The Environmental Impact of International Trade: Measuring How Changes in Trade Lead to Different Levels of Polluting Emissions

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Abstract

In the recent years, the awareness of the negative impact that economic activity has on the environment has increased enormously, and countries in the international community are realizing that such environmental degradation is an urgent issue that demands immediate and convincing solutions. However, despite a common interests in the environmental preservation, countries also face economic interests, and push international negotiations to be able to increase their production and, consequently, their emissions. In front of such challenge, academic research has tried to better understand the economic drivers hiding behind environmental degradation to provide international institutions with new solutions, and one special issue that has received much attention has been international trade. In particular, the present study delves into this question, addressing the particular relation that exists between trade and global emission of polluting gases. Based on the application of Input-Output Analysis and the use of Environmentally Extended World Input-Output Tables, this study provides a measure of the impact that actual trade has on emissions of greenhouse and local gases by considering the situation of total reduction in international trade (counterfactual). Finally, results rise important considerations in terms of economic and environmental efficiency, as well as some important policy implications.

Keywords: Environmental Impact, International Trade, Emissions, Greenhouse Gases, Local Gases, Transport, Input-Output Analysis, World Input-Output Database.

JEL Codes: C67, E23, F17, F18, Q53.

1. Introduction

The awareness of the negative impact that economic activities have on the environment has increased enormously in the recent years. Of the many forms of this negative impact, like the intensive waste of water or the massive deforestation, the emission of polluting gases is one of the main factors affecting the global ecosystem. In particular, it has been widely argued how the global emission of greenhouse gasses (GHG) is having a very significant impact on global warming. Other kind of gases, often called 'local gases' because of their local range of impact, have been considered one of the main drivers, for example, of changes in the chemical composition of soils and seas, and the most explanatory factors of phenomenons like acid rain. In addition, more generally, it has been discussed how all these gases resulting from economic activities have contributed to the lowering of air quality, affecting all kind of living beings and bringing very bad consequences to human health.

In the face of this conflict, governments and international organizations are trying to propose new solutions, not only to alleviate current negative conditions but especially to avoid future devastating consequences. Efforts devoted, for instance, in the 21st session of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties, or COP 21, in Paris proved this awareness and this need of addressing the issue at a global level (**C2ES 2015**). However, members of the international community face conflicting interests. On the one hand, governments try to preserve or improve their economic situation, addressing to spur income per capita and protect domestic consumption patterns. For such reason, policies and international agreements are often directed to foster growth and employment, mainly through technological development, increased productivity and the fostering of a positive balance of trade through the specialization in those products in which countries have their highest competitive advantage.

Nevertheless, on the other hand, the current environmental degradation presents an important challenge to such international negotiations, as pollution is a connatural result of production and it is only moderated by the existence of more or less polluting technologies. This environmental dilemma, moreover, is global; mainly for three reasons: first, because the generation of polluting gases crosses national borders and the warming of earth affects all countries in the world; second, because actual trade network implies the transaction of not only goods but also the environmental responsibility for their production; and finally, because there exists an asymmetry in disposable technology of countries, what can lead to a misallocation of global production in terms of environmental impact.

In short, the environment is no other thing than a global public good, as countries, behaving on their self-interest, would increase their production and pollution at the expense of other countries reducing their emissions to refrain global environmental damage. As a global issue that cannot be addressed individually but through collective agreement, environmental degradation presents nowadays a very deep concern for international institutions, just as it rises numerous concerns and questions in the academia not only to understand better its driving forces but also to suggest new efficient solutions.

In particular, in response to this challenge, there has been a wide trend of research trying to analyze the different economic factors influencing gas emissions, and one crucial factor that has received a very special attention has been international trade (**Jayadevappa and Chhatre 2000**). Firstly, regarding this interrelation between international trade and emissions, many scholars have paid much attention to the volumes of pollutants generated to produce goods that later have been exported and imported, i.e. emissions involved or 'embodied' in traded goods (**Wiebe el at. 2012**). Furthermore, from this approach, many researchers have dealt with the issue of existing misbalances between emissions associated to imported and exported goods, and many considerations about the responsibility of those emissions have emerged in the academia (**Munksgaard and Pedersen 2001**). Nevertheless, all this body of literature has only addressed the question of how much pollution is generated or involved in import and exports, but it has not addressed the question of how such emissions would increase or decrease if countries decided to enlarge or diminish their amounts of imported or exported goods, nor the question of how large is the impact that actual international trade finally has on emissions.

This study tries to address this particular question. More precisely, the applied procedure is based on the foundations of the Input-Output Analysis, and it makes use of the World Input-Output Tables and the 'Environmental Accounts' provided by the World Input-Output Database (WIOD). Moreover, the designed methodology is capable of analyzing how reductions in international trade for both intermediate goods and final goods could lead to different emission levels for the case of eight different types of pollutants. Furthermore, the evaluation of emissions that would be generated if overall trade was reduce serves as the counterfactual to estimate which is the impact that trade alone has on global emissions.

The study is structured as follows. In the first place, **Section 2** provides an extensive review of previous research addressing the relation between international trade and emissions, and pays special attention to those approaches grounded in the Input-Output Analysis. Secondly, **Section 3** describes the methodology, from the fundamentals of the Input-Output Analysis to the particular procedure applied in this study. Later, **Section 4** gives a wide explanation about the disposable data in the World Input-Output Database (WIOD) from which World Input-Output Tables and environmental data are obtained. Following, **Section 5** shows and comments the most relevant results, and gives some interpretations. Finally, **Section 6** presents some critical implications and **Section 7** summarizes the main conclusions of the study.

2. Literature Review

In front of the actual and dramatic worsening of natural conditions, there has been a wide trend of research trying to understand which economic factors hide behind gas emissions. For instance, scholars have accounted for increases in pollution driven by economic factors like population, consumption per capita, consumption patterns or technological structure (**Arto and Dietzenbacher 2014**), and one crucial factor that has received much attention has been international trade (**Jayadevappa and Chhatre 2000**; **Antweiler et al. 2001**). On the one hand, from a historical perspective, it has been discussed how international trade sharply increased in the second half of the 20th century and how this process largely lead to the recent economic development. However, on the other hand, it has been also argued how such process of globalization was greatly accompanied by an increasing environment degradation (**Burnete and Choomta 2015**). The interrelation of international trade, economic development and environmental degradation has been often in the center of the debate and the very diverse approaches that have tried to address this question have held conflicting results (**Elbasha and Roe 1996**; **Kleemann and Abdulai 2013**). Moreover, many scholars have tried to estimate how the increasing process of globalization has led not only to certain inequalities and misbalances across countries in terms of income, but also in terms of environmental preservation or degradation (**Atici 2012**; **Le et al. 2016**).

In order to address this general issue, the first important body of literature has focused on the measurement of the emissions involved, directly or indirectly, in international flows of goods. In particular, the term used by scholars to describe the amount of emissions generated because of production set aside by countries for importing or exporting has been the term of 'Embodied Emissions in Trade' (EET). Such assessment of emissions involved in international trading, made possible thanks to the use of Input-Output Tables and the methodology of Input-Output Analysis, has raised many diverse and comprehensive results (**Sato 2014**).

Within this literature, some studies have addressed the emissions embodied globally in international trade, like **Wiebe el at. (2012)** focused on the measurement of CO_2 global emissions; while many studies have been concerned about the emissions embodied in trade of particular countries, like **Machado et al. (2001)** analyzing the energy and carbon embodied in Brazilian trade, or **Liu et al. (2015)** taking into account the emissions embodied in the value added by Chinese sectors. Other studies have addressed bilateral relationships between countries and their environmental implications. For instance, **Wu et al. (2016)** and **Zhao et al. (2016)** have been focused on emissions embodied in China-Japan trade, **Jayanthakumaran and Liu (2016)** and **Tan et al. (2013)** have been centered on the CO_2 embodiment in China–Australia trade, and **Mizgajski (2012)** on the Poland-Germany case.

In addition, from a wider perspective, some other studies like **Arto and Dietzenbacher (2014)** have made use of the methodology of 'structural decomposition analysis' within the Input-Output framework and, together with trade, they have assessed the impact of other economic variables like consumption structure, population, or technology on local and global emissions. In particular, this last study showed, for instance, that factors like population, consumption per capita and trade structure had a positive effect on the increase of global emissions of greenhouse gases in the last decade, while factors like structure of consumption and technology helped to soften this overall increase in GHG emissions. Furthermore, this analytical procedure of structural decomposition, also based on the key notion of 'embodied emissions in trade', has been also used in studies like **Xu and Dietzenbacher (2014)** at an international and global level, accounting for international flows of intermediate and final goods and the key drivers of the increasing emission of CO_2. On the other hand, other studies have applied this methodology in order to assess the case of certain countries, like **Yamakawa and Peters (2011)** and their analysis of the economy of Norway and greenhouse gases emissions, or **Liu and Wang (2015)** in their study of the Chinese emissions of SO_2. Other studies, more concerned about the different characteristics of trade, have assessed, for example, how changes in trade structures can lead to different emissions embodied in trade (**Dietzenbacher et al. 2012**; **Su et al. 2013**; **Weitzel 2014**), or how differences in the usage of energy can rise important environmental comparisons within countries (**Cosmo and Hyland 2013**; **Du et al. 2011**).

Also based on the approach of the emissions embodied in exports or imports of countries, another body of literature has been grounded both in terms of 'environmental inequality' and in terms of 'emission responsibility'. In the case of environmental inequality, most part of the research has focused on the assessment of misbalances in emissions embodied in trade of exports and imports of certain countries. For instance, **Muradian et al. (2002)**, when comparing industrialized countries with the rest of the world economies, determined how emission embodied in imports of developed countries used to be higher than emissions embodied in exports; being this relation inverse for the case of developing countries. From this literature, some very relevant terms have emerged, like the 'environmental load displacement', the 'environmental terms of trade' (ETT) or the 'balance of embodied emissions in trade' (BEET), all of them referring to this misbalances in emissions traded internationally.

Such misbalance between countries and their emissions involved in trading has raised many concerns about the responsibility over emissions. From such debate, many scholars have focused on both the producers of goods and their consumers in order to find an appropriate view over the responsibility of emissions (**Munksgaard and Pedersen 2001**), and over the distinct ethical implications that arise (**Hoekstra and Janssen 2006**). In general, it has been argued how the producer-perspective on the responsibility over emissions might be insufficient in order to enforce countries and fulfill international emission objectives (**Mozner 2013**), and how the approach of the responsibility of the consumer is also necessary. Within this trend in the literature, other important studies have emerged, for example, analyzing the different frameworks and methodologies to quantify responsibility for emission, like in **Serrano and Dietzenbacher (2010)**; or other studies centered in the responsibility on emissions at lower spatial levels like cities or households (**Choi 2015**; **Munksgaard et al. 2005**).

