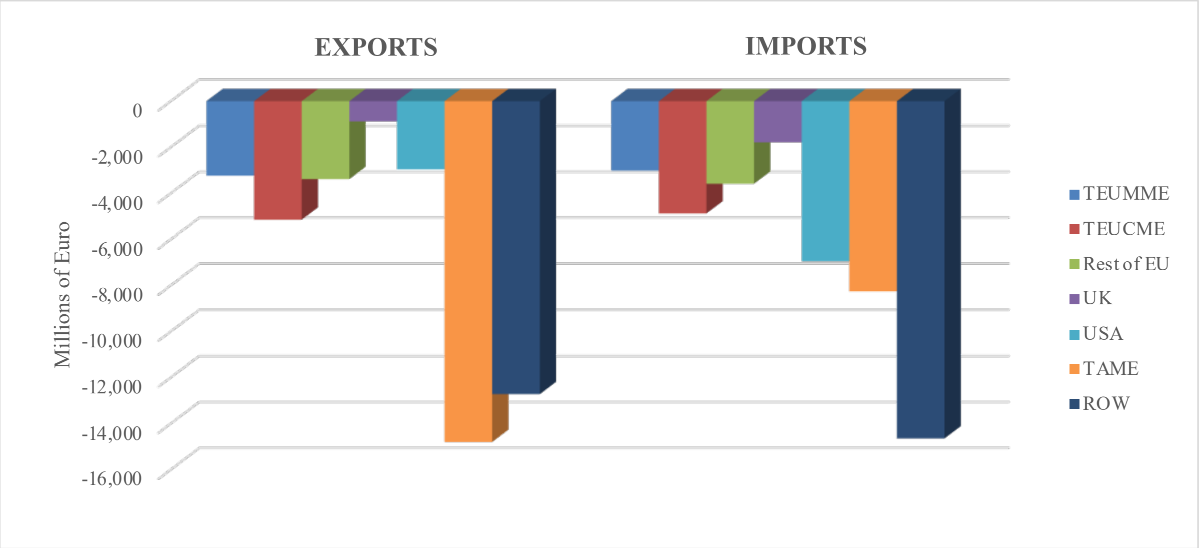
	Composite D	Substitution	Supply
TEUMME (Sea)	-1.2	0.42	0.75
TEUMME (Road)	-1.2	0.42	0.75
TEUMME (Rail)	-1.2	0.42	0.75
TEUMME (Barge)	-1.2	0.42	0.75
TEUMME (Air)	-1.2	0.42	0.75
TEUCME (Sea)	-1.2	0.42	0.75
TEUCME (Road)	-1.2	0.42	0.75
TEUCME (Rail)	-1.2	0.42	0.75
TEUCME (Barge)	-1.2	0.42	0.75
TEUCME (Air)	-1.2	0.42	0.75
Rest of EU (Sea)	-1.2	0.42	0.75
Rest of EU (Road)	-1.2	0.42	0.75
Rest of EU (Rail)	-1.2	0.42	0.75
Rest of EU (Barge)	-1.2	0.42	0.75
Rest of EU (Air)	-1.2	0.42	0.75
UK (Sea)	-1.2	0.42	0.75
UK (Road)	-1.2	0.42	0.75
UK (Rail)	-1.2	0.42	0.75
UK (Barge)	-1.2	0.42	0.75
UK (Air)	-1.2	0.42	0.75
USA (Sea)	-1.2	0.42	0.75
USA (Road)	-1.2	0.42	0.75
USA (Rail)	-1.2	0.42	0.75
USA (Barge)	-1.2	0.42	0.75
USA (Air)	-1.2	0.42	0.75
TAME (Sea)	-1.2	0.42	0.75
TAME (Road)	-1.2	0.42	0.75
TAME (Rail)	-1.2	0.42	0.75
TAME (Barge)	-1.2	0.42	0.75
TAME (Air)	-1.2	0.42	0.75
ROW (Sea)	-1.2	0.42	0.75
ROW (Road)	-1.2	0.42	0.75
ROW (Rail)	-1.2	0.42	0.75
ROW (Barge)	-1.2	0.42	0.75
ROW (Air)	-1.2	0.42	0.75

