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The shipping industry under the EU Green Deal: An Input-Output impact analysis

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ABSTRACT

In 2021, the European Commission introduced the 'Fit for 55' package, a set of policies aimed at reducing greenhouse gas (GHG) emissions by at least 55% by the year 2030. This initiative, aligned with the European Green Deal, seeks to make Europe a climate-neutral continent by 2050. A pivotal aspect of 'Fit for 55' is the proposed extension of the European Union Emissions Trading System (EU ETS) to the shipping industry. According to the European Commission, water transport accounts for 2.5% of global GHG emissions, while the shipping industry accounts for 13% of the EU's GHG emissions from transportation.

This stringent new shipping policy makes it imperative to determine how the world's economy will respond, considering three distinct implementation proposals with different rates of policy introduction. Evaluating the short-term impacts of the policy is crucial to ensuring that the sustainability initiative is not only ambitious but also pragmatic and adaptable to the realities. To assess the implications, this paper uses the Leontief price model, the environmental input-output (EIO) model, and the OECD Inter-Country Input-Output (ICIO) Table for 2018, which contains information for 45 sectors. The focus is on EU countries and its Top 10 Trading Countries.

Our findings show that a short-term trade-off exists between economic and environmental goals and that environmental gains incur economic losses for key stakeholders. They also show that the impact of this policy is felt more by producers in the EU and consumers in non-EU countries than by other agents in the respective countries. Lastly, a recommendation from our study is that the policy should be phased in progressively to provide economic agents with the necessary adjustment time and thus minimize economic losses.

1. Introduction

Industrialization has had an enormous impact on how the world sees the economy, economic activities, and welfare in society. It has brought greater productivity to all industries, including the shipping industry with the introduction of steam-powered engines to the merchant ships (Lehmacher, 2017; Durua, 2010). After the onset of industrialization, humankind moved away from living in an Empty World¹ towards living in a Full World, a transformation that has affected the Earth's carrying capacity and set us on the course

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¹ In the Empty World, natural capital is abundant and other capitals, such as human or financial capital, are scarce, In the Full World, on the other hand, natural capital is scarce while other capitals are relatively abundant (Daly and Farley, 2004).

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towards climate change. This effect has been felt for decades now. In 2015 it led to the introduction of the Paris Climate Accord, or Paris Agreement (as it is famously called), which established the framework for limiting global warming to 2 °C below pre-industrial levels while seeking to extend this limit to 1.5 °C (European Commission, 2019). According to the Intergovernmental Panel on Climate Change (IPCC)'s sixth assessment report, the world is likely to exceed the 1.5 °C mark in the next two decades, though it can reach the 1.5 °C limit if some transformational measures are adopted (Levin et al., 2021).

With the goal of making Europe a climate-neutral continent by 2050, the European Commission has introduced a transformative measure in the form of the EU Green Deal. This incorporates the 'Fit for 55' package, a group of policies aimed at reducing greenhouse gas (GHG) emissions by at least 55% with respect to the levels of the 1990s by 2030. Carbon pricing, whether executed through a carbon tax or an emission trading system, is touted as a cost-effective measure for reducing emissions (Baranzini et al., 2017; Baumol & Oates, 1971). Following its introduction in 2005, the European Union Emissions Trading System (EU ETS)² was able to reduce emissions by 35% by 2019 (Directorate-General for Climate Action, 2020) and is now planning to expand its horizons by also including the shipping industry.

Over 90% of global trade is transported via ships (OECD, 2019). Although shipping is one of the most energy-efficient modes of transportation, it makes up 3.2% of global CO₂ emissions.³ Thus far, no measures have been introduced to encourage the water transport industry to contribute towards the world's collective climate ambition (Directorate-General for Climate Action, 2021). Now, however, the 'Fit for 55' package is extending the EU ETS to cover CO₂ emissions by the shipping industry.

The European Commission proposes that the EU ETS should be introduced in a phased manner whereby the shipping industry would cover 20% of its CO₂ emissions by 2023, 45% by 2024, 70% by 2025 and 100% by 2026 (Howard, 2022). MEP Peter Liese, on the other hand, has called for this phase-in period to be accelerated to 33.3% by 2023, to 66.6% by 2024 and to 100% by 2025 (EEB, 2022), while the European Parliament has adopted legislation to cover 100% of CO₂ emissions by 2024 without any phase-in period (European Parliament, 2022). Moreover, under the European Commission's proposal, 100% of emissions on intra-EU routes and 50% of emissions on extra-EU routes are to be covered by 2026, with this latter figure extended to 100% from 2027 onwards (Norton Rose Fulbright, 2021). The European Parliament further suggests that if the International Maritime Organization (IMO) fails to bring in similar legislation to hold the maritime transportation of non-EU countries to account, then 100% of extra-EU routes should be covered by the EU ETS (European Parliament, 2022). At the time of writing, only vessels with over 5,000 gross tonnage are covered under the EU ETS (Gerretsen, 2022), though coverage is expected to be extended to vessels with a gross tonnage of between 400 and 5000 (Ship Technology, 2022).

Incorporating one of the most emissions-intensive⁴ industries into the EU ETS makes it imperative to analyse the consequences of this new policy on agents (consumers and producers) in the economies of the EU and its top 10 (non-EU) trading partners (henceforth, EU's Top 10 Trading Countries). Greater interdependence between countries often leads to the domestic policies of one country affecting the other countries (Owens, 1993). This phenomenon is often studied in a partial equilibrium framework using regression analysis, as was conducted by Gober & Burns (1997) and Crozet et al. (2016).

Unlike the usual approaches for analysing the inter-country influence of domestic measures, this paper uses a general equilibrium perspective that includes every country in the world. Specifically, the analysis is based on a multi-national input–output model using the Leontief price model. The input–output model illuminates economic interdependencies within a single economy, showcasing how industries are linked through both input and output exchanges. Extending this concept, the multi-national input–output model broadens the perspective to illustrate global economic linkages among countries. The Leontief price model within input–output analysis examines the impact of cost shocks on the production prices, providing a comprehensive understanding of the cost and price interconnectedness between sectors and nations.

The macroeconomic model used for the analysis is based on the interdependence of different sectors across countries and is used to analyse the ripple effects of a shock in the economy. This linear model follows the principles⁵ of homogeneity and proportionality, and assumes fixed technology (IMPLAN, 2021). The model does not take into account substitution effects among modes of transportation or products from different countries. It depicts immediate changes (i.e., short term impacts) in the economy (Government of British Columbia, 2019). Only impacts from shock to the economy in the first year are therefore analysed. However, given the model's linear nature, the impacts of 20%, 33.3% and 100% of CO₂ emission coverage will be proportional. Nevertheless, it is still interesting to put things into perspective and this paper will therefore study the following three cases:

- Case 1: The European Commission's proposal: to cover 20% of the shipping industry's CO₂ emissions under EU ETS in the first year.
- Case 2: MEP Peter Liese's proposal: to cover 33.3% of the shipping industry's CO₂ emissions under EU ETS in the first year.
- Case 3: the European Parliament's proposal: to cover 100% of the shipping industry's CO₂ emissions under EU ETS in the first year⁶.

The rest of this paper is organised as follows. Section 2 describes the models (i.e., the Leontief price model and the environmental

² The EU ETS works on the 'cap and trade' system. A cap on the total amount of GHG emissions is set and reduced over time. Entities can buy and trade emission allowances within this cap.

³ This number is based on the authors' calculations (see section 5).

⁴ With respect to CO₂ emission intensity, *water transport* is second only following the *electricity, gas, steam and air conditioning supply*.

⁵ According to the principle of homogeneity, each industry uses a unique set of inputs to produce its respective output. And according to the principle of proportionality, the inputs used are directly proportional to the output, and economies of scale are not taken into consideration.

⁶ To keep the estimation simple, this paper takes 50% coverage of extra-EU routes into account for all the three cases.

input–output model) used for the analysis, and explains the methodology for estimating consumer welfare, the cost of living, changes in output and emissions, and revenue generated. Section 3 discusses the data and report limitations. Section 4 presents the empirical results from the simulation, and section 5 discusses those results. Finally, section 6 presents our conclusions.

2. Methodology

Input-output (IO) modelling, along with computable general equilibrium (CGE) models, provides unique insights into the wider economic impacts resulting from sectoral linkages (Lakshmanan, 2011; Rey, 2000). It recognizes the interdependencies between industries and describes the connections between transportation and other sectors, allowing for a comprehensive understanding of the impacts on the economy. IO models offer several advantages, including the ability to identify how aggregated impacts are distributed among different economic sectors, enabling sector-specific modelling (Allan, 2015). Additionally, IO models are more straightforward to construct compared to CGE models, which can be complex and challenging (Loveridge, 2004; Partridge & Rickman, 2010). The simplicity and widely recognized multiplier effect concept of IO modelling have led to its extensive application in both practical and academic contexts, making it a valuable tool for informed decision-making in policy formulation and economic analysis.

There are two main types of Leontief IO models: quantity models and price models. When studying the role of transportation in the economy, researchers have predominantly used quantity models in various papers. For example, Pompigna & Mauro (2020) developed a macro-level IO model to analyse freight demand in the Italian-Austrian cross-border stretch of the Brenner corridor. Alises & Vassallo (2016) explored the impact of economic restructuring on road freight transport demand in the UK and Spain, emphasizing the influence of non-economic factors on defining transport demand. Cascetta et al. (2013) created a multi-regional input–output (MRIO) model incorporating elastic trade coefficients to estimate freight demand in Europe. Jin et al. (2005) utilized a random-utility-based MRIO (RUMBRIO) model to study spatial trade patterns in Texas via highway and rail, assessing impacts of production technology change, transportation congestion, and demand fluctuations. Ali et al. (2021) quantified the macroeconomic impacts of a transportation strike in Pakistan using an inoperability input–output model. Lee & Yoo (2016) employed IO to examine transportation sectors' role in the Korean national economy. They also applied the price model to investigate a hypothetical scenario of a 10% increase in transport service rates. Additionally, Chang et al. (2014) utilized IO to assess the economic impact of port sectors on the South African economy, revealing high forward linkages indicating its significance as an input for other industries, but relatively weak backward linkages suggesting less reliance on other sectors for production. Furthermore, they used the price model to study hypothetical scenarios of port sectoral price increase.

This paper uses the Leontief price model for its suitability to study the cost and price impacts of implementing the EU ETS in the shipping industry. This model also enables an in-depth evaluation of the economic consequences of the cost effects – namely, the impact on consumption price, welfare, output, emissions, and public revenue. The IO table is in the form of a symmetrical matrix that provides information about how output is distributed across different sectors in different countries. It also shows how much input is used from different sectors across different countries to produce the output.

The IO model is based on the Leontief production function, where a fixed amount of input (intermediate goods and value added) is used to produce a unit of output. Final demand is an exogenous element in the model. The model also ignores economies of scale and operates under constant returns to scale. However, although these assumptions potentially simplify the complexities of real-world economic systems, they align with the aim of studying the immediate impacts of the new policy.

To understand the impact of a shock (i.e., implementing the EU ETS in the shipping industry), the first step is to set the benchmark Leontief price model as follows (Miller & Blair, 2022):

$$p = (I - A')^{-1}v = L'v \quad (1)$$

Here, I is an $n \times n$ dimension identity matrix, where n is 1710, i.e., 45x38 or the total number of sectors across all the countries under consideration. A is an $n \times n$ dimension matrix of technical coefficients, where a_{rs} is the amount of output from sector r used to produce \$1 worth of output from sector s . The Leontief inverse (L') with transposed technical coefficient matrix (A') is post-multiplied with the cost of value added per unit of output (v).⁷

Once the price model gives a column vector p of 1 s, the model is ready to introduce the shock. Since the shock is based on CO₂ emissions from 45 sectors and 38 countries, the next step is to use the Environment Input Output (EIO) model to estimate total emissions⁸ per unit of output for each of the 45 sectors in the 38 countries:

$$m = e(I - A)^{-1} \quad (2)$$

Here, e is a diagonal matrix of direct carbon intensity, i.e., direct carbon emission produced by \$1 worth of output for a sector. Pre-multiplying e by Leontief inverse (L) gives total carbon intensity (m)⁹. This is multiplied by a scalar (ϕ), which represents carbon price, expressed in \$/ton of CO₂, to arrive at ϵ (Gemechu et al., 2013):

⁷ Value added includes compensation for labour (or employees) and capital (i.e., gross operating surplus). It also includes taxes less subsidies on intermediate products (OECD, 2022).