Moreover, one special issue has raised much interest about the interrelation of international trade and polluting emissions, and especially about the existing misbalances between developed and developing countries in terms of environmental quality. More precisely, the literature has devoted a lot of effort in understanding why countries have opted to import certain goods instead of fostering domestic production, and why, therefore, production and emissions have been displaced towards other regions in the world. In particular, two conflicting hypothesis have been presented (**Azhar and Elliott 2007**; **Shen 2008**; **Aller et al. 2015**). The first one corresponds to the 'Pollution Haven Hypothesis' (PHH), and it states that, besides other factors, production misallocation takes place mainly from developed to developing economies as a result of strong environmental regulations in developed countries (**Marconi 2012**). On the contrary, the 'Factor Endowment Hypothesis' (FEH), or the 'Capital-Labor Hypothesis' (KLH), suggests that countries should specialize in those activities in which they have an important competitive advantage. From this second perspective, as developed countries do have a higher disposability of capital, these countries should then specialize in the production of manufactured goods, which result being highly pollution-intensive (**Aller et al. 2015**).

Many studies have address this particular question. For instance, some studies have focused on bilateral relations across countries with different income levels and different trade patterns. Such is the case, for instance, of **Marconi (2012)** focusing on the relation between Europe and China, and finding no evidence in support or the pollution haven hypothesis between these two regions; or the case of **Azhar and Elliott (2007)** focusing on trade patterns across North and South economies in the world. Additionally, other studies have centered the attention on the relation between particular economies (**He 2006**) and the rest of the world, and have provided strong evidence in support of the pollution haven hypothesis, like **Al-Mulali et al. (2015)** in relation to Vietnam, or **Gokmenoglu and Taspinar (2015)** regarding the case of Turkey. However, others, like **Eskelanda and Harrison 2003** for the USA, have not provided conclusive evidence in support of such hypothesis. Finally, some scholars have addressed this question at a global level. For instance, **Khan and Yoshino (2004)** uses trade data over 17 years, 128 nations and 34 manufacturing industries, and finds support to the pollution haven hypothesis, as they show that increases in national income are generally followed by a lowering in exported dirty goods relative to exports of clean goods.

In particular, this interrelation between income, displacement of production, and the subsequent environmental impact has also received much attention in this body of literature under the concept of the 'Environmental Kuznets Curve' (EKC). More precisely, the hypothesis of the environmental

Kuznets curve suggests that countries may increase their emissions as a result of increasing their income but only until they reach a certain technological level, after which emissions would be reduced because of an increase in the environmental efficiency of production. Such hypothesis, suggesting an inverted-U relation between income and emissions, has been investigated by many authors. For instance, **Cole (2004)** observes the existence of an EKC for the North and South regions of the world, but he observes that this relation inverted-U relation between income and emissions is mainly driven by the pollution haven hypothesis of the North regions displacing polluting production to the South. In the same line, **Kearsley and Riddel (2010)** shows that the existence of pollution havens explains much of the existence of EKC. Moreover, the study argues how the turning point in the relationship between income and emissions is hardly found in the data, suggesting that the EKC hypothesis of technology lowering emissions in the long run might be an overoptimistic perspective.

In sum, the body of research that has addressed both issues of international trade and polluting emissions is very broad. However, it is crucial to mention that most research assessing the link between the two issues has been highly descriptive, as it has departed from the observation of actual levels of trade and the actual levels of emissions. For instance, on the one hand, many studies have applied econometrical models to estimate the relationship between international trade and overall country emissions, making use of panel data (**Kleemann and Abdulai 2013**; **Kozul-Wright and Fortunato 2012**; **Le et al. 2016**; **Atici 2012**). Such studies, however, have provided narrow confidence intervals, first, due to the small variations in overall trading activity in the world, and second, due to the lack of complete datasets encompassing enough time information. On the other hand, all literature related to the 'emissions embodied in trade' and the 'responsibility' or 'imbalances' over those emissions has made used of Input-Output analysis to calculate actual emissions involved in the exporting or importing of goods. In addition, this approach has been enriched with time-series analysis and the application of 'structural decomposition' in order to assess how the actual evolution of trade has altered the temporal evolution of emissions (**Arto and Dietzenbacher 2014**).

Nevertheless, despite all contributions to the topic, a very important issue has remained unanswered in the literature. This is the evaluation and measurement of the real and absolute impact that actual international trade has on global emissions. In particular, such impact evaluation corresponds to the comparison of the actual and observable levels of global emissions and those levels of global emissions that would be generated in the case of a reduction in international trade (counterfactual of the impact evaluation). As previous research has paid much attention to the actual levels of emissions and not to the hypothetical situation in which trade was reduced, this measurement of the emission that take place nowadays due to international trade alone has been generally omitted in the academia. In sum, this precise evaluation, as well as a general assessment of how different trade structures can lead to different levels of pollution, are the main research questions and issues that this study addresses.

To conclude, then, this literature review, a final piece of research deserves some attention for both its research question and its methodological approach. In particular, this is the study **Arto et al. (2014a)**, addressed to measure the ‘Net Emissions Avoided’ by trade (NEA) for the case of the Spanish economy in the years from 1995 to 2007. In particular, the term of NEA is very closed to the concept of impact measurement considered in this study, as the NEA of a certain country is exactly defined as ‘the difference between the emissions that would take place in that country if it was closed to international trade (Emissions Without Trade, EWoT) and its actual emissions’ (**Arto et al. 2014a**). Therefore, this last study also establishes a comparison between observable emissions and the emission in a counterfactual situation, but for the particular case of a single country. However, the approach for a global and international assessment, although being similar from a theoretical perspective, does require a different methodological approach, the one that is explained in next section.

3. Methodology

The present study takes as a baseline the methodology of Input-Output Analysis (IO). In particular, this methodology is grounded in the use of the so-called Input-Output Tables, numerical tables encompassing economic flows across industries and other economic agents. From the analysis of this information, the Input-Output Analysis is able to delve into the existing economic network within a particular economy. In other words, the methodology is able to explain how production (output) from a certain sector in the economy is translated into intermediate consumption (inputs) of one another at an inter-industry level, and how some production is consumed by economic agents as final goods at the end of the chain. Additionally, Input-Output Analysis is able to study how final output from sectors is inherently linked to certain resources, such as capital, employment, or the consumption of water or energy; as well as to the production of waste like polluting gases and other waste materials. Given this broad industry-based information, and through the appropriate matrix calculation, the Input-Output Analysis methodology is powerful enough to show, for instance, the levels of production, resources used and pollution generated due to the demand of very specific agents; or how certain changes in one particular economy could lead to very different economic, social or environmental outcomes.

Addressing the interrelation between international trade and global emissions, this study makes use of the Environmentally Extended Multi-regional Input Output (EE-MRIO) model, which considers in the Input-Output framework all countries in the world and the generation of polluting gases by all existing sectors. The foundations of this particular model and the Input-Output Analysis in general are explained in **Section 3.1**. In addition, in order to evaluate the environmental impact that international trade has on the environment nowadays, this study applies its own particular procedure, in which three different scenarios are considered (besides the current and observable situation of the global economy that is considered to be **Scenario 0**). The first scenario, **Scenario 1**, is developed in **Section 3.2**, and it addresses only the generation of emissions coming from international trade of final goods. More precisely, this scenario considers a variation in this type of trade by taking into account a shift in the demand of final consumers towards more-domestic products, while the existing inter-sectorial trade network remains completely unchanged. Later, **Scenario 2**, presented in **Section 3.3**, does not consider any change in demand of final consumers, but it considers a change in the inter-sectorial network by encompassing a shift in the demand of industries for more-domestic intermediate inputs. In this way, this second scenario addresses a variation in international trade for intermediate goods, and captures the subsequent effect on the environment. Finally, **Scenario 3**, discussed in **Section 3.4**, considers a common variation in both types of international trade, or overall international trade, as both demand of consumers for intermediate goods and demand of industries for final goods are altered. Arbitrarily, variations in international trade for both final and intermediate goods are considered as reductions (and not increases), this is, reductions in both the volume of exports and imports for all countries. Moreover, this reduction in trade is applied linearly to all countries and economic sectors in the same proportion. This way to consider changes in trade results useful in order to build a good counterfactual to estimate the actual impact that international trade has on the environment, as it is finally discussed in **Section 3.5**. In sum, all these considerations, the assumptions made and the most important implications of the procedure and each scenario are discussed in each subsection.

3.1. Foundations of the Input-Output Analysis

As previously mentioned, in order to address the question of how changes in international trade can lead to changes in polluting emissions, the required Input-Output framework of analysis is the EE-MRIO model (**Wiedmann 2009**; **Wiedmann et al. 2011**), encompassing all the regions in the world and gathering the environmental information of gasses emitted by economic sectors and agents. The structure of an EE-MRIO table is shown in **Figure 1** and explained next in detail.

Figure 1. Representation of the EE-MRIO table

	Intermediate use	Final use	Industry output
Intermediate use	$\mathbf{Z}$	$\mathbf{F}$	$\mathbf{x}$
Value added	$\mathbf{v}'$		
Industry output	$\mathbf{x}'$		
Emissions	$\mathbf{G}$		

Source: own elaboration

The EE-MRIO is formed mainly by five elements. Firstly, the square matrix **Z** represents the flows of intermediate goods across sectors and regions in the entire world. In particular, this matrix can be expressed as

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \mathbf{Z}^{12} & \dots & \mathbf{Z}^{1m} \\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \dots & \mathbf{Z}^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{Z}^{m1} & \mathbf{Z}^{m2} & \dots & \mathbf{Z}^{mm} \end{bmatrix} = \begin{bmatrix} z^{11} & z^{12} & \dots & z^{1(m \cdot n)} \\ z^{21} & z^{22} & \dots & z^{2(m \cdot n)} \\ \vdots & \vdots & \ddots & \vdots \\ z^{(m \cdot n)1} & z^{(m \cdot n)2} & \dots & z^{(m \cdot n)(m \cdot n)} \end{bmatrix}, \tag{1}$$

where each submatrix $\mathbf{Z}^{rs}$ contained in **Z** represents the economic flows from region *r* to region *s*, being *m* the total number of regions. At the same time, each submatrix $\mathbf{Z}^{rs}$ has dimensions *n* per *n*, being *n* the total number of industries in each region. Moreover, as **Expression 1** shows, matrix **Z** can also be expressed not in relation to regions but in relation to all existing industries. In this way, matrix **Z** can be represented as the matrix capturing each specific inter-industry flow z^{ij}, this is, the economic flow from sector *i* to sector *j* if it is considered that there exist *m·n* industries in total in the world (as all *m* regions have *n* industries each), no matter the region to which sector *i* or *j* belongs. Finally, it is important to notice that, if one wants to distinguish both the index of the region and the index of the sector within that region, there exists an alternative to represent inter-industry flows z^{ij}. In particular, it is just necessary to consider the indexes i and j as $i = (r_1 - 1) \cdot n + s_1$ and $= (r_2 - 1) \cdot n + s_2$, being r_1 the region and s_1 the sector (within the region r_1) from which the flow departures, and r_2 the region and s_2 the sector (within the region r_2) to which the flow arrives.