Appendix 7

Strategy 1; Scenario 1 and 2: variation in traded values of containerised goods



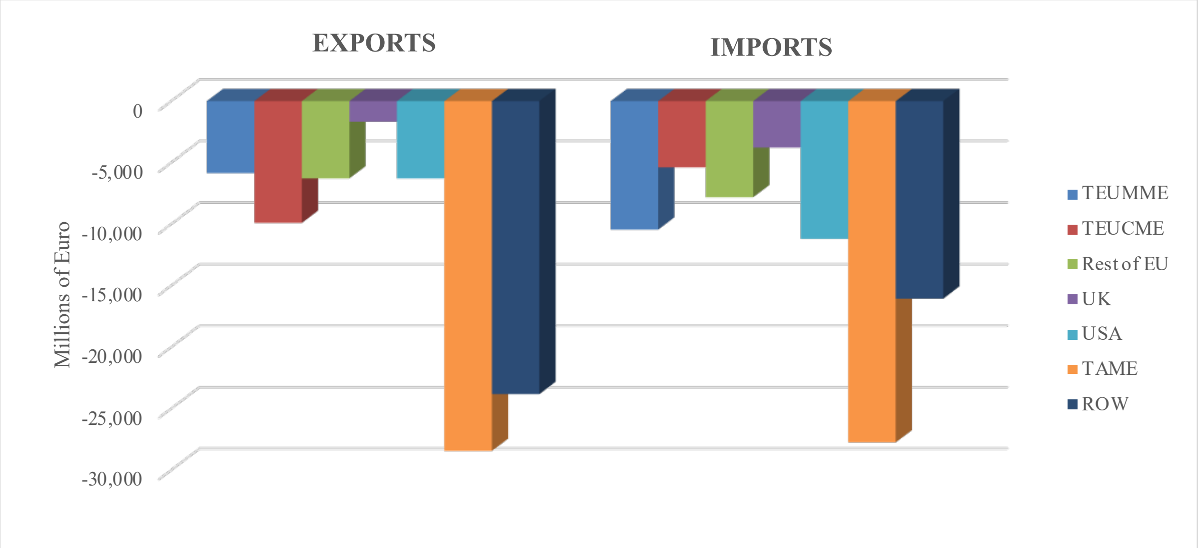
Scenario 1



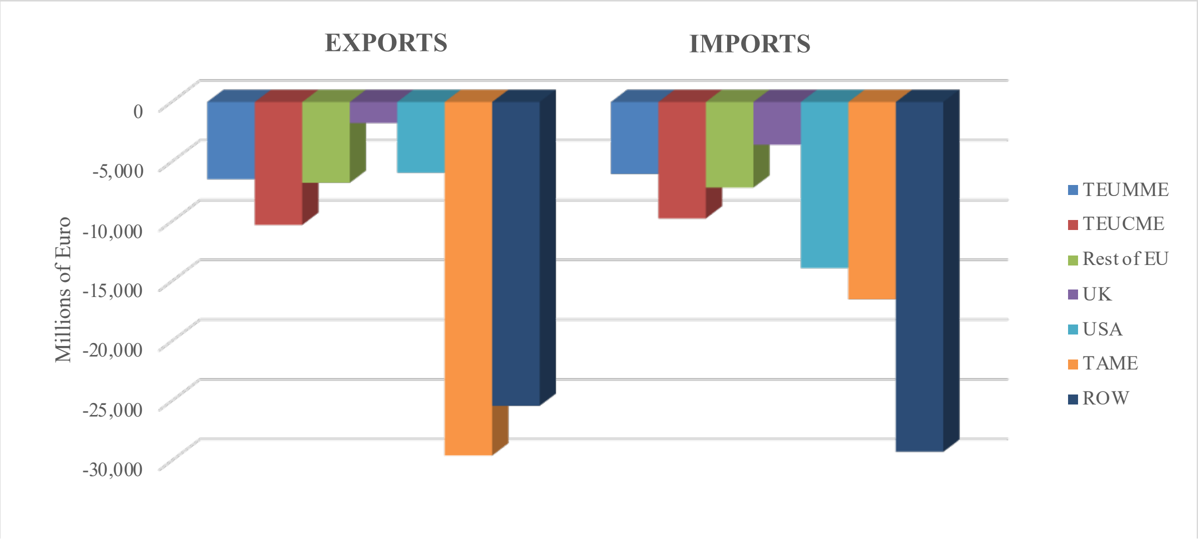
Scenario 2

Appendix 8

Strategy 2; Scenario 1 and 2: variation in traded values of containerised goods