⁸ This includes both direct and indirect emissions.

⁹ The matrix m is summed over column to arrive at total carbon intensity of each sector of the 38 regions.

$$\varepsilon = \phi m \tag{3}$$

Note that ε is a vector that represents all sectors across all countries. However, the shock introduced in this paper is only for the forward linkages of the shipping industry (i.e., wherever shipping industry is used as an input), which is 100% for EU countries and 50% for non-EU countries. This involves the construction of a shock matrix (E), where output from the shipping industry used as an input has the shock value ε_i for EU countries i and $\varepsilon_i/2$ for all non-EU countries i when trading with the EU. Input used from other sectors and trade between non-EU countries has a shock value of 0. The transposed version of the shock matrix (E') is depicted below:

$$E' = \begin{matrix} & \begin{matrix} \text{EU} & & \text{Non - EU} & & \text{So on} \end{matrix} \\ \begin{matrix} \text{EU} \\ \text{Non - EU} \\ \text{So on} \end{matrix} & \begin{bmatrix} 0 & \dots & \varepsilon_i & 0 & 0 & \dots & \varepsilon_i/2 & 0 & \dots & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & \varepsilon_i & 0 & 0 & \dots & \varepsilon_i/2 & 0 & \dots & \dots \\ 0 & \dots & \varepsilon_i & 0 & 0 & \dots & \varepsilon_i/2 & 0 & \dots & \dots \\ 0 & \dots & \varepsilon_i/2 & 0 & 0 & \dots & 0 & 0 & \dots & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & \varepsilon_i/2 & 0 & 0 & \dots & 0 & 0 & \dots & \dots \\ 0 & \dots & \varepsilon_i/2 & 0 & 0 & \dots & 0 & 0 & \dots & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \end{matrix}$$

This matrix (E') was used to introduce shock into the Leontief price model as follows:

$$p^E = [(1 + E') \cdot (I - A)^{-1}]v \tag{4}$$

Here, p^E gives the production price due to the introduced shock. The matrix $(1 + E')$ is dot-multiplied (i.e., multiplied element-by-element) with the Leontief inverse (L) and then post-multiplied by v .

This change in price also affects the consumer price index (CPI). The CPI (p^c) is defined as follows (Llop & Pié, 2008):

$$p_i^c = \sum_{j=1}^n p_{ij}^E \alpha_{ij} \tag{5}$$

Here, p_i^c is the CPI for country i given by the sum of the product of the new price (p_{ij}^E) in country i for sector j ¹⁰ and share (α_{ij}) of sector j final good in the final private consumption of country i . It can also be referred to as the consumption price.

To ascertain the impact of the shock on private real income, the change in consumer welfare can be estimated as follows:

$$\Delta W_i = W_i - W_i^E = \sum_{j=1}^n p_{ij}^c C_{ij} - \sum_{j=1}^n p_{ij}^{cE} C_{ij} \tag{6}$$

Welfare is estimated as expenditure on consumption by the final consumer.¹¹ Here, W_i and W_i^E are the welfare of country i before and after the introduction of EU ETS, respectively. C_{ij} is the consumption of final good from sector j in country i .

The change in production price can also be used to estimate new output (x^E) and CO₂ emissions (ε^E) (Gemechu et al., 2013):

$$x_{ij}^E = p_{ij} x_{ij} / p_{ij}^E \tag{7}$$

$$\varepsilon_{ij}^E = e_{ij} x_{ij}^E \tag{8}$$

New CO₂ emissions (ε^E) can be used to estimate the total revenue (R^s) that the European Commission receive by introducing EU ETS for the shipping industry.

$$R^s = \sum_{i=1}^{38} \varepsilon_i^s \phi \theta_i \rho_i \tag{9}$$

¹⁰ Note that sector j is 45x38 sectors, i.e., the sectors of all countries are included.

¹¹ For the analysis, 'Household Final Consumption Expenditure' is taken as consumption by the final consumer.

Here, e_i^s is the new CO₂ emissions from the shipping industry, ϕ is the carbon emission price, and θ_i is the share of shipping industry trade of country i with the EU.¹² For EU countries, this share will always be 1 as they themselves will always be a party to the trade activity. Additionally, ρ_i is the share of emissions country i is held accountable for by the European Commission.¹³ For EU countries, $\rho_i = 1$ (i.e., 100% of emissions), while for non-EU countries, $\rho_i = 0.5$ (i.e., 50% of emissions).

3. Data

This paper uses the OECD Inter-Country Input-Output (ICIO)¹⁴ Table for 2018 for 45 sectors, with the *water transport* sector taken as a proxy for the shipping industry¹⁵. OECD ICIO tables¹⁶ comprise 66 countries and Rest of the World (RoW). Since the focus is on the EU and its Top 10 Trading Countries, the paper has used data for 37 countries (27 EU countries and the EU's Top 10 Trading Countries), while the remaining countries are collapsed with the RoW. The ICIO table for 2018 is also used to determine the EU's Top 10 Trading Countries (in goods and services), which are USA, UK, China, Switzerland, Russia, Japan, India, Turkey, Norway, and South Korea, in that order.¹⁷

The IO table used for the analysis is a 1710×1710 symmetric matrix representing the production side of the economy. The rows provide information about the distribution of the output from sector j of country i , while the columns provide information about the input used to produce the output by sector j of country i . Direct CO₂ emissions based on production for sector j of country i (OECD, 2021) are used to estimate the impact of the introduced shock. The carbon price is taken as \$45 per ton.¹⁸

The ICIO Tables describe the economic structure by reflecting the inter-industry and inter-country transactions. The starting point for constructing any multi-regional input-output (MRIO) table are the individual country's input-output tables together with international trade data. This leads to uncertainties in relation to the data source, such as adjustment to common base currency, mismatch in import and export data between any two countries, dealings with the 'Rest of the World', and the assumption of proportionality. Also, since the tables are given *industry-by-industry*, this leads to uncertainties associated with the aggregated sector classification (Owen, 2013). For instance, the *Agriculture, hunting, forestry* sector in the OECD ICIO Tables includes both animal and plant farming but the difference between the CO₂ emissions for these two types of farming is not captured in the table.

4. Results

In this section, we present the results obtained by applying the methodology outlined in section 2 to the data from section 3. The analysis provides valuable insights into the changes in production prices, consumption prices, consumer welfare, output, CO₂ emissions, and total revenue generated for each of the three cases studied.

Fig. 1 illustrates the size of the contributions of the EU and the EU's Top 10 Trading Countries to emissions from their respective shipping industries in the year 2018. In terms of total CO₂ emissions from the shipping industry, China leads the way¹⁹. Amongst the EU countries, Denmark, Italy, and Greece are the main contributors to global CO₂ emissions from that industry.

Like any tax increase on goods and services, introducing EU ETS into the shipping industry leads to a corresponding increase in production prices in the shipping industry. This increase will have a snowball effect that will be felt by producers (of other industries) and consumers across the economy.

Based on the average change in production price, the impact felt by the EU countries is roughly 0.02%, while in the EU's Top 10 Trading Countries it is 0.0003% when the shipping industry is held accountable for only 20% of its CO₂ emissions in the first year (Case 1). Due to the linear nature of IO, this average percentage change in production price will increase when the accountability for CO₂ emissions increases. For instance, in Case 3, when the European Parliament's proposal is implemented, when the shipping industry is

¹² Since e_i^s provides the total emissions of the shipping industry for country i but the revenue is generated only for emissions when trade is conducted with an EU country, it is essential to consider only the share of shipping industry trade that takes place with the EU, which is represented by θ_i .

¹³ Based on the differential treatment of intra-EU routes and the extra-EU route.

¹⁴ The OECD ICIO Database was selected for this study because, with a release date of November 2021, it provided the most recent data available at the time of analysis. Moreover, its credibility is underscored by the OECD's benchmarking to the National Accounts and Balance of Payments of the individual countries. In addition, it incorporates underlying data from over 130 countries to estimate the Rest of the World (RoW), thus ensuring a closed economy model (OECD Directorate for Science, Technology and Innovation, 2021; Guilhoto, 2021).

¹⁵ The gross tonnage of the vessels has not been taken into consideration. The water transport sector of the OECD ICIO Tables includes both inland water transport and sea transport.

¹⁶ These tables provide information about the flow of final and intermediate goods and services for all countries and all industries. It is assumed that each industry produces one good. The blocks of diagonal matrices provide information about the domestic flow of intermediate goods and services, while the blocks of off-diagonal matrices provide information about trade in intermediate goods and services between two countries.

¹⁷ Except for the order in which the countries appear, the list of the Top 10 Trading Countries of EU27 is the same as that recorded by the European Commission for 2020 (Directorate General for Trade, 2022).

¹⁸ The European Commission's Impact Assessment Report uses €45 as the average carbon price for assessment between 2021 and 2025 (European Commission, 2021). Since the data in the OECD table are presented in \$ and €45 is currently roughly equivalent to \$46.02, to keep the calculations simple the carbon price is assumed to be \$45.

¹⁹ China is followed by USA, India, Russia, and Japan. No EU country features among the top five CO₂ emitters when all 45 sectors are taken into account.

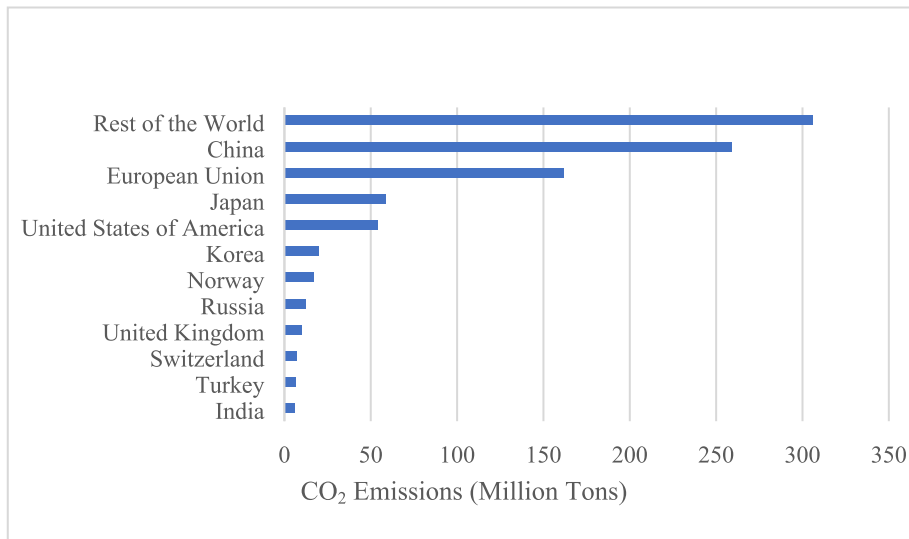


Fig. 1. Shipping Industry Emissions.

accountable for 100% of its CO₂ emissions in the first year (but only 50% accountability is held from the extra-EU routes), the average percentage increase in production prices in the EU is roughly 0.08%, while in the EU's Top 10 Trading Countries it is roughly 0.002%. On average, the world will experience a 0.06% increase in production prices in the first year if 100% of CO₂ emissions from the shipping industry are accounted for and a 0.01% increase if only 20% of CO₂ emissions are (Table 1). Map 1 (below) shows the comparative increase in production price across the EU countries and the EU's Top 10 Trading Countries. The highest increases are seen in Malta, Croatia, Spain, Slovenia, and Greece.

Except for the *water transport* sector, where the change in production price is highest (0.40%),²⁰ the top ten sectors are shown in Table 2 for the EU, the EU's Top 10 Trading Countries, and the World.