Moreover, it is important to define vector **z** as the vector capturing the production of each sector that has been allocated only as intermediate goods in the economy, and not as final goods for consumption. In this way, vector **z**, with dimension *m·n*, can be obtained by the multiplication of matrix **Z** by the identity vector **i** and finally expressed as

$$\mathbf{z} = \begin{bmatrix} z^{1} \\ z^{2} \\ \dots \\ z^{m \cdot n} \end{bmatrix} = \mathbf{Z} \cdot \mathbf{i} = \begin{bmatrix} z^{11} + z^{12} + \dots + z^{1(m \cdot d)} \\ z^{21} + z^{22} + \dots + z^{2(m \cdot d)} \\ \vdots \\ z^{(m \cdot n)1} + z^{(m \cdot n)2} + \dots + z^{(m \cdot n)(m \cdot d)} \end{bmatrix}. \tag{2}$$

Secondly, the following element in the EE-MRIO table is the non-square matrix **F**, which captures the economic flows that go from sectors to economic agents because of their demand, this is, the consumption of sectorial outputs as final goods. As before, matrix **F** can be decomposed as

$$\mathbf{F} = \begin{bmatrix} \mathbf{F}^{11} & \mathbf{F}^{12} & \dots & \mathbf{F}^{1m} \\ \mathbf{F}^{21} & \mathbf{F}^{22} & \dots & \mathbf{F}^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{F}^{m1} & \mathbf{F}^{m2} & \dots & \mathbf{F}^{mm} \end{bmatrix} = \begin{bmatrix} f^{11} & f^{12} & \dots & f^{1(m \cdot d)} \\ f^{21} & f^{22} & \dots & f^{2(m \cdot d)} \\ \vdots & \vdots & \ddots & \vdots \\ f^{(m \cdot n)1} & f^{(m \cdot n)2} & \dots & f^{(m \cdot n)(m \cdot d)} \end{bmatrix}, \tag{3}$$

where submatrices $\mathbf{F}^{rs}$ capture the demand for goods produced in region *r* from a certain region *s*, within a market composed by *m* countries. In particular, each of these $\mathbf{F}^{rs}$ matrices has dimensions *n* per *d*, being *n* again the total number of industries in each region and *d* the number of types of consumers or agents demanding final goods (e.g. households, governments and investors). Like before, matrix **F** can be expressed not in relation to regions but in relation to all existing industries and all existing types of demand in the world. In this way, matrix **F** can be represented as the matrix capturing each specific industry-to-consumer flow f^{ik}, this is, the economic flow from sector i to consumer *k*, considering the existence of $m{\cdot}n$ productive sectors and $m{\cdot}d$ different consumers. Finally, the flow f^{ik} can also be expressed considering $i = (r_1 - 1) \cdot n + s_1$ and $k = (r_2 - 1) \cdot d + a_2$, there is the need to specify the country of origin r_1 and the sector of origin s_1 of the good, as well as the country of destination r_2 and the agent demanding the final good a_2.

In addition, it is possible to define the vector **f** as the one representing aggregate final consumption for all sectors in all countries in the world; this is, without the distinction of the type of consumer (e.g. household, government, and investor) that is having this demand. Consequently, vector **f** has dimension *m·n* and is computed as

$$\mathbf{f} = \begin{bmatrix} f^1 \\ f^2 \\ \dots \\ f^{m\cdot n} \end{bmatrix} = \mathbf{F} \cdot \mathbf{i} = \begin{bmatrix} f^{11} + f^{12} + \dots + f^{1(m\cdot d)} \\ f^{21} + f^{22} + \dots + f^{2(m\cdot d)} \\ \vdots \\ f^{(m\cdot n)1} + f^{(m\cdot n)2} + \dots + f^{(m\cdot n)(m\cdot d)} \end{bmatrix}. \quad (4)$$

Thirdly, vector **v** refers to the value added generated by each of the *m·n* industries existing in the world in the form

$$\mathbf{v} = \begin{bmatrix} v^1 \\ v^2 \\ \dots \\ v^{m\cdot n} \end{bmatrix}, \quad (5)$$

being v^i the value added by industry *i*; while vector **x** refers to the total output generated by each of the *m·n* industries in the form

$$\mathbf{x} = \begin{bmatrix} x^1 \\ x^2 \\ \dots \\ x^{m\cdot n} \end{bmatrix}, \quad (6)$$

referring each term x^j to the total output of industry *j*.

Finally, the non-square matrix **G** captures the emissions generated by all *m·n* sectors in the world for all *p* types of polluting gases considered as

$$\mathbf{G} = \begin{bmatrix} g^{11} & g^{12} & \dots & g^{1(m\cdot n)} \\ g^{21} & g^{22} & \dots & g^{2(m\cdot n)} \\ \vdots & \vdots & \ddots & \vdots \\ g^{p1} & g^{p2} & \dots & g^{p(m\cdot n)} \end{bmatrix}, \quad (7)$$

where each value g^{lj} in the matrix expresses the level of emissions of one type of gas *l* generated by industry *j*. In addition, the vector **g**, computed as

$$\mathbf{g} = \begin{bmatrix} g^1 \\ g^2 \\ \dots \\ g^p \end{bmatrix} = \mathbf{G} \cdot \mathbf{i} = \begin{bmatrix} g^{11} + g^{12} + \dots + g^{1(m \cdot n)} \\ g^{21} + g^{22} + \dots + g^{2(m \cdot n)} \\ \vdots \\ g^{p1} + g^{p2} + \dots + g^{p(m \cdot n)} \end{bmatrix}, \tag{8}$$

represents the global emissions for all p types of polluting gases in the entire world, being g^l the global emissions of gas l.

Once the matrices in the EE-MRIO have been defined, it is necessary to establish the mathematical relation between them. First,

$$\mathbf{x} = \mathbf{z} + \mathbf{f} \tag{9}$$

shows how the total production **x** generated by all $m \cdot n$ sectors in the world has to be equal to the sum of the production used as intermediate goods **z** and the production used as final goods by other economic agents **f**.

Moreover, if matrix **Z** is transformed and each column in the matrix (each sector) is divided by the total output of the corresponding sector as it is possible to obtain the matrix of input coefficients **A**,

$$\mathbf{A} = \mathbf{Z} \cdot \hat{\mathbf{x}}^{-\mathbf{1}}, \tag{10}$$

where $\hat{\mathbf{x}}^{-\mathbf{1}}$ represents the inverse of the diagonal matrix of the vector of total output **x**. Such matrix, if analyzed vertically in columns, captures the production function of each productive sector, this is, the necessary amount of each input (from another industry) to produce one unit of output.

Thanks to this transformation, it is possible to transform **Equation 9** into the linear expression

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f}, \tag{11}$$

and resolve the linear system by expressing total production **x** as a function of final demand **f** in the form

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f} = \mathbf{L} \cdot \mathbf{f}, \tag{12}$$

where the term multiplying $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is denoted by **L** and corresponds to the Leontief inverse matrix of the Input-Output table, the matrix capturing the direct and all indirect production necessary to satisfy such level of demand.

As it is possible to observe, using the Leontief inverse matrix as in **Equation 12**, it is almost immediate to compute the total production required to satisfy both the intermediate consumption of the different industries in the world (intermediate goods) and the final demand of all sort of consumers or agents (final goods).

In addition, the process to calculate the emissions brought by this total production of goods is straightforward. As shown in the expression

$$\mathbf{E} = \mathbf{G} \cdot \hat{\mathbf{x}}^{-\mathbf{1}} , \qquad (13)$$

it is first necessary to compute the matrix of emission coefficients **E**, this is, the matrix containing, for each sector, the amount of gases emitted per unit of industry output. Computed the matrix of emission coefficients, it is possible to extract the emissions brought by a certain level of production $\mathbf{x}$ by applying

$$\mathbf{g} = \mathbf{E} \cdot \mathbf{x} \qquad (14)$$

and, assembling **Equation 12** and **Equation 14**, it is immediate to calculate the emissions brought by a certain level of final demand **f** through

$$\mathbf{g} = \mathbf{E} \cdot (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f} . \qquad (15)$$

In sum, mainly using **Equation 12** and **Equation 15**, it is possible to compute the levels of production and emissions coming from a new structure in the demand of final consumers, a procedure that is used in next subsection to assess the environmental impact of international trade of final goods.

3.2. Changes in International Trade of Final Goods

The first step and scenario to analyze the environmental impact of international trade considers only trade of final goods. Within the Input-Output framework, final goods are no more than output from industries that arrives to other economic agents (e.g. households, governments, and investors) for their consumption. If such industries and such agents are placed in different countries, the goods produced will cross the borders of the country exporting and will arrive to country importing as traded final goods.

Now, in order to consider a reduction in this form of international trade, it is only necessary to impose a new setting in which economic agents substitute their demand of foreign final goods for an equivalent amount of domestically produced final goods. In particular, such shift applied to each country would not alter the absolute amount of goods consumed by agents but only their geographic origin. Moreover, this shift would not affect the domestic-foreign structure of inputs of industries, nor the global inter-industry network for intermediate goods. Nevertheless, it is important to notice that the distribution of production across industries would change to satisfy the new distribution of the demand for final goods; and therefore international trade of intermediate goods would be affected but only in an indirect way.