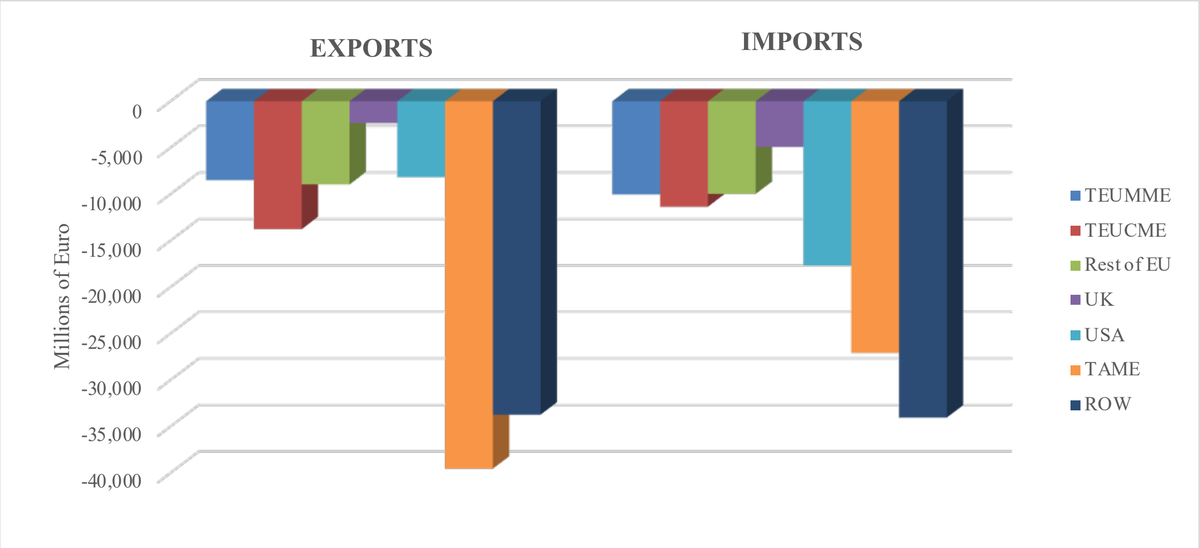
Scenario 1



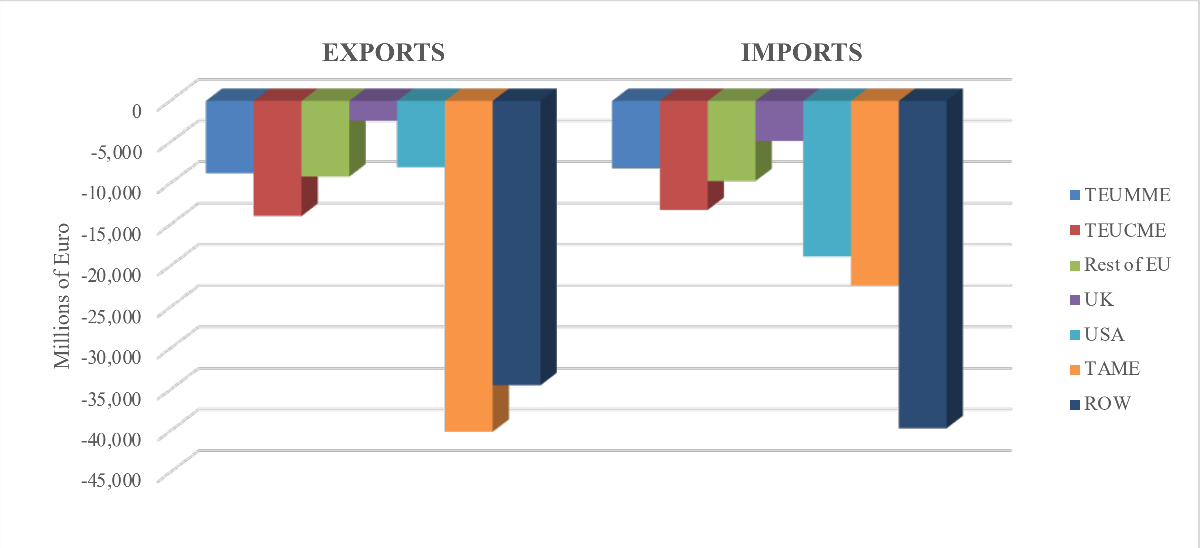
Scenario 2

Appendix 9

Strategy 3; Scenario 1 and 2: variation in traded values of containerised goods



Scenario 1



Scenario 2