Since the EU is affected the most by the implementation of the EU ETS in the shipping industry,²¹ the top ten sectors for the World are the same as those for the EU except for the ranking of the first three sectors (due to the influence of the EU's Top 10 Trading Countries). Intuitively, the sectors related to the water transportation and supply chain are expected to be the most affected, as is illustrated by the *Fishing and aquaculture* and the warehousing and transportation sectors. This change in the average production price also affects the metallic and non-metallic mineral sectors. Notably, *Food products, beverages and tobacco* is also among the top sectors in the EU countries to be affected by this increase in average production price.

Table 3 shows the changes in the consumer price index (CPI) and consumer welfare (in both percentage and absolute terms). The CPI provides information about cost of living in an economy. An increase in the cost of living reduces consumers' purchasing power, thus leading to a reduction in their economic welfare.²²

Both these parameters, which help to determine the impact on consumers, show that, in percentage terms, consumers in EU countries are impacted more than those in the EU's Top 10 Trading Countries. However, in terms of absolute change, the EU's Top 10 Trading Countries face greater reductions in consumer welfare than EU countries.

In EU countries, the highest percentage increases in the cost of living are observed in Malta, Greece, Croatia, Italy, and Sweden. However, the highest absolute decreases in consumer welfare are observed in Italy, Germany, Greece, Spain, and France. Italy and Greece have not only the highest cost of living but also the largest decrease in private real income. These decreases in the welfare of Italy and Greece are due to the large amount of initial final consumption.

Among the EU's Top 10 Trading Countries, the largest increase in the cost of living is observed in Norway, India, Switzerland, the UK and Turkey. However, the greatest decrease in consumer welfare (in absolute terms) is observed in China, USA, Russia, Norway, and the UK. The UK and Norway saw an increase in the cost of living as well as the greatest decrease in consumer welfare. This implies that final consumption in those countries is highly dependent on foreign goods and services.

Maps 2 and 3 show comparative changes in the CPI and consumer welfare across EU countries and the EU's Top 10 Trading Countries, respectively. As Table 3 shows, the cost of living in EU countries increased the most. In fact, the only non-EU country in the top 10 is Norway, which, being in continental Europe, is close to the countries of the EU. Moreover, an absolute decrease in consumer welfare is observed in larger economies such as Italy, Germany, Greece, and Spain. Notably, two of the EU's Top 10 Trading Countries

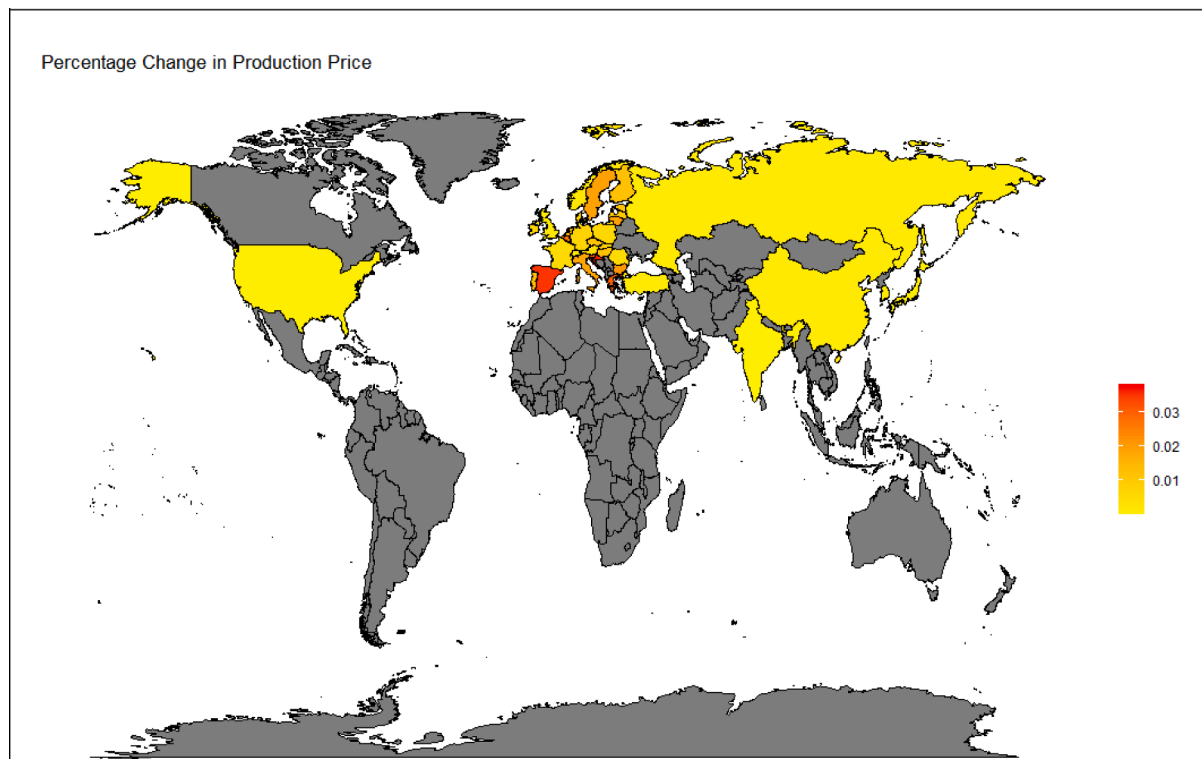
²⁰ This is the percentage change in production price across the world for the *water transport* sector. It is 0.57% for the EU and 0.003% for the EU's Top 10 Trading Countries.

²¹ The weight of EU countries is also greater in the analysis than the EU's Top 10 Trading Countries and the RoW, i.e., 27 versus 11.

²² As now, consumers must pay more to consume the same goods and services.

Table 1
Average Percentage Change in Production Prices (%).

Region	Case 1	Case 2	Case 3
EU	0.0157	0.0262	0.0786
EU's Top 10 Trading Countries	0.0003	0.0006	0.0017
World	0.0113	0.0187	0.0563



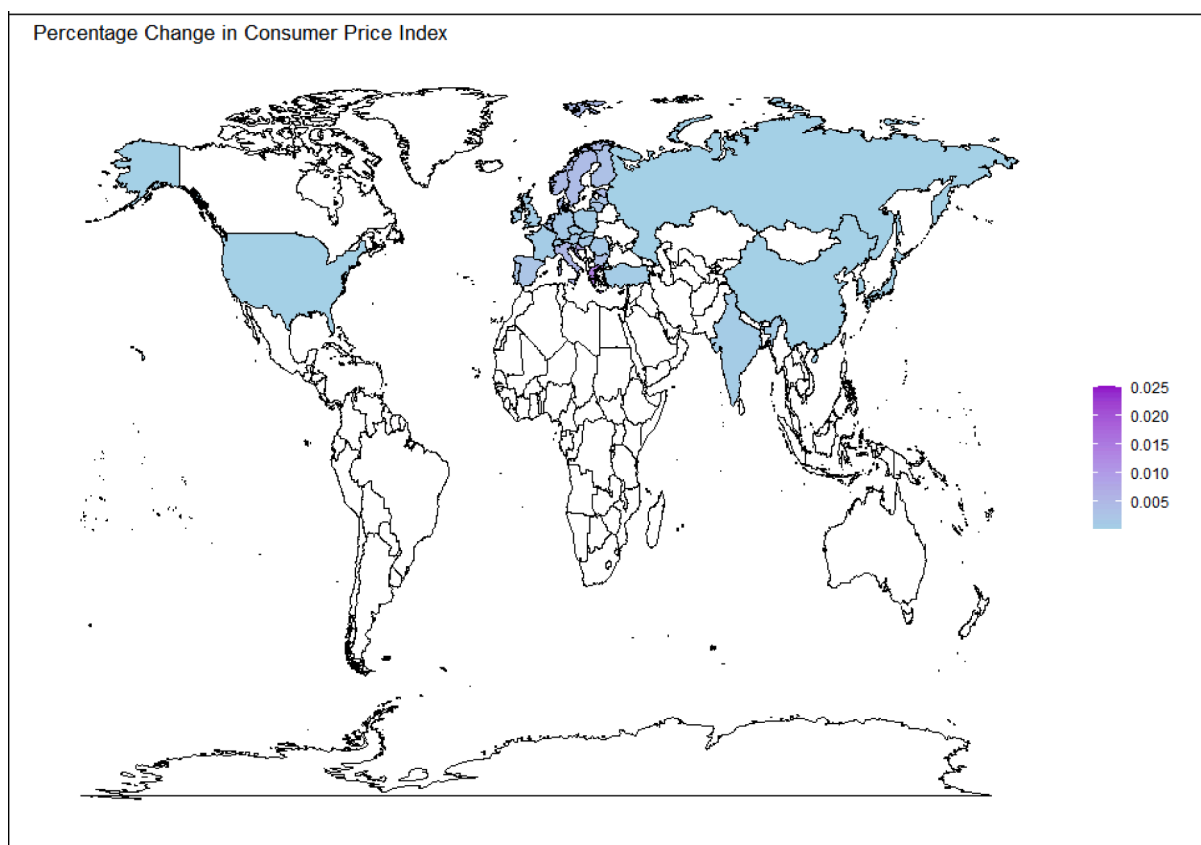
Map 1. Percentage increase in production prices for EU countries and the EU's Top 10 Trading Countries.

Table 2
Ranking of Sectors by Change in Production Price (Descending Order).

EU	EU's Top 10 Trading Countries	World
Fishing and aquaculture	Warehousing and support activities for transportation	Fishing and aquaculture
Land transport and transport via pipelines	Land transport and transport via pipelines	Warehousing and support activities for transportation
Warehousing and support activities for transportation	Fishing and aquaculture	Land transport and transport via pipelines
Air transport	Other non-metallic mineral products	Air transport
Basic metals	Coke and refined petroleum products	Basic metals
Mining and quarrying, energy producing products	Mining and quarrying, non-energy producing products	Mining and quarrying, energy producing products
Electrical equipment	Paper products and printing	Electrical equipment
Other non-metallic mineral products	Wood and products of wood and cork	Other non-metallic mineral products
Coke and refined petroleum products	Basic metals	Coke and refined petroleum products
Food products, beverages and tobacco	Rubber and plastics products	Food products, beverages and tobacco

Table 3
Impact on Consumers.