In particular, to apply the described change in trade for final goods within the Input-Output framework, both the matrix of demands **F** shown in **Expression 3** and the aggregate world demand **f** shown in **Expression 4** should be modified. As shown in the expressions

$$\mathbf{F}_{\mathrm{M}}(\lambda) = \begin{bmatrix} \mathbf{F}^{11} + \lambda \cdot \sum_{i \neq 1}^{m} \mathbf{F}^{i1} & (1-\lambda) \cdot \mathbf{F}^{12} & \cdots & (1-\lambda) \cdot \mathbf{F}^{1m} \\ (1-\lambda) \cdot \mathbf{F}^{21} & \mathbf{F}^{22} + \lambda \cdot \sum_{i \neq 2}^{m} \mathbf{F}^{i2} & \cdots & (1-\lambda) \cdot \mathbf{F}^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ (1-\lambda) \cdot \mathbf{F}^{m1} & (1-\lambda) \cdot \mathbf{F}^{m2} & \cdots & \mathbf{F}^{mm} + \lambda \cdot \sum_{i \neq m}^{m} \mathbf{F}^{im} \end{bmatrix} \quad (16)$$

$$\mathbf{f}_{\mathrm{M}}(\lambda) = \mathbf{F}_{\mathrm{M}}(\lambda) \cdot \mathbf{i} \quad (17)$$

corresponding to the modified versions of the world demand matrix $\mathbf{F_M}(\lambda)$ and the world aggregate demand vector $\mathbf{f_M}(\lambda)$, the reduction of foreign demand could be applied linearly and be later compensated by an increase in the domestic demand. In particular, the reduction in international trade of final goods would be reduced, for all countries in the same proportion, by the real parameter $\lambda \in (0,1)$. For example, for $\lambda = 0$ there would be no change in final demand, for $\lambda = 0.5$ foreign demand would have been reduced by 50%, and for $\lambda = 1$ all foreign demand for final goods would have been eliminated and later compensated by the corresponding increase in domestic demand. Although it is not carried out in this study for the sake of simplicity, note that this reduction in trade could have been applied in different proportions to different countries just by creating a λ_r specific for each country.

Finally, with this new vector $\mathbf{f_M}$ of the world total demand it is possible to compute both the global output required to satisfy this new demand and the subsequent emissions by the use of **Equation 12** and **Equation 15** respectively in the form

$$\mathbf{x_1}(\lambda) = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f_M}(\lambda) \quad (18)$$

$$\mathbf{g_1}(\lambda) = \mathbf{E} \cdot (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f_M}(\lambda)\ . \quad (19)$$

Being $\mathbf{x_0}$ and $\mathbf{g_0}$ the observable levels of output and levels of emissions in the original EE-MRIO (**Scenario 0**), now $\mathbf{x_1}$ and $\mathbf{g_1}$ correspond to the new levels of output and levels of emissions for this **Scenario 1**.

Nevertheless, it is important to note that the validity of the procedure here presented relies on two crucial assumptions. First, this procedure assumes that technology available in both scenarios so far considered is the same, and therefore changes in production and emissions come only from actual changes in international trade. Second, the procedure assumes a free disposal of domestic inputs in order to satisfy the new structure in the world final demand.

3.3. Changes in International Trade of Intermediate Goods

The second step and scenario to analyze the interrelation between international trade and pollutant emission does not consider the previous shift in final demand, but only a change in the inter-industry network and trade for intermediate goods. In particular, as previously were consumers who shifted from foreign to domestic goods, now industries exert that change by substituting their foreign inputs by domestic inputs. Applying such condition, although not changing the global demand for final goods, the demand for intermediate goods varies considerably for two reasons. First, because of the industries shifting from foreign to domestic inputs, which would correspond to a change in the industry-specific 'production function' vector, as explained for matrix **A** in **Expression 10**. Second, once applied this 'technological' change, industries have to adjust their production to meet the levels of global demand; and such adjustment has an effect on the trade of intermediate goods. In particular, some industries are to produce more to satisfy an increased demand of their compatriot sectors, while other producers have to cut down production because of a reduction in exports of intermediate goods.

To apply this change in international trade for intermediate goods within the framework of Input-Output Analysis, it is necessary to modify first the inter-industry global network for intermediate inputs. In a similar fashion as in **Section 3.2**, now matrix **Z** as expressed in **Expression 1**, representing flows of intermediate goods across sectors in the world, needs to be modified to obtain the new matrix

$$\mathbf{Z_M}(\lambda) = \begin{bmatrix} \boldsymbol{Z}^{11} + \lambda \cdot \sum_{i\neq 1}^{m} \boldsymbol{Z}^{i1} & (1-\lambda)\cdot \boldsymbol{Z}^{12} & \dots & (1-\lambda)\cdot \boldsymbol{Z}^{1m} \\ (1-\lambda)\cdot \boldsymbol{Z}^{21} & \boldsymbol{Z}^{22} + \lambda \cdot \sum_{i\neq 2}^{m} \boldsymbol{Z}^{i2} & \dots & (1-\lambda)\cdot \boldsymbol{Z}^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ (1-\lambda)\cdot \boldsymbol{Z}^{m1} & (1-\lambda)\cdot \boldsymbol{Z}^{m2} & \dots & \boldsymbol{Z}^{mm} + \lambda \cdot \sum_{i\neq m}^{m} \boldsymbol{Z}^{im} \end{bmatrix}, \qquad (20)$$

where all economic sectors have reduced their consumption of foreign inputs by the real parameter $\lambda \in (0,1)$, and have compensated this decrease by increasing their consumption of domestic inputs. Once again, this procedure could account for different levels of trade reduction for each country if a specific λ_r was used for each. In this study, however, only a proportional reduction and common for all countries is considered.

Nevertheless, it is important to notice that this last procedure, as explained so far, needs from a slight modification in order to guaranty accuracy and natural feasibility. In particular, such process of all sectors in the world shifting their demand for foreign inputs to the same amounts of domestic inputs would assume that all countries and regions in the world have enough natural resources to satisfy all demand of their industries. Of course, such situation might not be possible, as natural resources are limited by the endowments of each region. Consequently, the previous shift in the inputs' origin should not by applied to all kind of industries, but only to manufacturing and service industries, excluding therefore industries from the primary sector which directly extract the natural resources. In the end, to apply this change, $\mathbf{Z_M}$ should be slightly modified. In particular, rows corresponding to primary sectors would remain the same as in **Z**, and rows corresponding to manufacturing or service sectors would remain as those obtained by the **Expression 20**.

Once the change in the matrix volumes of imports and exports of intermediate goods has been applied, it is finally possible to compute the new matrix of input coefficients or technology matrix $\mathbf{A_M}$ through the expression

$$\mathbf{A_M} = \mathbf{Z_M}(\lambda) \cdot \hat{\mathbf{x}}^{-\mathbf{1}} \tag{21}$$

where $\hat{\mathbf{x}}^{-\mathbf{1}}$ represents once again the inverse of the diagonal matrix of the same vector of total output **x**. This new technology matrix $\mathbf{A_M}$, in the end, is the one capturing the change in the inter-industry trade network in terms of units of production.

Finally, with the new technology matrix $\mathbf{A_M}$ and with the old and observable demand **f**, it is possible to compute the new levels of production and the new level of emissions in such economy through the application of **Equation 12** and **Equation 15** in the form

$$\mathbf{x_2}(\lambda) = [\mathbf{I} - \mathbf{A_M}(\lambda)]^{-1} \cdot \mathbf{f} \tag{22}$$

$$\mathbf{g_2}(\lambda) = \mathbf{E} \cdot [\mathbf{I} - \mathbf{A_M}(\lambda)]^{-1} \cdot \mathbf{f}\ , \tag{23}$$

being $\mathbf{x_2}$ and $\mathbf{g_2}$ the new levels of output and levels of emissions respectively of **Scenario 2**.

3.4. Changes in Overall International Trade

The third scenario of the procedure aims to estimate the levels of production and emissions if reductions where applied to both international trade of intermediate goods and international trade of final goods. With that purpose, this third steps relies on the previous estimations of $\mathbf{f_M}$, the demand in which consumers (partially or totally) move towards domestic final goods, and $\mathbf{A_M}$, in which industries (partially or totally) shift towards domestic intermediate inputs. In particular, the effect of both changes combined can be computed again by the application of **Equation 12** and **Equation 15** in the form

$$\mathbf{x_3}(\lambda) = [\mathbf{I} - \mathbf{A_M}(\lambda)]^{-1} \cdot \mathbf{f_M}(\lambda) \tag{24}$$

$$\mathbf{g_3}(\lambda) = \mathbf{E} \cdot [\mathbf{I} - \mathbf{A_M}(\lambda)]^{-1} \cdot \mathbf{f_M}(\lambda)\ , \tag{25}$$

being $\mathbf{x}_3$ and $\mathbf{g}_3$ respectively the new levels of output and levels of emissions in **Scenario 3**, or the case of reductions in both types of international trade.

In addition, it is worth mentioning that the simultaneous reductions in trade for final goods (in **Section 3.2**) and trade for intermediate goods (in **Section 3.3**) have been applied in this section using a common parameter λ to refer to general reductions in international trade. Consequently, the case of $\lambda = 0$ would correspond to the actual situation of final and intermediate demand; a reduction of $\lambda = 0.5$ would correspond to a 50% decrease of all type of imported goods and the corresponding increase of domestic production for domestic markets; and finally $\lambda = 1$ would correspond to a total reduction in international trade or a situation of autarky (at least for manufactured goods and services, as mentioned in **Section 3.3**).

3.5. Estimation of the Environmental Impact of Trade

In summary, **Figure 2** shows the different measures for production **x** and emissions **g** in all the four cases considered in the procedure, whether changes in international trade have been applied only for final goods (**Scenario 1**), only for intermediate goods (**Scenario 2**) or for both types of goods (**Scenario 3**).

Figure 2. Industry output and emissions coming from changes in international trade

		Demand for final goods	
		Observable	**Reduced**
Demand for intermediate goods	**Observable**	***Scenario 0*** $\mathbf{x}_0 = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f}$ $\mathbf{g}_0 = \mathbf{E} \cdot (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f}$	***Scenario 1*** $\mathbf{x}_1(\lambda) = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f}_\mathbf{M}(\lambda)$ $\mathbf{g}_1(\lambda) = \mathbf{E} \cdot (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{f}_\mathbf{M}(\lambda)$
	Reduced	***Scenario 2*** $\mathbf{x}_2(\lambda) = [\mathbf{I} - \mathbf{A}_\mathbf{M}(\lambda)]^{-1} \cdot \mathbf{f}$ $\mathbf{g}_2(\lambda) = \mathbf{E} \cdot [\mathbf{I} - \mathbf{A}_\mathbf{M}(\lambda)]^{-1} \cdot \mathbf{f}$	***Scenario 3*** $\mathbf{x}_3(\lambda) = [\mathbf{I} - \mathbf{A}_\mathbf{M}(\lambda)]^{-1} \cdot \mathbf{f}_\mathbf{M}(\lambda)$ $\mathbf{g}_3(\lambda) = \mathbf{E} \cdot [\mathrm{I} - \mathbf{A}_\mathbf{M}(\lambda)]^{-1} \cdot \mathbf{f}_\mathbf{M}(\lambda)$

Source: own elaboration

These measures, moreover, can be used to estimate the impact of international trade on each type of emissions just by using the appropriate counterfactual. As shown in **Figure 3**, the environmental impact of trade of final goods would correspond to the difference between the actual levels of emissions $\mathbf{g_0}$ and the counterfactual of a total reduction in international trade of final goods $\mathbf{g_1}(\lambda = 1)$. Secondly, the impact of trade of intermediate goods would correspond to the difference between $\mathbf{g_0}$ and the counterfactual of a total reduction in international trade for intermediate goods $\mathbf{g_2}(\lambda = 1)$. Finally, the last impact measure would correspond to the overall impact of international trade in emissions, and would be computed by the difference of $\mathbf{g_0}$ and the emissions in the case of total autarky in the world $\mathbf{g_3}(\lambda = 1)$.

Figure 3. Measures of the impact of trade on emissions

Impact of international trade on emissions		
Trade of final goods	**Trade of intermediate goods**	**Overall trade**
Scenario 1	***Scenario 2***	***Scenario 3***
$\mathbf{g_0} - \mathbf{g_1}(\lambda = 1)$	$\mathbf{g_0} - \mathbf{g_2}(\lambda = 1)$	$\mathbf{g_0} - \mathbf{g_3}(\lambda = 1)$

Source: own elaboration

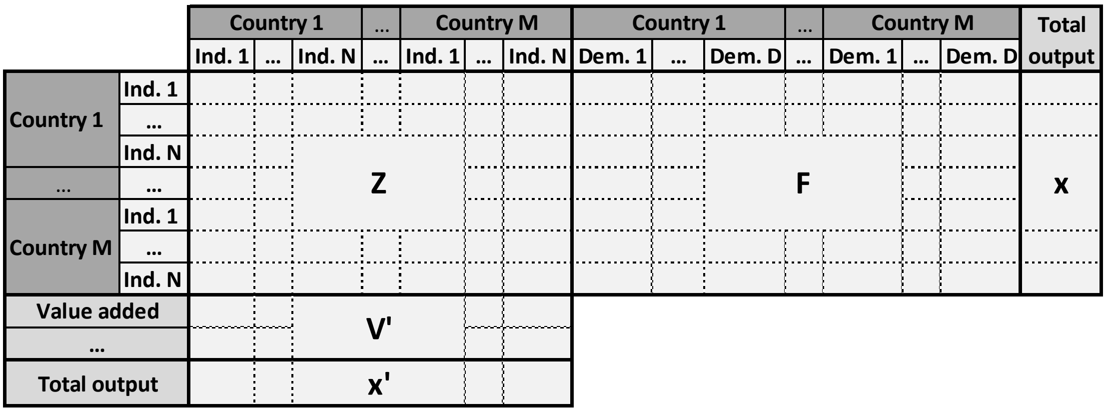
In the end, from the application of this methodology it is possible both to evaluate the impact that small changes in trade would have on emissions, and to evaluate the impact that current levels of international trade have on the environment. The results for both types of analysis, after the presentation of the dataset used in this study, are presented in detail in following sections.

4. Dataset

In order to address the question about the interrelation between international trade and the emission of polluting gases, this study makes use of the data available in the World Input-Output Database (WIOD). The WIOD, officially launched for the first time in April 2012 (**Dietzenbacher et al. 2013**), mainly provides annual time-series of the so-called World Input-Output Tables (WIOTs), a group of Multiregional Input-Output Tables (MRIO) encompassing monetary flows across all the regions in the world and the different economic sectors or industries in each. In addition, the WIOD includes other information gathered in the ‘Socioeconomic accounts’ and the ‘Environmental accounts’, which include sector-specific information regarding socioeconomic variables like labor participation and productivity, or other environmental variables like consumption of resources and generation of waste material. Moreover, the information provided by the WIOD encompasses 41 countries or regions in the entire world, considering 35 sectors in each region, and it encompasses yearly data from 1995 to the year 2011. These considerations about the dataset and some important implications that directly relate to this study are discussed in detail in this section.

4.1. Economic Information in the WIOD

Figure 4. Structure of the World Input-Output Table (WIOT)



Source: own elaboration

The most relevant economic information available in the WIOD corresponds to the World Input-Output Tables. As **Figure 4** shows, a WIOT provides information of all transactions in the global economy. Firstly, the WIOT captures all economic (and monetary) flows across sectors within a certain country, and cross-border sectorial trade (matrix **Z** in the WIOT). Second, the WIOT includes the information of final consumption for each industry and for all regions in the world, differentiating consumption of domestic final goods (produced by a domestic sector) and consumption of foreign and imported final products (matrix **F** in the WIOT). Third, the WIOT includes industry-based information on value added and other data referring to tax-subsidy adjustments on sectors and international transport margins (matrix **V'** in the WIOT). Finally, the WIOT includes the information of the production of each sector (vector **x** in the WIOT) and, therefore, the total production of each economy and the production of the entire world. All economic flows in the WIOTs are expressed in monetary terms, at current and constant prices, and in million US dollars.

First, if the information available in the WIOT is analyzed by columns, it is possible to observe the 'production process' of each economic sector (**Timmer et al. 2015**). In this way, it is possible to observe (in matrix **Z**) the different inputs that a certain industry needs from other industries in the same or foreign regions, as well as the value added generated (matrix **V'**) in order to produce its total and gross output (vector **x**).

On the other hand, if the information in the WIOT is analyzed by the rows of the table, the resulting information would correspond to the 'distribution of the output' produced by each industry (**Timmer et al. 2015**). In this way, the volume of production of a certain industry could be used as an intermediate input by a domestic or a foreign region (matrix **Z**), or it could be employed in domestic or foreign agents demanding such production as a final good for consumption (vector **F**). In the end, all the economic value distributed by a certain industry across other industries or economic agents (matrix **x'**) needs to equal the production generated by such industry (vector **x**).

Table 1. Countries in the WIOD

EU members			NAFTA	Asia	BRIIAT
Austria	Germany	Netherlands	USA	China	Brazil
Belgium	Greece	Poland	Canada	Japan	Russia
Bulgaria	Hungary	Portugal	Mexico	South Korea	India
Cyprus	Ireland	Romania		Taiwan	Indonesia
Czech Republic	Italy	Slovakia			Australia
Denmark	Latvia	Slovenia			Turkey
Estonia	Lithuania	Spain			
Finland	Luxembourg	Sweden			
France	Malta	United Kingdom			

Source: WIOD

The information provided in the WIOTs of the WIOD is very broad. First, as previously mentioned, the WIOD encompasses information for the entire world, and more precisely, for 40 countries and an extra region named ‘Rest of the World’ encompassing the information for the remaining countries. As shown in **Table 1**, these 40 countries include 27 European Union (EU) members (all EU members by January 2007, before the entrance of Croatia); the three countries belonging to the North American Free Trade Agreement (NAFTA); a group of Asian countries formed by China, Japan, South Korea and Taiwan; and the six countries of the BRIIAT group. All these 40 countries together represent a largest part of the global economy covering more than 85% of world gross domestic product (GDP) according to 2008 data at current exchange rates (**Timmer et al. 2015**). Therefore, the rest of economies left to the Rest of the World region represent a relatively small share of the global economy.

Table 2. Economic sectors in the WIOD

ISIC Code	WIOD Code	Name of the industry
AtB	c1	Agriculture, Hunting, Forestry and Fishing
C	c2	Mining and Quarrying
D		Manufacturing*
15t16	c3	Food, Beverages and Tobacco
17t18	c4	Textiles and Textile Products
19	c5	Leather, Leather and Footwear
20	c6	Wood and Products of Wood and Cork
21t22	c7	Pulp, Paper, Paper , Printing and Publishing
23	c8	Coke, Refined Petroleum and Nuclear Fuel
24	c9	Chemicals and Chemical Products
25	c10	Rubber and Plastics
26	c11	Other Non-Metallic Mineral
27t28	c12	Basic Metals and Fabricated Metal
29	c13	Machinery, Nec
30t33	c14	Electrical and Optical Equipment
34t35	c15	Transport Equipment
36t37	c16	Manufacturing, Nec; Recycling
E	c17	Electricity, Gas and Water Supply
F	c18	Construction
G		Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods*
50	c19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
51	c20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
52	c21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
H	c22	Hotels and Restaurants
I		Transport, storage and communications*
60	c23	Inland Transport
61	c24	Water Transport
62	c25	Air Transport
63	c26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	c27	Post and Telecommunications
J	c28	Financial Intermediation
K		Real estate, renting and business activities*
70	c29	Real Estate Activities
71t74	c30	Renting of M&Eq and Other Business Activities
L	c31	Public Admin and Defence; Compulsory Social Security
M	c32	Education
N	c33	Health and Social Work
O	c34	Other Community, Social and Personal Services
P	c35	Private Households with Employed Persons

* Sectors in the ISIC rev.3 disaggregated in the WIOD database

Source: WIOD

Secondly, the WIOD and the WIOT tables provide information for 35 productive sectors or industries in each country or region, based on the 99-sector classification of the International Standard Industrial Classification of All Economic Activities (ISIC rev.3) of the United Nations. Sectors encompassed by the WIOD, enlisted in **Table 2**, cover primary sectors like Agriculture, Hunting, Forestry and Fishing, or Mining and Quarrying; manufacturing sectors like Food, Beverages and Tobacco; and service sectors like Transportation, Hotels and Restaurants, or Education.