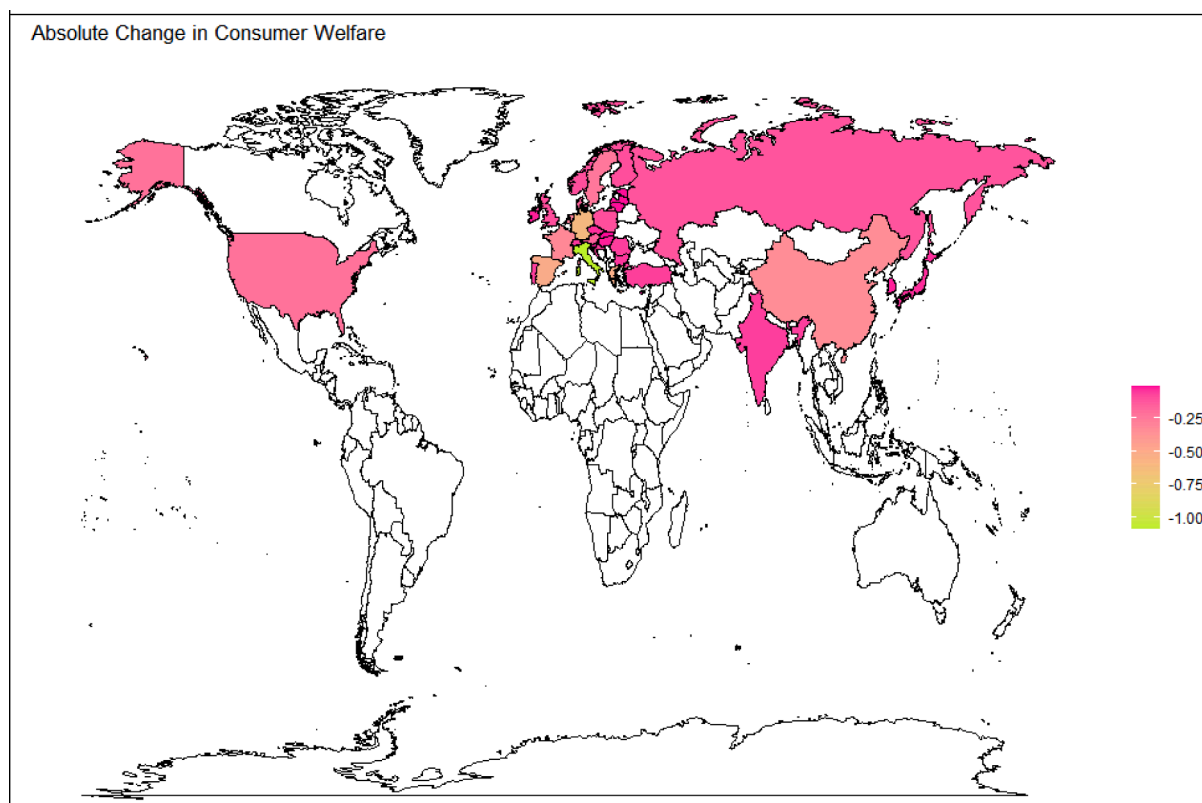
Region	Case 1	Case 2	Case 3
<i>Percentage Change in Consumer Price Index (%)</i>			
EU	0.0039	0.0065	0.0194
EU's Top 10 Trading Countries	0.0008	0.0013	0.0040
World	0.0030	0.0050	0.0149
<i>Percentage Change in Consumer Welfare (%)</i>			
EU	-0.0017	-0.0028	-0.0083
EU's Top 10 Trading Countries	-0.0001	-0.0001	-0.0003
World	-0.0002	-0.0004	-0.0011
<i>Absolute Change in Consumer Welfare (in million USD)</i>			
EU	-0.10	-0.16	-0.49
EU's Top 10 Trading Countries	-1.09	-1.82	-5.46
World	-7.13	-11.88	-35.67



Map 2. Percentage increase in the consumer price index for EU countries and the EU's Top 10 Trading Countries.

(China and USA) are among the countries most affected, in terms of loss of consumer welfare, by the implementation of EU ETS in the shipping industry.

According to the IO model, any increase in production price will lead to a decrease in CO₂ emissions on account of decreased output. This is shown in Table 4. Both these changes are most noted for EU countries, while an extremely small percentage decrease is recorded for the EU's Top 10 Trading Countries (in both percentage and absolute terms). Intuitively, EU countries are expected to have to cut more CO₂ emissions, since that is the whole purpose of introducing EU ETS, whereas the EU's Top 10 Trading Countries have to



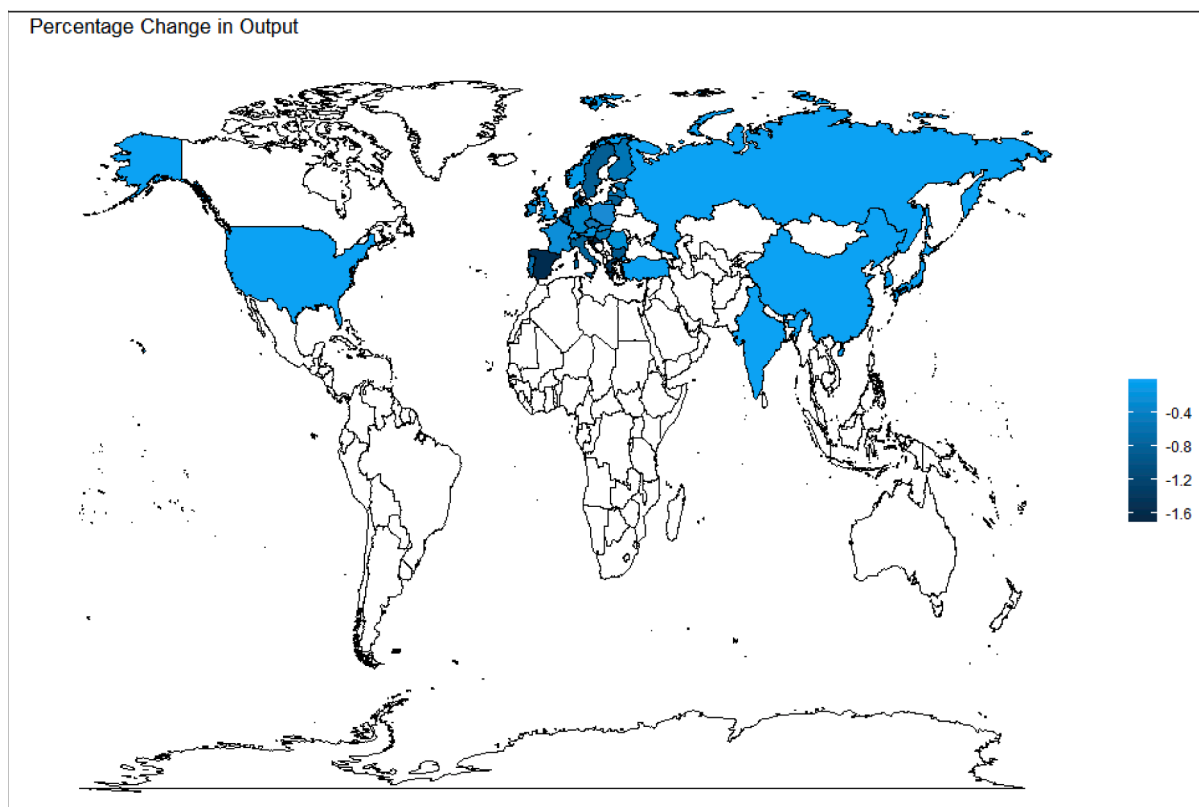
Map 3. Absolute decrease in consumer welfare (in million USD) for EU countries and the EU's Top 10 Trading Countries.

Table 4
Impact on Production.

Region	Case 1	Case 2	Case 3
Percentage Change in Output (%)			
EU	-0.70	-1.16	-3.42
EU's Top 10 Trading Countries	-0.02	-0.03	-0.08
World	-0.50	-0.83	-2.45
Absolute Change in Output (in million USD)			
EU	-1,116.25	-1,853.34	-5,489.76
EU's Top 10 Trading Countries	-113.23	-188.53	-566.16
World	-1,331.06	-2,211.01	-6,563.81
Percentage Change in CO₂ Emissions (%)			
EU	-0.69	-1.14	-3.34
EU's Top 10 Trading Countries	-0.02	-0.03	-0.08
World	-0.49	-0.82	-2.40
Absolute Change in CO₂ Emissions (in million tons)			
EU	-1.01	-1.67	-4.89
EU's Top 10 Trading Countries	-0.04	-0.06	-0.18
World	-1.08	-1.80	-5.27

reduce their emissions only by 50% when trading with an EU country.

Maps 4–7 show the comparative decreases in output and CO₂ emissions in both percentage and absolute terms for EU countries and the EU's Top 10 Trading Countries. In percentage terms, the biggest reduction in output is observed in Malta, Croatia, Spain, Greece, and Slovenia, while in absolute terms, the biggest reduction is observed in Greece, Italy, Germany, Netherlands, and Denmark. This implies that Greece must reduce its output the most compared to the rest of the world (i.e., in absolute terms) and compared to its benchmark output (i.e., in percentage terms). In percentage terms, the biggest reduction in CO₂ emissions is seen in Croatia, Spain,



Map 4. Percentage decrease in output for EU countries and the EU's Top 10 Trading Countries.

Malta, Greece, and Slovenia. In absolute terms, the biggest reduction is seen in Greece, Italy, Spain, Belgium, and the Netherlands. This implies that Greece and Spain must reduce their CO₂ emissions the most compared to the rest of the world (i.e., in absolute terms) and compared to their benchmark CO₂ emissions (i.e., in percentage terms). Among the EU's Top 10 Trading Countries, Norway and Switzerland observe the highest reductions in output and CO₂ emissions in percentage terms, while in absolute terms these reductions are mainly observed for China.

Water transport ranks highest on both these parameters, i.e., decrease in output and CO₂ emission. The ranking of the other sectors in terms of decrease in output are the same as those which saw the largest increase in production price. However, the ranking differs when it comes to the decrease in CO₂ emissions, which can be attributed to emissions per unit and dependence on the shipping industry.

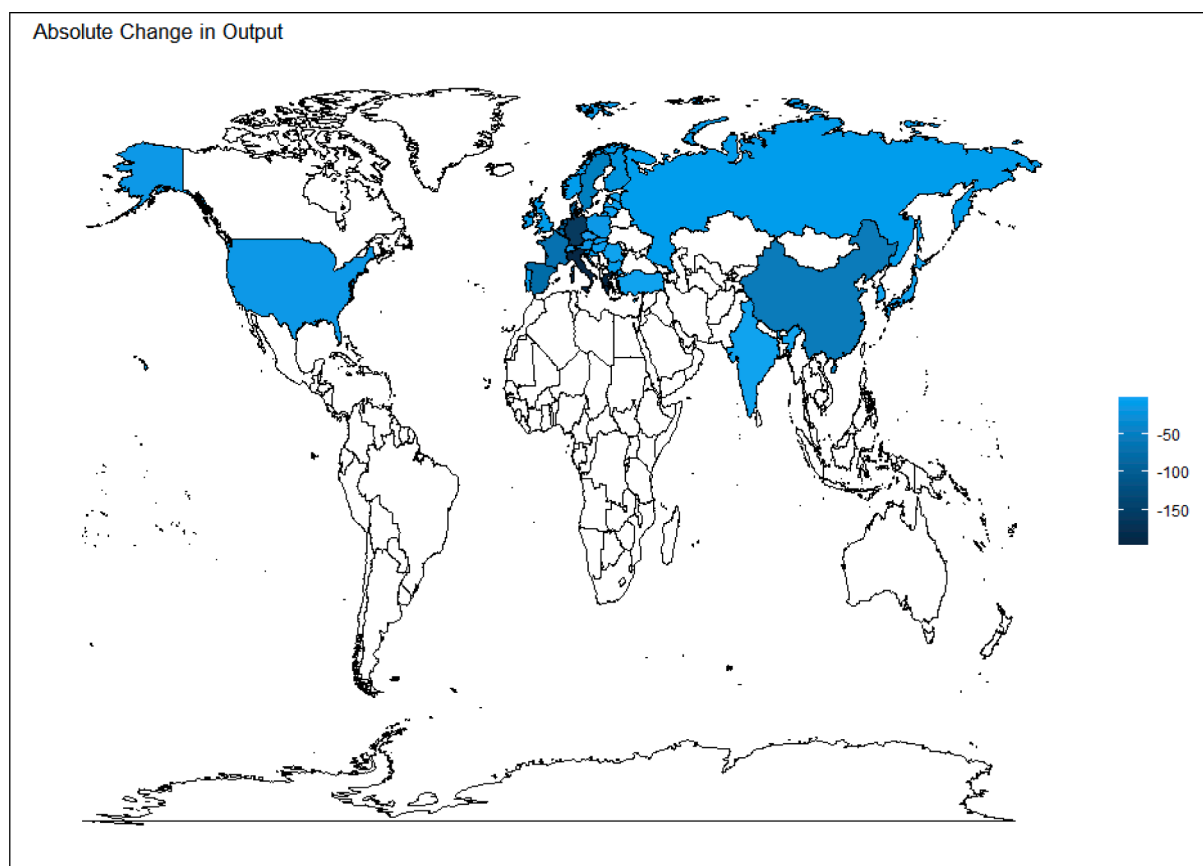
Finally, implementing the EU ETS in the shipping industry will generate revenue for the European Commission. The estimated value of this revenue (6.1% of the gross domestic product (GDP) for the European Union's shipping industry) is shown in Table 5. Note that, as more CO₂ emissions from the shipping industry are covered by the EU ETS, the revenue generated decreases on account of the reduction in output.