Table 3. Final consumption and investment in the WIOD

WIOD Code	Name of the industry
c37	Final consumption expenditure by households
c38	Final consumption expenditure by non-profit organisations serving households (NPISH)
c39	Final consumption expenditure by government
c41	Gross fixed capital formation
c42	Changes in inventories and valuables

Source: WIOD

In addition, goods produced by industries can serve as intermediate goods for other domestic or foreign industries, but also as final goods if they are purchased or consumed by other economic agents. Based on this distinction, the WIOTs distinguish five types of final recipients of the goods produced by industries (matrix **F** in **Figure 1**). As shown in **Table 3**, there are three final consumers, households, non-profit organizations serving households and government; and two forms or channels of investment by firms, gross fixed capital formation and changes in inventories and valuables.

Moreover, the WIOD is enriched by three other data packages. The first corresponds to the National Input-Output Tables (NIOTs) for all the 40 countries, which incorporate the same information as the WIOTs but only considering one particular country/region and taking into account all national imports and exports each one in one aggregated matrix. Such synthetized Input-Output tables, being very useful for the study of particular economies in a certain or several years, are in fact unsuitable for the study of trade across nations and its economic and environmental implications.

4.2. Socioeconomic Information in the WIOD

The second packages of data that the WIOD includes and that deserves some attention are the 'Socio-Economic Accounts', which include, for all countries and in particular for each industry, data on employment, capital stocks, gross output and value added. The information on labor is very broad, distinguishing the number of workers involved in production, including employees, self-employed and family workers; the labor skill type according to the International Standard Classification of Education (ISCED), including low-skilled workers, medium skilled and high-skilled; and the amount of time worked by each group. In addition, the Socio-Economic Accounts provide information on the capital income coming from each industry, which broadly represents the returns on physical capital, land, intangible capital and financial capital (**Timmer et al. 2015**). All this information, being very relevant for the analysis of the social impact of trade patterns, is still far from the strongest interest of this article, as it tries to center its attention only on the environmental implications of international trade.

4.3. Environmental Information in the WIOD

For the purpose of this study, the last package of information that deserves a special attention is the so-called 'Environmental Accounts' included in the WIOD. These datasets, as in the previous Socio-Economic Accounts, gather industry-based and country-specific information for five environmental dimensions: use of energy, use of mineral and fossil resources, land use, water use, and emission of main greenhouse gases and other main air pollutants (**Genty et al. 2012**). Such environmental measures are expressed in the WIOD in physical units, and not in monetary units as the WIOTs or the NIOTs, and all of them are accounted following the framework of National Accounting Matrices Including Environmental Accounts (NAMEA). As summarized in **Table 4**, all these five environmental dimensions gather information for a broad range of types of resources or waste products (**Genty et al. 2012**).

Table 4. Environmental information in the WIOD

Energy Use *		Land Use	Materials Use **	Water Use	Emissions to Air
Hard coal and derivatives	Biogasoline including hydrated ethanol	Arable land	Animal biomass	Blue Water	CO2 - Carbon dioxide ***
Lignite and derivatives	Biodiesel	Permanent crops	Feed biomass	Green Water	CH4 - Methane
Coke	Biogas	Permanent meadows	Food biomass	Grey Water	N2O - Nitrous oxide
Crude oil, NGL and feedstocks	Other combustible renewables	Productive forest area	Forestry biomass		NOx - Nitrogen oxides
Diesel oil for road transport	Electricity		Other biomass		SOx - Sulphur oxides
Motor gasoline	Heat		Coal		CO - Carbon monoxide
Jet fuel (kerosene and gasoline)	Nuclear		Natural gas		NMVOC - Non-methane volatile organic compounds
Light Fuel oil	Hydroelectric		Crude oil		
Heavy fuel oil	Geothermal		Other fossil fuels		NH3 - Ammonia
Naphtha	Solar		Non-metallic minerals		
Other petroleum products	Wind power		Other non-metallic minerals		
Natural gas	Other sources		Metals		
Derived gas	Distribution losses				
Industrial and municipal waste					

* The WIOD distinguishes both the *gross energy use*, directly related to expenditures for energy inputs, and *emission relevant energy use*, the gross energy use excluding the non-energy use of energy commodities and the input of energy commodities for transformation.

** The WIOD distiguished both *materials used*, those which enters the economic system for further processing or direct consumption, and *materials unused*, those that do not enter the economic system but are left unusable.

*** The WIOD also provides disaggregated data about the CO2 emissions of each industry according to the type of energy used for its processes.

Source: WIOD

In particular, the information from the WIOD's Environmental Accounts that is used intensively in this study is the last one, referring to the emission of polluting gases. As **Table 4** already shows, the WIOD gathers information for each country and sector (including both industries and final consumers like households or governments) of the emission of eight types of gases. The first three gases, the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are considered greenhouse gases and the main originators of climate change. Other greenhouse gases like SF6, CFCs and HFCs are not considered in the WIOD, although the impact these gases have on global warming is mainly small (**Genty et al. 2012**). On the other hand, the nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), the non-methane volatile organic compounds (NMVOC) and ammonia (NH_3) are often referred as 'local gases', as they to do not have such global impact as the greenhouse gases but do have negative effects at a more local level. These negative effects are very diverse, but mainly two are considered when analyzing the emission of these gases (**Genty et al. 2012**): 'acidification', the decrease in the pH of the water in oceans, in freshwater or in the soils with harmful results for living beings; and 'tropospheric ozone formation', which may foster the formation of toxic oxides. As provided in **Genty et al. (2012)**, now **Table 5** shows which gases contribute to each of these three forms of environmental negative impact.

Table 5. Air pollutants and environmental negative impact

Air pollutant	Global warming	Acidification	Ozone formation
CO2	X		
CH4	X		X
N2O	X		
NOx		X	X
SOx		X	
CO			X
NMVOC			X
NH3		X	

Source: WIOD

Finally, it is important to remark that, although the WIOD encompasses yearly economic information for all years between 1995 and 2011, the information about gas emissions only exists for all years between 1995 and 2009.

4.4. Aggregate Measures for Gas Emissions

As shown in **Table 4**, the Environmental Accounts of the WIOD provide information for eight different polluting gases, and all of them have been used to construct the EE-MRIO table used in this study. Consequently, the resulting information from the methodology described in **Section 3.5** refers to 8 measures of emissions each, and to 32 measures in total considering the four existing scenarios. Then, to synthetize this information, three aggregate measures have been used, each related to a certain form of negative environmental impact. In this way, the emissions for the different types of gases are considered not only in absolute terms but also in relation to their contribution to a certain environmental issue, what also allows for the summation of emissions of very different types of gases. More precisely, as shown in **Table 5**, the three aggregate measures correspond to the issues of global warming (capturing the information of CO_2, CH_4 and N_2O), acidification (formed by NO_x, SO_x and NH_3) and tropospheric ozone formation (driven by CH_4, NO_x, CO, and NMVOC).

First, being global emissions of CO_2 the main driver of the greenhouse effect and, therefore, global warming, the aggregate measure for this environmental problem takes CO_2 as a benchmark and it makes use of the so-called 'CO_2 equivalent units'. The other gases involved in global warming, therefore, are evaluated in terms of their negative contribution to this environmental issue in relation to that of CO_2. This is also known as the Global Warming Potential (GWP) of a certain gas. In sum, the formula to compute the CO_2 equivalent emissions for the combination of the three gases greenhouse considered in this study is

$$\mathrm{E}_{\mathrm{CO2\ Eq.}} = \mathrm{E}_{\mathrm{CO2}} + 25 \cdot \mathrm{E}_{\mathrm{CH4}} + 298 \cdot \mathrm{E}_{\mathrm{NO2}}\ , \tag{26}$$

where $\boldsymbol{E}_i$ refers to the level of emissions of gas i and each coefficient refers to the global warming potential of each type of gas, as considered in **Environmental Protection Agency (2016)**.

Second, the aggregate measure for the phenomenon of acid rain, or in general, the environmental issue of acidification, takes the gas of SO_2 as a benchmark and it is expressed in 'SO_2 equivalent units'. In the same way as before, the different gases contributing to this phenomenon are evaluated in terms of their Acidification Potential (AP). In particular, taking the coefficients from **Heijungs et al. (1992)**, the formula to compute the global emissions of equivalent SO_2 is

$$\mathrm{E}_{\mathrm{SO2\ Eq.}} = \mathrm{E}_{\mathrm{SOx}} + 0.7 \cdot \mathrm{E}_{\mathrm{NOx}} + 1.88 \cdot \mathrm{E}_{\mathrm{NH3}}\ . \tag{27}$$

Finally, the third aggregate measure corresponds to the environmental issue of tropospheric ozone formation, or the formation of atmospheric oxidants. In the case of this negative environmental phenomenon, the different types of gases are evaluated in terms of their Photochemical Ozone Creation potential (POCP), and the gas of reference is ethene (C_2H_4). The subsequent formula to evaluate this overall impact, taking the coefficients from **Heijungs et al. (1992)**, is

$$\mathrm{E}_{\mathrm{C2H4\ Eq.}} = 0.007 \cdot \mathrm{E}_{\mathrm{CH4}} + 0.04 \cdot \mathrm{E}_{\mathrm{CO}} + 0.416 \cdot \mathrm{E}_{\mathrm{NMVOC}} \ , \qquad (28)$$

where the Photochemical Ozone Creation potential of NO_x is considered to be sufficiently low not be considered in the aggregate measure.

5. Results

The developed methodology has been applied to the economic and environmental information of the year 2008, as no more recent and accurate data was available in the WIOD. According to the main objective of this study, this section summarizes the results obtained for each of the three scenarios described in the procedure, giving not only information for the levels of emissions but also some insights about the economic implications of reductions in international trade. In addition, for each scenario, five degrees of reduction in trade have been considered: no reduction (corresponding to $\lambda = 0$), reduction of the 25% ($\lambda = 0.25$), reduction of the 50% ($\lambda = 0.5$), reduction 75% ($\lambda = 0.75$), and no international trade ($\lambda = 1$) for each specific good.

5.1. International Trade of Final Goods

The first scenario, or **Scenario 1**, corresponds to the reduction of international trade for final goods, this is, those goods demanded by domestic economic agents to foreign productive sectors as final products. Consequently, this first scenario is that in which changes in trade come only from the consumer's decision to substitute foreign products by the same amount of domestic products, but not altering the amount nor the variety of their consumption basket.