EU countries contribute 75% of this revenue (with Denmark, Italy and Germany leading the way), the EU's Top 10 Trading Countries contribute 14%, and the RoW contributes 11%. Interestingly, China, a non-EU country, is the fourth largest contributor (8%), which makes it the highest contributor of the EU's Top 10 Trading Countries. This could be because China is not only one of the EU's Top 10 Trading Countries but its shipping industry also emits the most CO₂ emissions²³, more in fact than the shipping industries of all EU countries combined (see Fig. 1). Map 8 shows the comparative revenue contribution of the countries through the shipping industry EU ETS.

5. Discussion

In 2018, CO₂ emissions from the 45 sectors considered amounted to 28,944 million tons (MTs). EU countries contributed 7.92% (2,293 MTs) of these emissions, while the EU's Top 10 Trading Countries contributed a whopping 66.14% (19,144 MTs). Of these total CO₂ emissions, the *water transport* sector (used for the purposes of this analysis as a synonym for the shipping industry) contributed

²³ In fact, when referring to total CO₂ emissions (taking all 45 sectors into account), China is the highest emitter (more, even, than the Rest of the World (RoW)).



Map 5. Absolute decrease in output (in million USD) for EU countries and the EU's Top 10 Trading Countries.

3.17% (918 MTs). The EU accounts for 17.59% (161 MTs) of shipping industry emissions, while the EU's Top 10 Trading Countries accounted for 49.13% (451 MTs) of these emissions. It is clear that while the proportion of the EU's total emissions is less than that of the EU's Top 10 Trading Countries, the shipping industry accounts for a significant share of the EU's total CO₂ emissions. In fact, based on the ranking of CO₂ emissions by sector in the EU, shipping is second only to *Electricity, gas, steam and air conditioning supply*.

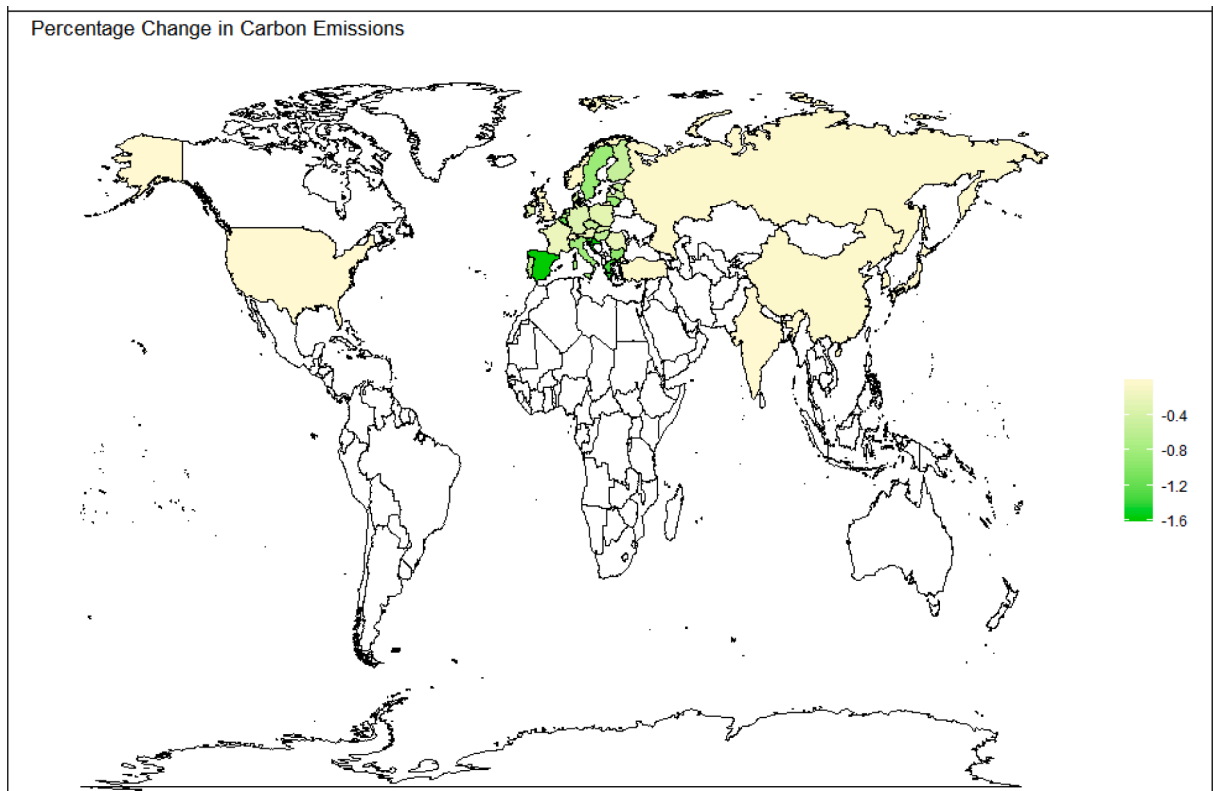
The results of this paper suggest that, in the short run, implementing EU ETS in the shipping industry for 20% of CO₂ emissions will reduce both output and CO₂ emissions by 0.5%. If more CO₂ emissions by the shipping industry are held accountable, a greater reduction in CO₂ emissions will be observed in the first year. For example, if 100% of CO₂ emissions from the shipping industry are covered by the EU ETS in the first year, a 2.4% reduction in CO₂ emissions will be noted around the world. Gu et al. (2019) and Zhu et al. (2018) suggest that the impact of ETS for the shipping industry is contingent on factors such as bunker price and allowance cost. Zhu et al. (2018) contend that even in the minimal CO₂ reduction scenario, the annual mitigation ratio can reach 1.5%. On the other hand, Gu et al. (2019) report that ETS does not necessarily guarantee CO₂ emission reduction in the short run and that its effectiveness will be higher with global coverage.

The reductions in CO₂ emissions reported in this study will come at substantial cost to economic agents. This distortion caused by the introduction of the new policy can be measured in terms of loss in welfare (Tol, 2019). For example, consumers will lose welfare to the tune of USD 36 million if the EU ETS covers 100% of CO₂ emissions, as opposed to USD 7 million if it covers 20% (Table 3).

5.1. EU agents versus agents from the EU's Top 10 Trading Countries

In the EU, the increase in production price (0.02%) is more than the increase in consumption price (0.004%) as depicted by the CPI. This trend is underscored in a World Bank study by Halim et al. (2019), where GHG mitigation policies in the shipping industry led to a notable increase in maritime transportation costs that ranged from 0.4% to 16%. Simultaneously, the uptick in import prices is marginal (below 1%). In our scenario, this dynamic translates into higher production expenses and a corresponding dip in consumption prices. Conversely, Cariou et al. (2021) observed that implementing EU ETS for the shipping industry will substantially increase the cost per voyage, thus potentially leading to a rise in freight costs and consequential higher prices for consumers. In contrast, a study by NZIER (2018) that investigated the effects of higher fuel prices on the New Zealand shipping industry found no significant economic costs.

For the EU's Top 10 Trading Countries, on the other hand, the increase in consumption price (0.0008%) is higher than the increase



Map 6. Percentage decrease in CO₂ emissions for EU countries and the EU's Top 10 Trading Countries.

in production price (0.0003%). This implies that, overall, both consumers and producers in the EU face increased prices. However, in the EU producers are more worse off, whereas in the EU's Top 10 Trading Countries, consumers are worse off compared to other agents in those countries (Fig. 2).

The fact that consumers outside the EU are affected more by the implementation of EU ETS is further highlighted by the USD 1 million decrease in consumer welfare in the EU's Top 10 Trading Countries, which is much more (10 times) than the decrease in welfare experienced by EU consumers (Table 3). This result shows that changes in import prices have a greater impact on consumer welfare than changes in domestic²⁴ prices. An important implication of this result is that, although the EU is the policy-deciding agent, in addition to the negative welfare effect inside the EU, there is also a negative welfare impact outside the EU. If the European Parliament's proposal were implemented, consumer welfare in both groups of consumers would decrease five-fold.

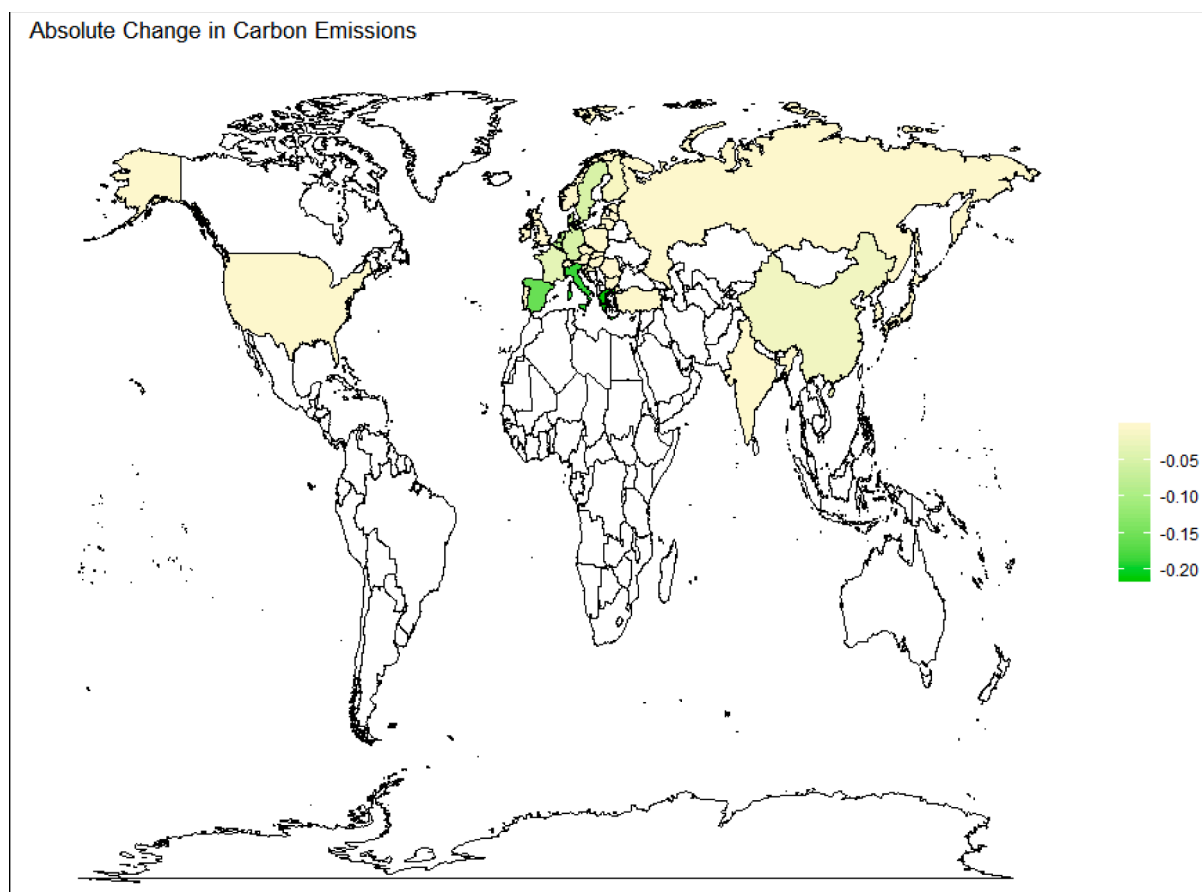
5.2. Phased-in versus immediate approach

Reducing emissions necessitates addressing both behavioural changes and technological advancements, which can be influenced by the consumption of durable goods and capital investments. An immediate approach (i.e., 100% accountability for the CO₂ emissions) will lead to discomfort to the agents as it will penalize them for the investment decisions made prior to the existence of such a policy. In the very short run, the price inelasticity of supply and demand will not only lead to a hike in price owing to the implementation of EU ETS but also to an inefficient allocation of resources (Pindyck, 1982), leading to a deadweight loss in the economy (Tol, 2019). The phased roll out of the policy, on the other hand, gives economic agents the time to adjust to new changes and provides them with an opportunity to learn and grow.