Table 6. Changes coming from reductions in trade of final goods

	Units	**0%**	**25%**	**50%**	**75%**	**100%**	% change of total reduction
Total value added	***billions of US$***	**58,372**	**58,373**	**58,374**	**58,375**	**58,376**	**0.0%**
Total production	***billions of US$***	**122,789**	**122,618**	**122,446**	**122,274**	**122,102**	**-0.6%**
Emissions of CO2	*gigatonnes (Tg)*	25,598	25,563	25,528	25,492	25,457	-0.5%
Emissions of CH4	*kilotonnes (Gg)*	284,017	282,337	280,657	278,977	277,304	-2.4%
Emissions of N2O	*kilotonnes (Gg)*	11,096	11,026	10,956	10,885	10,815	-2.5%
Emissions of Eq. CO2	***gigatonnes (Tg)***	**36,005**	**35,907**	**35,809**	**35,711**	**35,613**	**-1.1%**
Emissions of NOX	*kilotonnes (Gg)*	102,250	102,011	101,773	101,534	101,296	-0.9%
Emissions of SOX	*kilotonnes (Gg)*	111,011	110,102	109,193	108,283	107,377	-3.3%
Emissions of CO	*kilotonnes (Gg)*	414,682	413,598	412,514	411,430	410,351	-1.0%
Emissions of NMVOC	*kilotonnes (Gg)*	114,857	114,228	113,599	112,971	112,345	-2.2%
Emissions of NH3	*kilotonnes (Gg)*	30,938	30,706	30,475	30,243	30,013	-3.0%
Emissions of Eq. SO2	***kilotonnes (Gg)***	**240,750**	**239,238**	**237,726**	**236,214**	**234,709**	**-2.5%**
Emissions of Eq. C2H4	***kilotonnes (Gg)***	**66,356**	**66,039**	**65,722**	**65,406**	**65,090**	**-1.9%**

Source: own elaboration

In particular, as shown in **Table 6**, this reduction in international trade for final goods seems first not to have any overall effect on the value added generated in the world. Without paying attention to changes in its cross-country distribution, the global value added remains constant at 58,372 billion US$. Production, on the other hand, is affected by this reduction in trade for final goods, as it goes from 122,789 to 122,102 billion US$, in a 0.6% decrease, when a total trade reduction is applied.

With regard to emissions of pollutants, the total reduction in trade of final goods has a clear negative effect on the volume of emissions, and, therefore, a resulting positive effect in the environment. For instance, CO_2 emissions are reduced by a moderate 0.5%, what corresponds to a reduction of 141 gigatonnes of CO_2. The reductions in emissions of the other GHG are higher, being reduced by 2.4% in the case of CH_4 and 2.5% in the case of N_2O. In the end, overall GHG gases are reduced by 1.1% percent, what means an avoidance of 392 gigatonnes of equivalent CO_2. Regarding emission of local gases, reductions go from a 0.9% in the case of NO_x to 3.3% in the case of SO_x. In sum, reductions in emission of local gases lead to the avoidance of 6,041 kilotonnes of equivalent SO_2 and 1,266 kilotonnes of equivalent C_2H_4.

This general decrease in both global levels of production and levels of emissions may show two simultaneous facts. Firstly, it is important to note that, as consumption levels and consumption distribution have not been changed, the decrease in global production cannot have been driven by any of these two factors. Consequently, this decrease in production, holding constant consumption patterns, may have induced an increase in the overall efficiency of productive sectors in the world. In particular, as this first scenario only has taken into account shifts in demand from foreign industries to local industries, this increase in the overall efficiency could have been driven by an increase in the demand to high-efficient sectors and/or a decrease in the demand to low-efficient sectors. Moreover, this reduction in levels of global production or this increase in overall efficiency explains much about the general reduction in emissions of GHG and local gases. However, reductions in emissions of equivalent CO_2 (-1.1%), equivalent SO_2 (-2.5%) and equivalent C_2H_4 (-1.9%) clearly overtake that of production (-0.6%). This fact could induce to think that not only an increased efficiency has fostered lower emission, but also a better distribution in production towards less polluting industries. In other words, this shift in emissions could have been triggered by demand shifting from low-eco-efficient industries to high-eco-efficient industries. From these results, moreover, it could be derived that the actual level of trade for final goods might be one driver of economic and environmental inefficiency, as reductions in this type of trade could lead to lower production and lower emissions without any changes in consumption patterns.

5.2. International Trade of Intermediate Goods

The second scenario, or **Scenario 2**, corresponds to the reduction in trade for intermediate goods, this is, those goods that domestic sectors demand to foreign sectors to be used as intermediate inputs. In this scenario, therefore, final consumers do not change their consumption patterns, and this shift in international trade is only driven by sectors' decision to shift from foreign inputs to the same amounts of domestic inputs. Consequently, the inter-sectorial network is altered in this situation, although final consumers do not realized about this shift because they do receive the same amounts of domestic and foreign products. The only difference between these products and the previous ones, nevertheless, is that these are more intensively produced within a domestic market.

Table 7. Changes coming from reductions in trade of intermediate goods

	Units	**0%**	**25%**	**50%**	**75%**	**100%**	% change of total reduction
Total value added	***billions of US$***	**58,372**	**58,378**	**58,386**	**58,397**	**58,412**	**0.1%**
Total production	***billions of US$***	**122,789**	**122,757**	**122,718**	**122,668**	**122,599**	**-0.2%**
Emissions of CO2	*gigatonnes (Tg)*	25,598	25,733	25,895	26,096	26,350	2.9%
Emissions of CH4	*kilotonnes (Gg)*	284,017	282,869	281,760	280,695	279,681	-1.5%
Emissions of N2O	*kilotonnes (Gg)*	11,096	11,087	11,081	11,079	11,085	-0.1%
Emissions of Eq. CO2	***gigatonnes (Tg)***	**36,005**	**36,108**	**36,241**	**36,415**	**36,645**	**1.8%**
Emissions of NOX	*kilotonnes (Gg)*	102,250	102,710	103,287	104,027	105,006	2.7%
Emissions of SOX	*kilotonnes (Gg)*	111,011	110,940	110,870	110,805	110,752	-0.2%
Emissions of CO	*kilotonnes (Gg)*	414,682	419,338	426,192	436,254	451,213	8.8%
Emissions of NMVOC	*kilotonnes (Gg)*	114,857	115,479	116,562	118,326	121,143	5.5%
Emissions of NH3	*kilotonnes (Gg)*	30,938	30,911	30,885	30,863	30,846	-0.3%
Emissions of Eq. SO2	***kilotonnes (Gg)***	**240,750**	**240,949**	**241,235**	**241,646**	**242,247**	**0.6%**
Emissions of Eq. C2H4	***kilotonnes (Gg)***	**66,356**	**66,793**	**67,510**	**68,639**	**70,402**	**6.1%**

Source: own elaboration

As shown in **Table 7**, the second scenario in which inter-sectorial and international trade is reduced leads to an overall increase of the global value added generated in the world but to a small reduction in the global production of goods. In particular, value added is softly increased by 40 billion US$, what means a 0.1% increase, when a total trade reduction is applied. On the other hand, total production is reduced by 190 billion US$, what means a reduction of the 0.2%.

Results for emissions, as for production and value added, are diverse. For instance, emissions of CO_2 increase by 2.9% and 752 gigatonnes, but emissions of the other GHG gases of CH_4 and N_2O are reduced more moderately by 1.5% and 0.1% respectively. Being CO_2 the main component of GHG emissions, the overall generation of equivalent CO_2 raises in the end by 1.8% and by 640 gigatonnes of equivalent units. Regarding emission of local gases, results are also diverse, as some emissions of pollutants like SO_x and NH_3 are reduced, and those of others like NOS and NMVOC are increased. In sum, changes in emissions of local gases lead to an increase of 1,497 kilotonnes of equivalent SO_2, what corresponds to an increase of the 0.6%, and to a dramatic increase of 4,046 kilotonnes of equivalent C_2H_4, corresponding to an increase of the 6.1% in the gases affecting ozone formation.

This second situation in which industries substitute domestic inputs for foreign ones leads a broader range of interpretations. First, in line with the discussion about the previous scenario, this reduction in total production, and the fact that final consumption has not changed during this procedure, can induce to think about an increase in the overall efficiency in productive sectors of the world. In a similar way as before, it seems that probably now are industries the ones that have shifted, in general terms, from (economically) low-efficient to high-efficient providers. Moreover, this shift seems to have happened also from industries with low generation of value added towards industries with a higher generation of value added per unit of output. On the other hand, it seems that this change in inter-sectorial trade has happened from high-eco-efficient industries to low-eco-efficient industries, as emissions of these aggregate measures have increased considerably (by 1.8%, 0.6% and 6.1% respectively) despite the general decrease in the global production. In contrast with **Scenario 1**, these results would induce to think that the exiting trade of intermediate goods could be imputed to be one driver of low economic efficiency but one driver of high environmental efficiency, as reductions in this type of trade would lead to lower production and higher emissions.

5.3. Overall International Trade

The last scenario to be discussed is **Scenario 3**, the one regarding reductions in overall international trade. The reductions in trade considered in this scenario relate to both the decisions of consumers, not changing their consumption basket but the origin of those products, and the decisions of industries, moving from foreign to domestic intermediate inputs. In other words, this third scenario considers the proportional reduction in imports from other countries, which are compensated by the equivalent domestic production.

Results for this last scenario are displayed in **Table 8**, and they give no more than the combined information of the previous two considered situations. In particular, a total reduction in international trade (autarky) finally leads to an increase of 0.1% in value added and a big decrease in total production of 0.9%, which corresponds to a decrease of 56 billion US$ and 1,055 billion US$ respectively.