Moreover, transitioning emission reduction targets from lenient to stringent over time not only ensures a smoother adjustment for economic agents but it also proves cost-effective (Tol, 2019). By gradually increasing the stringency of the targets, industries and businesses can plan and implement emission-reducing measures in a more financially sustainable manner. This approach allows for better allocation of resources, promotes innovation, and minimizes sudden financial burdens, ultimately contributing to the overall success and effectiveness of the emission reduction strategy.

Additionally, Table 5 shows that revenue collection in the immediate period decreases as more CO₂ emissions are held accountable. As an Ocean Fund is to be created with 75% of the revenue collection, with the objective to make the shipping industry climate resilient

²⁴ Given that the European Union is "the world's biggest single market" (European Union, 2012).



Map 7. Absolute decrease in CO₂ emissions (in million tons) for EU countries and the EU's Top 10 Trading Countries.

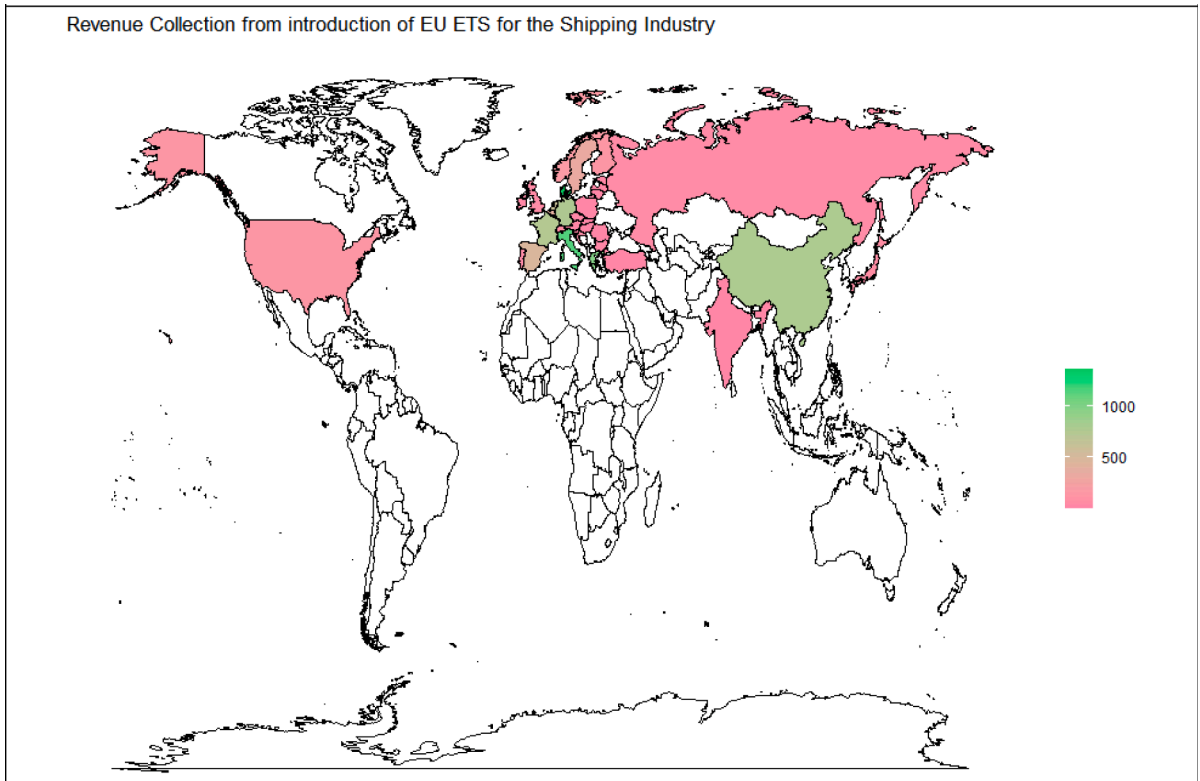
Table 5
Total Revenue from the Shipping Industry EU ETS (in million USD).

Case 1	Case 2	Case 3
9,644.28	9,615.68	9,476.94

and energy efficient (European Parliament, 2022), it would be prudent to have more funds to undertake this transition to greener energy. A phased-in implementation would therefore be a suitable approach.

5.3. The Porter effect

Environmental improvement will lead to economic losses for all agents except the governing body (i.e., the European Commission), who will receive a revenue of roughly 6.1% of the EU shipping industry's GDP (i.e., total output). In the very short run, there is therefore a trade-off between economic development and environmental quality as both producers and consumers incur losses for the reduction in CO₂ emissions and environmental improvement. This trade-off in the short run has also been noted by Gemechu et al. (2013), who studied the impact of environmental tax on Spanish products. Additionally, Wang et al. (2019) underscored this further by revealing that ETS for tramp ships could drive a 17.8% reduction in CO₂ emissions but concurrently lead to a substantial 38.5% decrease in profits for ship operators. However, this trade-off may cease to exist in the long run, as Dong et al. (2019) found when they studied ETS in China. These authors observed a trade-off in the short run but, in the long run, ETS generated the Porter effect, i.e., environmental policies paved the way to improvements not only in environmental quality but also in economic development. Furthermore, Dessens et al. (2014) studied the global ETS scenario for the shipping and aviation industries to reduce emissions by 65% below the BASE levels in 2050 and found that this would lead to a 1.9% increase in GDP on account of investment in research and development. It is also important to stress the long-term benefits of improved environmental quality on health-related issues in terms, for instance, of fewer working hours lost and lower expenditure on healthcare. These benefits in the long run have also been reported by Espinosa (1996) using Environmental Computable General Equilibrium Modelling.



Map 8. Revenue Contributions of EU countries and the EU's Top 10 Trading Partners.

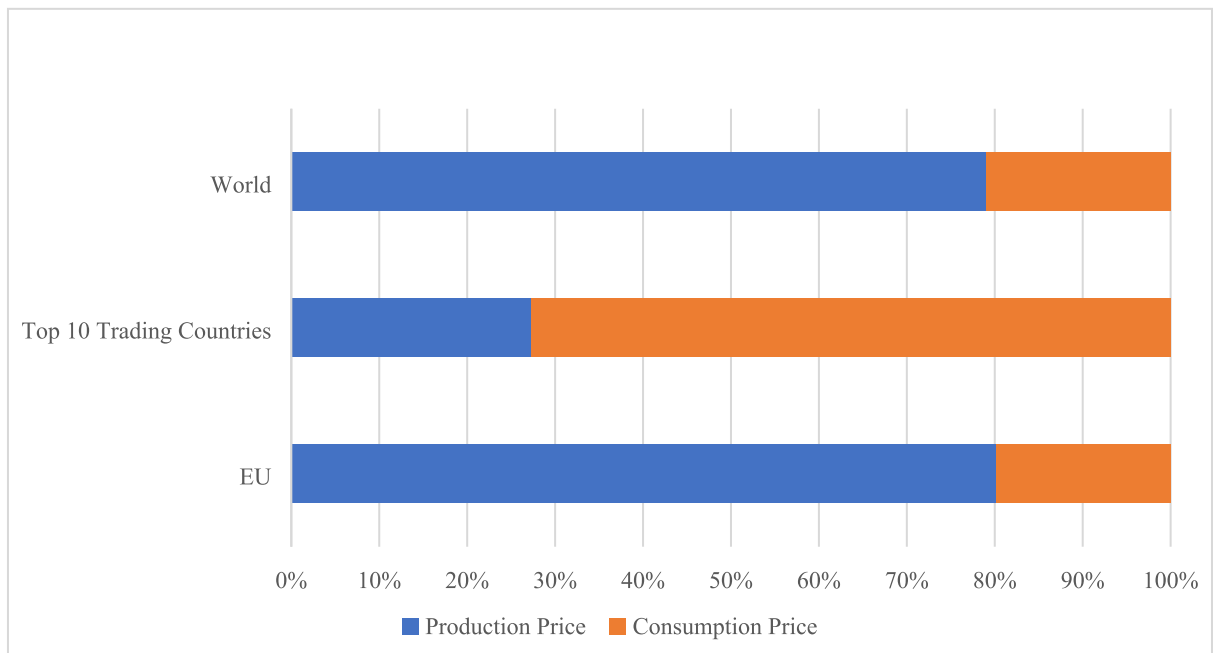


Fig. 2. Change in Production Price Vs Consumption Price.

The IO model does not take into account substitution effects on the mode of transportation used or on products consumed from different countries. This feature of the model places our results in the short run (the immediate term), when there is no time to make adjustments to take substitution into account. However, in the long run, where adjustments have time to unfold, cautionary findings emerge. Several studies warn of potential pitfalls such as carbon leakage, regional distortion, and the EU ETS's capacity to undercut the International Maritime Organization's pursuit of a global agreement on emissions control (Lagouvardou & Psarafitis, 2022; Shi, 2016; Hermeling et al., 2015). Despite these challenges, Cariou et al. (2021) assert that the EU ETS for the shipping industry is poised not to expedite the decarbonization of this crucial sector.

In considering policy implications, it becomes essential for policymakers to adopt a balanced approach. Short-term economic sacrifices for environmental gain should be weighed against the prospect of long-term benefits. Policymakers could explore mechanisms to mitigate immediate economic losses, possibly through targeted support programmes or incentives for affected industries during the transitional phase. Moreover, emphasizing the long-term advantages of improved environmental quality, such as potential reductions in healthcare expenditures and increased productivity due to healthier working conditions, provides a robust foundation for sustainable policymaking.

6. Conclusion

This paper has employed IO modelling to analyse the initial impact of extending EU ETS for CO₂ emissions to the shipping industry on economic agents in EU countries and the EU's Top 10 Trading Countries. The EIO model was used to estimate this impact using carbon dioxide emissions based on production, while the price version of the IO model was used to simulate the impact on producers and consumers in EU countries and the EU's Top 10 Trading Countries in 2018.

The use of IO modelling offers a more comprehensive perspective compared to the partial equilibrium approach, capturing broader economic impacts through its consideration of sectoral linkages and interactions. Furthermore, its simplicity and its extensive application in both practical and academic contexts, makes it a valuable tool for informed decision-making in policy formulation and economic analysis. The model used a linear production function with fixed technology, adhering to the principles of homogeneity and proportionality while assuming constant returns to scale. The paper used water transport as a proxy for shipping industry. As noted by Wang et al. (2015), the shipping industry is not a homogenous sector and the effect on emissions and international trade could differ depending on the carrier. Moreover, as the paper focused on effectively assessing immediate changes in the economy, the substitution effect, which influences long-term impacts and outcomes, was not taken into account. Notably, the paper focused on the first-year introduction of the EU ETS for the shipping industry, mapping three cases based on increased CO₂ emissions accountability. Despite its limitations, this approach has provided valuable insights into the initial impact of introducing this new policy on the economic agents in EU countries and the EU's Top 10 Trading Countries.

The results of the paper suggest that this policy will influence the reduction in CO₂ emissions by increasing production prices, which will reduce output. It will also increase consumption prices, which will reduce consumer welfare in the short term. Due to price inelasticity in the very short term, producers will have to take most of the brunt. However, producers in the EU countries will be worse off, while consumers in the EU's Top 10 Trading Countries will be worse off compared to the other agent in their respective countries. A trade-off was noted between the environmental and economic objectives, which suggests that the Porter effect does not hold in the very short term.

The economic agents in Greece, Italy, Spain, and Germany will be impacted the most by the implementation of EU ETS in the shipping industry. Among the EU's Top 10 Trading Countries, China will be impacted the most. Malta, Croatia, and Slovenia will observe the biggest change in percentage terms since their small economies experience the biggest change in the parameters with respect to their starting points.

The shipping industry will face the direct impact of this new policy. The indirect impact will be felt most by closely related sectors such as *Fishing and aquaculture* and warehousing and other transport, which ultimately will also affect the *Food products, beverages and tobacco* sector.

To comprehensively understand the impact of the phased introduction of the EU ETS into the shipping industry on the global economy and explore the potential long-term presence of the Porter effect, an avenue for future research could involve conducting a Dynamic Computable General Equilibrium analysis. This approach would enable a more nuanced examination of the intricate economic dynamics and long-term implications associated with the implementation of the EU ETS in the shipping industry. This future research would help policymakers design strategies that not only address immediate concerns but also capitalize on the long-term synergies between environmental sustainability and economic prosperity.

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CRedit authorship contribution statement

Srishti Goyal: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Maria Llop:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix

Table A1

CO₂ emission from the Shipping Industry and the Revenue Collection.

Country	CO ₂ Emissions from the Shipping Industry in 2018 (in MTs)	Revenue collected due to the new policy from the countries (in millions USD)		
		Case 1	Case 2	Case 3
Rest of the World	305.75	1,058.53	1,058.48	1,058.24
China	258.91	783.33	783.33	783.29
Japan	58.72	62.53	62.53	62.53
United States of America	53.99	132.78	132.78	132.78
Denmark	30.16	1,354.48	1,352.62	1,343.36
Italy	25.42	1,135.73	1,130.39	1,104.34
Greece	21.94	977.84	971.57	941.27
South Korea	20.19	24.58	24.58	24.58
Germany	16.94	760.29	759.02	752.7
Norway	16.93	165.8	165.78	165.73
France	16.51	741.49	740.59	736.08
Netherlands	13.51	604.27	601.85	589.99
Russia	12.57	49.32	49.32	49.32
United Kingdom	10.42	38.62	38.62	38.61
Spain	10.26	454.97	450.51	429.42
Belgium	8.77	390.63	387.97	375.17
Sweden	7.22	322.42	320.88	313.37
Switzerland	7.05	55.54	55.54	55.53
Turkey	6.54	30.13	30.13	30.13
India	6.15	13.34	13.34	13.34
Finland	3.29	147.3	146.87	144.72
Malta	1.53	68.33	67.96	66.15
Portugal	1.08	48.44	48.27	47.46
Croatia	1.04	45.95	45.54	43.6
Estonia	0.72	32.24	32.16	31.77
Austria	0.65	29.3	29.28	29.15
Ireland	0.52	23.13	23.1	22.95
Poland	0.47	21.1	21.07	20.91
Romania	0.25	11.05	11.04	10.98
Lithuania	0.24	10.8	10.74	10.46
Cyprus	0.23	10.38	10.38	10.34
Hungary	0.21	9.36	9.32	9.17
Bulgaria	0.19	8.5	8.46	8.29
Luxembourg	0.18	7.93	7.91	7.81
Slovenia	0.15	6.44	6.39	6.13
Czech Republic	0.09	4.17	4.15	4.09
Latvia	0.06	2.56	2.55	2.52
Slovakia	0.02	0.67	0.67	0.67

Table A2

Percentage change in production price by top sectors for the EU, the EU's Top 10 Trading Countries, and the World (%).

Industry	Case 1	Case 2	Case 3
EU			
Water Transport	0.56755	0.94497	2.83775
Fishing and aquaculture	0.01230	0.02047	0.06148
Land transport and transport via pipelines	0.00525	0.00874	0.02624
Warehousing and support activities for transportation	0.00519	0.00864	0.02594
Air transport	0.00499	0.00831	0.02495
Basic metals	0.00498	0.00828	0.02488
Mining and quarrying, energy producing products	0.00526	0.00876	0.02631
Electrical equipment	0.00459	0.00765	0.02297
Other non-metallic mineral products	0.00451	0.00750	0.02254
Coke and refined petroleum products	0.00455	0.00757	0.02273
Food products, beverages and tobacco	0.00420	0.00699	0.02098
EU's Top 10 Trading Countries			
Water Transport	0.0031	0.0051	0.0154
Warehousing and support activities for transportation	0.0008	0.0013	0.0038
Land transport and transport via pipelines	0.0006	0.0011	0.0032
Fishing and aquaculture	0.0006	0.0011	0.0032
Other non-metallic mineral products	0.0005	0.0008	0.0024
Coke and refined petroleum products	0.0004	0.0007	0.0022
Mining and quarrying, non-energy producing products	0.0004	0.0007	0.0022
Paper products and printing	0.0004	0.0007	0.0021
Wood and products of wood and cork	0.0004	0.0007	0.0020
Basic metals	0.0004	0.0007	0.0020
Rubber and plastics products	0.0004	0.0007	0.0020
World			
Water Transport	0.4043	0.6731	2.0213
Fishing and aquaculture	0.0088	0.0147	0.0441
Warehousing and support activities for transportation	0.0039	0.0065	0.0195
Land transport and transport via pipelines	0.0039	0.0065	0.0195
Air transport	0.0037	0.0061	0.0183
Basic metals	0.0036	0.0061	0.0182
Mining and quarrying, energy producing products	0.0037	0.0061	0.0184
Electrical equipment	0.0034	0.0056	0.0168
Other non-metallic mineral products	0.0033	0.0056	0.0167
Coke and refined petroleum products	0.0033	0.0055	0.0166
Food products, beverages and tobacco	0.0031	0.0051	0.0154

Table A3

Percentage change in CPI by country (%).

Country	Case 1	Case 2	Case 3
Malta	0.0252	0.0420	0.1260
Greece	0.0142	0.0237	0.0711
Croatia	0.0079	0.0132	0.0396
Italy	0.0052	0.0086	0.0259
Sweden	0.0043	0.0071	0.0214
Norway	0.0042	0.0069	0.0208
Estonia	0.0042	0.0069	0.0208
Denmark	0.0037	0.0062	0.0186
Bulgaria	0.0036	0.0060	0.0180
Luxembourg	0.0033	0.0055	0.0166
Finland	0.0032	0.0053	0.0160
Belgium	0.0029	0.0049	0.0147
Cyprus	0.0029	0.0049	0.0147
Latvia	0.0025	0.0041	0.0124
Netherlands	0.0024	0.0040	0.0121
Portugal	0.0022	0.0036	0.0109
Spain	0.0022	0.0036	0.0108
Slovenia	0.0021	0.0035	0.0104
Lithuania	0.0021	0.0035	0.0104
Germany	0.0016	0.0027	0.0082
Austria	0.0015	0.0026	0.0077
Romania	0.0014	0.0023	0.0070
Hungary	0.0014	0.0023	0.0068
India	0.0011	0.0019	0.0056

(continued on next page)

Table A3 (continued)

Country	Case 1	Case 2	Case 3
Poland	0.0011	0.0018	0.0054
Slovakia	0.0010	0.0017	0.0052
Czech Republic	0.0010	0.0017	0.0050
France	0.0009	0.0016	0.0047
Ireland	0.0009	0.0014	0.0043
Switzerland	0.0007	0.0011	0.0034
United Kingdom	0.0006	0.0010	0.0031
Rest of the World	0.0006	0.0010	0.0029
Turkey	0.0005	0.0008	0.0024
Russia	0.0003	0.0005	0.0015
China	0.0002	0.0003	0.0010
United States of America	0.0002	0.0003	0.0009
South Korea	0.0001	0.0002	0.0006
Japan	0.0001	0.0001	0.0004

Table A4

Change in consumer welfare by country.

Country	Absolute Change (in million USD)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Rest of the World	-1.27	-2.12	-6.36	-0.0002	-0.0003	-0.001
Italy	-1.09	-1.82	-5.46	-0.0014	-0.0024	-0.0072
Germany	-0.61	-1.02	-3.07	-0.0006	-0.001	-0.0029
Greece	-0.54	-0.9	-2.7	-0.0056	-0.0094	-0.0281
Spain	-0.51	-0.86	-2.57	-0.0009	-0.0015	-0.0046
China	-0.34	-0.57	-1.71	-0.0001	-0.0002	-0.0005
France	-0.32	-0.53	-1.6	-0.0003	-0.0005	-0.0015
Netherlands	-0.28	-0.46	-1.39	-0.0011	-0.0018	-0.0055
Belgium	-0.25	-0.41	-1.25	-0.0017	-0.0028	-0.0084
Sweden	-0.24	-0.4	-1.21	-0.0015	-0.0025	-0.0076
United States of America	-0.21	-0.34	-1.03	0	0	-0.0001
Austria	-0.16	-0.26	-0.79	-0.0011	-0.0018	-0.0055
Denmark	-0.16	-0.26	-0.78	-0.0016	-0.0026	-0.0078
Russia	-0.11	-0.19	-0.56	-0.0002	-0.0003	-0.001
Norway	-0.1	-0.17	-0.51	-0.0008	-0.0014	-0.0042
Poland	-0.1	-0.16	-0.48	-0.0007	-0.0011	-0.0034
Finland	-0.09	-0.14	-0.43	-0.0008	-0.0014	-0.0041
United Kingdom	-0.09	-0.14	-0.43	-0.0001	-0.0001	-0.0003
Turkey	-0.07	-0.12	-0.35	-0.0003	-0.0004	-0.0013
Portugal	-0.06	-0.11	-0.32	-0.0007	-0.0011	-0.0035
Romania	-0.06	-0.1	-0.3	-0.0007	-0.0012	-0.0035
Croatia	-0.06	-0.09	-0.28	-0.0031	-0.0051	-0.0153
India	-0.06	-0.09	-0.28	-0.0001	-0.0001	-0.0003
Switzerland	-0.05	-0.09	-0.27	-0.0002	-0.0003	-0.001
Bulgaria	-0.05	-0.08	-0.24	-0.0027	-0.0044	-0.0133
Japan	-0.04	-0.07	-0.21	0	0	-0.0001
Malta	-0.04	-0.06	-0.18	-0.0177	-0.0295	-0.0885
Czech Republic	-0.04	-0.06	-0.18	-0.0006	-0.001	-0.0031
South Korea	-0.02	-0.04	-0.12	0	-0.0001	-0.0002
Hungary	-0.02	-0.04	-0.11	-0.0007	-0.0012	-0.0035
Ireland	-0.02	-0.03	-0.09	-0.0004	-0.0007	-0.0022
Latvia	-0.01	-0.02	-0.07	-0.0016	-0.0026	-0.0079
Slovenia	-0.01	-0.02	-0.07	-0.0012	-0.0019	-0.0058
Estonia	-0.01	-0.02	-0.06	-0.002	-0.0033	-0.01
Slovakia	-0.01	-0.02	-0.06	-0.0005	-0.0009	-0.0027
Luxembourg	-0.01	-0.02	-0.06	-0.0009	-0.0014	-0.0043
Lithuania	-0.01	-0.02	-0.06	-0.0009	-0.0016	-0.0047
Cyprus	-0.01	-0.02	-0.05	-0.0014	-0.0023	-0.007

Table A5

Change in output by country.

Country	Absolute Change (in million USD)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Greece	-197.21	-326.49	-953.28	-1.341	-2.223	-6.523
Italy	-188.33	-312.74	-926.88	-0.811	-1.345	-3.958
Germany	-159.7	-265.64	-793.74	-0.3	-0.498	-1.486
Rest of the World	-101.58	-169.13	-507.88	-0.018	-0.03	-0.09

(continued on next page)

Table A5 (continued)

Country	Absolute Change (in million USD)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Netherlands	-95.56	-158.67	-470.04	-0.69	-1.146	-3.381
Denmark	-88.91	-147.88	-441.65	-0.374	-0.623	-1.863
Spain	-79.5	-131.71	-386.22	-1.569	-2.588	-7.427
France	-67.15	-111.72	-334.24	-0.215	-0.357	-1.066
Belgium	-63.36	-105.11	-309.94	-1.156	-1.913	-5.575
China	-54.91	-91.43	-274.56	-0.008	-0.013	-0.04
Sweden	-50.95	-84.61	-250.9	-0.863	-1.432	-4.216
Finland	-20.76	-34.51	-102.69	-0.521	-0.865	-2.564
Austria	-12.68	-21.11	-63.36	-0.188	-0.313	-0.936
Poland	-12.3	-20.48	-61.43	-0.273	-0.454	-1.356
United States of America	-11.96	-19.91	-59.79	-0.002	-0.003	-0.01
Croatia	-11.57	-19.16	-56.04	-1.613	-2.665	-7.718
Portugal	-8.99	-14.95	-44.62	-0.586	-0.973	-2.879
Norway	-8.25	-13.74	-41.24	-0.06	-0.101	-0.302
Malta	-8.06	-13.39	-39.86	-1.709	-2.838	-8.409
Ireland	-8.03	-13.37	-40.09	-0.25	-0.416	-1.243
United Kingdom	-7.25	-12.08	-36.27	-0.013	-0.022	-0.067
Russia	-6.94	-11.56	-34.7	-0.017	-0.028	-0.083
Bulgaria	-6.15	-10.23	-30.63	-0.926	-1.536	-4.545
Czech Republic	-5.69	-9.47	-28.4	-0.51	-0.846	-2.506
Switzerland	-5.67	-9.43	-28.33	-0.021	-0.034	-0.103
Luxembourg	-5.24	-8.72	-26.08	-0.548	-0.91	-2.707
Romania	-5.01	-8.34	-25.01	-0.204	-0.339	-1.014
Turkey	-4.93	-8.2	-24.64	-0.018	-0.03	-0.09
South Korea	-4.67	-7.77	-23.33	-0.008	-0.014	-0.042
Japan	-4.37	-7.28	-21.86	-0.003	-0.005	-0.015
Estonia	-4.34	-7.22	-21.55	-0.502	-0.834	-2.483
India	-4.29	-7.14	-21.44	-0.004	-0.007	-0.022
Hungary	-4.01	-6.67	-19.97	-0.563	-0.934	-2.762
Slovenia	-3.16	-5.24	-15.56	-1.359	-2.245	-6.491
Lithuania	-2.63	-4.37	-12.94	-0.867	-1.436	-4.207
Cyprus	-2.63	-4.38	-13.13	-0.213	-0.354	-1.062
Slovakia	-2.58	-4.3	-12.9	-0.336	-0.558	-1.662
Latvia	-1.73	-2.88	-8.63	-0.447	-0.743	-2.214

Table A6

Change in CO₂ emissions by country.

Country	Absolute Change (in million tons)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Greece	-0.2177	-0.3602	-1.0486	-1.341	-2.223	-6.523
Italy	-0.1865	-0.3091	-0.9076	-0.811	-1.345	-3.958
Spain	-0.1569	-0.2587	-0.7416	-1.569	-2.588	-7.427
Belgium	-0.0924	-0.1529	-0.4443	-1.156	-1.913	-5.575
Netherlands	-0.0845	-0.1402	-0.4131	-0.69	-1.146	-3.381
Denmark	-0.0638	-0.106	-0.3162	-0.374	-0.623	-1.863
Sweden	-0.0531	-0.088	-0.2583	-0.863	-1.432	-4.216
Germany	-0.0503	-0.0836	-0.2493	-0.3	-0.498	-1.486
Rest of the World	-0.0409	-0.0681	-0.2046	-0.018	-0.03	-0.09
France	-0.032	-0.0533	-0.159	-0.215	-0.357	-1.066
China	-0.0191	-0.0319	-0.0957	-0.008	-0.013	-0.04
Finland	-0.0154	-0.0255	-0.0756	-0.521	-0.865	-2.564
Croatia	-0.0145	-0.0239	-0.0689	-1.613	-2.665	-7.718
Malta	-0.013	-0.0215	-0.0628	-1.351	-2.241	-6.619
Portugal	-0.0064	-0.0107	-0.0316	-0.586	-0.973	-2.879
Poland	-0.0033	-0.0056	-0.0166	-0.273	-0.454	-1.356
Russia	-0.0032	-0.0053	-0.0158	-0.017	-0.028	-0.083
India	-0.0031	-0.0051	-0.0153	-0.004	-0.007	-0.022
Estonia	-0.003	-0.005	-0.0148	-0.502	-0.834	-2.483
Bulgaria	-0.0027	-0.0045	-0.0133	-0.926	-1.536	-4.545
Lithuania	-0.0021	-0.0035	-0.0101	-0.867	-1.436	-4.207
Norway	-0.0021	-0.0035	-0.0104	-0.06	-0.101	-0.302
Slovenia	-0.002	-0.0033	-0.0096	-1.353	-2.235	-6.46
South Korea	-0.0019	-0.0031	-0.0094	-0.008	-0.014	-0.042
United States of America	-0.0018	-0.0029	-0.0088	-0.002	-0.003	-0.01
Austria	-0.0017	-0.0028	-0.0082	-0.188	-0.313	-0.936
Ireland	-0.0016	-0.0026	-0.0078	-0.249	-0.414	-1.235

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Table A6 (continued)

Country	Absolute Change (in million tons)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Turkey	-0.0015	-0.0025	-0.0076	-0.018	-0.03	-0.09
Hungary	-0.0015	-0.0025	-0.0075	-0.563	-0.934	-2.762
Czech Republic	-0.0014	-0.0023	-0.0068	-0.51	-0.846	-2.506
Japan	-0.0011	-0.0018	-0.0055	-0.003	-0.005	-0.015
Romania	-0.001	-0.0016	-0.0049	-0.204	-0.339	-1.014
Luxembourg	-0.001	-0.0016	-0.0047	-0.541	-0.899	-2.674
United Kingdom	-0.0009	-0.0015	-0.0045	-0.013	-0.022	-0.067
Slovakia	-0.0004	-0.0007	-0.0022	-0.334	-0.556	-1.655
Switzerland	-0.0004	-0.0007	-0.0021	-0.02	-0.034	-0.102
Cyprus	-0.0004	-0.0006	-0.0019	-0.197	-0.328	-0.984
Latvia	-0.0003	-0.0006	-0.0017	-0.415	-0.69	-2.056

Table A7

Percentage change in output by sector (%).

Sector	Case 1	Case 2	Case 3
Water transport	-15.24	-25.23	-73.78
Fishing and aquaculture	-0.33	-0.54	-1.62
Warehousing and support activities for transportation	-0.15	-0.25	-0.74
Land transport and transport via pipelines	-0.15	-0.25	-0.74
Air transport	-0.14	-0.23	-0.69
Basic metals	-0.14	-0.23	-0.69
Mining and quarrying, energy producing products	-0.13	-0.21	-0.64
Electrical equipment	-0.13	-0.21	-0.64
Other non-metallic mineral products	-0.13	-0.21	-0.63
Coke and refined petroleum products	-0.12	-0.20	-0.61
Food products, beverages and tobacco	-0.12	-0.19	-0.58
Fabricated metal products	-0.11	-0.19	-0.57
Wood and products of wood and cork	-0.11	-0.19	-0.57
Paper products and printing	-0.11	-0.19	-0.56
Chemical and chemical products	-0.11	-0.18	-0.55
Machinery and equipment, n.e.c.	-0.11	-0.18	-0.53
Computer, electronic and optical equipment	-0.10	-0.17	-0.50
Postal and courier activities	-0.10	-0.16	-0.50
Rubber and plastics products	-0.10	-0.16	-0.48
Other transport equipment	-0.09	-0.16	-0.47
Motor vehicles, trailers and semi-trailers	-0.09	-0.16	-0.47
Textiles, textile products, leather and footwear	-0.09	-0.15	-0.46
Wholesale and retail trade; repair of motor vehicles	-0.09	-0.15	-0.46
Mining and quarrying, non-energy producing products	-0.09	-0.14	-0.43
Manufacturing n.e.c.; repair and installation of machinery and equipment	-0.09	-0.14	-0.43
Construction	-0.08	-0.14	-0.42
Mining support service activities	-0.08	-0.14	-0.42
Pharmaceuticals, medicinal chemical and botanical products	-0.08	-0.14	-0.41
Administrative and support services	-0.08	-0.13	-0.39
Electricity, gas, steam and air conditioning supply	-0.07	-0.12	-0.37
Agriculture, hunting, forestry	-0.07	-0.12	-0.37
Accommodation and food service activities	-0.06	-0.11	-0.32
Water supply; sewerage, waste management and remediation activities	-0.05	-0.09	-0.27
Other service activities	-0.05	-0.08	-0.23
Telecommunications	-0.05	-0.08	-0.23
Publishing, audiovisual and broadcasting activities	-0.04	-0.07	-0.20
Professional, scientific and technical activities	-0.04	-0.06	-0.18
Human health and social work activities	-0.03	-0.06	-0.17
Arts, entertainment and recreation	-0.03	-0.05	-0.16
IT and other information services	-0.03	-0.05	-0.16
Financial and insurance activities	-0.03	-0.05	-0.14
Public administration and defence; compulsory social security	-0.03	-0.04	-0.13
Real estate activities	-0.02	-0.03	-0.10
Education	-0.02	-0.03	-0.08
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.00	0.00	0.00

Table A8
Percentage change in CO₂ emissions by industry (%).

Sectors	Case 1	Case 2	Case 3
Water transport	-15.24	-25.23	-73.78
Fishing and aquaculture	-0.32	-0.53	-1.60
Warehousing and support activities for transportation	-0.15	-0.25	-0.74
Land transport and transport via pipelines	-0.15	-0.25	-0.74
Air transport	-0.14	-0.23	-0.69
Other non-metallic mineral products	-0.13	-0.21	-0.63
Food products, beverages and tobacco	-0.12	-0.19	-0.58
Fabricated metal products	-0.11	-0.19	-0.57
Basic metals	-0.11	-0.19	-0.56
Computer, electronic and optical equipment	-0.10	-0.17	-0.50
Postal and courier activities	-0.10	-0.16	-0.50
Rubber and plastics products	-0.10	-0.16	-0.48
Wood and products of wood and cork	-0.09	-0.16	-0.47
Coke and refined petroleum products	-0.09	-0.15	-0.46
Wholesale and retail trade; repair of motor vehicles	-0.09	-0.15	-0.46
Mining and quarrying, non-energy producing products	-0.09	-0.14	-0.43
Manufacturing n.e.c.; repair and installation of machinery and equipment	-0.09	-0.14	-0.43
Chemical and chemical products	-0.08	-0.14	-0.42
Construction	-0.08	-0.14	-0.42
Paper products and printing	-0.08	-0.14	-0.41
Machinery and equipment, n.e.c.	-0.08	-0.13	-0.40
Electrical equipment	-0.08	-0.13	-0.39
Administrative and support services	-0.08	-0.13	-0.39
Electricity, gas, steam and air conditioning supply	-0.07	-0.12	-0.37
Agriculture, hunting, forestry	-0.07	-0.12	-0.37
Other transport equipment	-0.07	-0.12	-0.36
Textiles, textile products, leather and footwear	-0.07	-0.11	-0.34
Motor vehicles, trailers and semi-trailers	-0.07	-0.11	-0.33
Accommodation and food service activities	-0.06	-0.11	-0.32
Mining support service activities	-0.06	-0.10	-0.31
Pharmaceuticals, medicinal chemical and botanical products	-0.06	-0.09	-0.28
Water supply; sewerage, waste management and remediation activities	-0.05	-0.09	-0.27
Other service activities	-0.05	-0.08	-0.23
Telecommunications	-0.05	-0.08	-0.23
Mining and quarrying, energy producing products	-0.04	-0.07	-0.21
Publishing, audiovisual and broadcasting activities	-0.04	-0.07	-0.20
Professional, scientific and technical activities	-0.04	-0.06	-0.18
Human health and social work activities	-0.03	-0.06	-0.17
Arts, entertainment and recreation	-0.03	-0.05	-0.16
IT and other information services	-0.03	-0.05	-0.16
Financial and insurance activities	-0.03	-0.05	-0.14
Public administration and defence; compulsory social security	-0.03	-0.04	-0.13
Real estate activities	-0.02	-0.03	-0.10
Education	-0.02	-0.03	-0.08
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.00	0.00	0.00

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