Table 8. Changes coming from reductions in overall international trade

	Units	0%	25%	50%	75%	100%	% change of total reduction
Total value added	***billions of US$***	**58,372**	**58,379**	**58,390**	**58,405**	**58,428**	**0.1%**
Total production	***billions of US$***	**122,789**	**122,577**	**122,338**	**122,062**	**121,734**	**-0.9%**
Emissions of CO2	*gigatonnes (Tg)*	25,598	25,698	25,829	26,007	26,255	2.6%
Emissions of CH4	*kilotonnes (Gg)*	284,017	281,157	278,260	275,323	272,350	-4.1%
Emissions of N2O	*kilotonnes (Gg)*	11,096	11,016	10,936	10,859	10,788	-2.8%
Emissions of Eq. CO2	***gigatonnes (Tg)***	**36,005**	**36,010**	**36,045**	**36,126**	**36,279**	**0.8%**
Emissions of NOX	*kilotonnes (Gg)*	102,250	102,483	102,865	103,473	104,435	2.1%
Emissions of SOX	*kilotonnes (Gg)*	111,011	110,005	108,948	107,842	106,701	-3.9%
Emissions of CO	*kilotonnes (Gg)*	414,682	418,558	425,439	436,856	455,474	9.8%
Emissions of NMVOC	*kilotonnes (Gg)*	114,857	114,893	115,510	117,033	120,040	4.5%
Emissions of NH3	*kilotonnes (Gg)*	30,938	30,675	30,405	30,128	29,849	-3.5%
Emissions of Eq. SO2	***kilotonnes (Gg)***	**240,750**	**239,412**	**238,115**	**236,915**	**235,921**	**-2.0%**
Emissions of Eq. C2H4	***kilotonnes (Gg)***	**66,356**	**66,506**	**67,017**	**68,087**	**70,062**	**5.6%**

Source: own elaboration

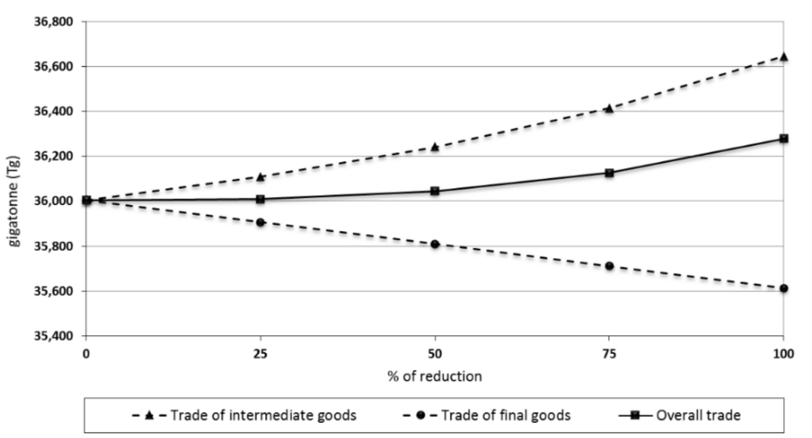
Moreover, in line with the discussion in the previous scenarios, results shown raise some important economic and environmental considerations. Firstly, the decrease in global production due to the total elimination of international trade shows that actual levels of international trade have in fact a positive effect on production, although they contribute negatively to the overall efficiency of productive sectors (as they produce more to finally provide the same final goods). In particular, the economic impact of international trade on the global production would be 1,055 billion US$, although the impact on the generation of value added would be negative and of 52 billion US$. Therefore, by the increase of international trade, production would be shifted, in average, towards a low-efficient industry network and industries with a lower generation of value added per unit of production.

Regarding global emissions of pollutants, the combined effect of reductions in international trade for both types of goods finally leads to an increase of the 0.8% in the global emission of GHG gases, corresponding to 274 extra gigatonnes of equivalent CO_2. In particular, being emission of CH_4 and NH2 reduced by 4.1% and 2.8%, the increase of 657 gigatonnes of CO_2, a 2.6% more, leads to that increase in the overall GHG emissions. With regard to local gases, however, results are diverse once again. For instance, emission of CO increase sharply by 9.8%, while other emissions of gases like SO_x and NH_3 decrease by 3.9% and 3.5% respectively. In sum, the aggregate measure for the phenomenon of acidification, finally decreases by 2.0%, thanks to a reduction of 4,829 kilotonnes of equivalent SO_2. On the other hand, the aggregate measure for ozone formation, increases considerably by 5.6%, driven by an increase of 3,706 kilotonnes of equivalent C_2H_4.

5.4. Impact Evaluation

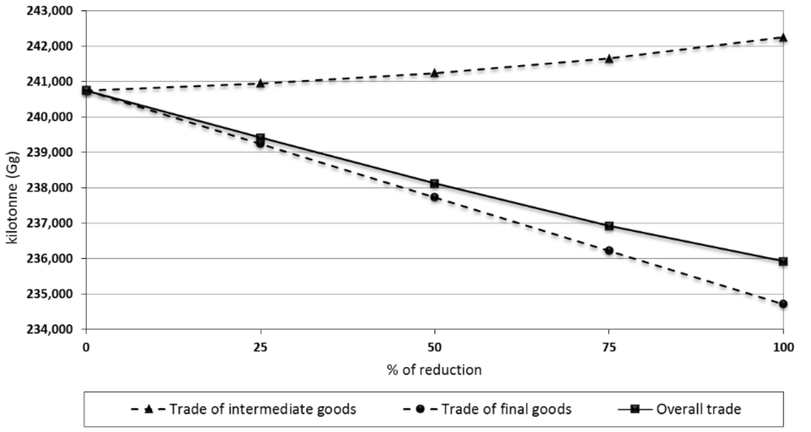
Finally, considered the case of total autarky and the subsequent volume of emissions generated, it is possible to estimate the impact that current trade activity has on the emission of pollutants. In particular, this impact is positive for some aggregate measures and negative for others. More previously, the environmental impact of overall international trade is of -274 gigatonnes of equivalent CO_2, 4,829 kilotonnes of equivalent SO_2, and -3,706 kilotonnes of equivalent C_2H_4. This situation leads to induce that current international trade has in fact a positive effect on the environment with regard to the issues of global warming and tropospheric ozone formation, as more eco-efficient industries in these emissions take over a higher share of the global production. However, it can also be induced the international trade has a negative impact on the environmental problem of acidification, as the current scheme in international trade shifts production, in general terms, towards regions les eco-efficient with regard to this environmental issue.

Figure 5. Global emissions of equivalent CO_2 (in gigatonnes, or Tg)



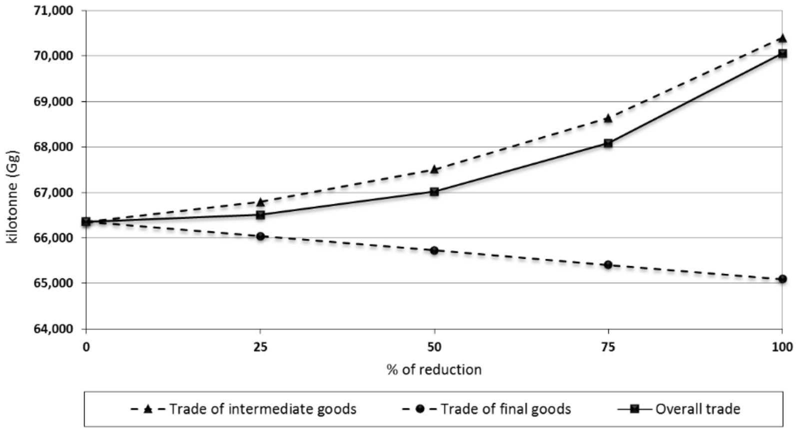
Source: own elaboration

Figure 6. Global emissions of equivalent SO_2 (in kilotonnes, or Gg)



Source: own elaboration

Figure 7. Global emissions of equivalent C_2H_4 (in kilotonnes, or Gg)



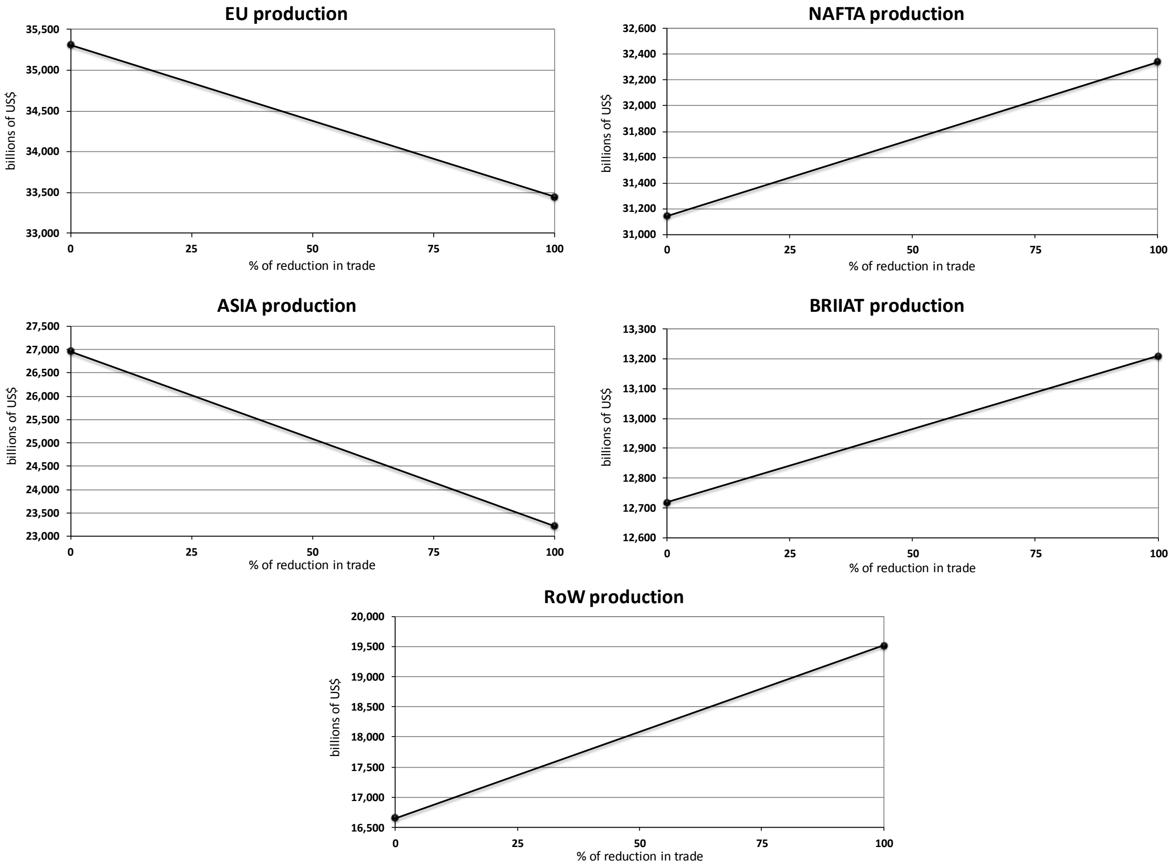
Source: own elaboration

As **Figures 5 to 7** illustrate, the effect of trade for final goods and the effect of trade for intermediate goods is opposite for the three aggregate measures of global emission of equivalent CO_2, equivalent SO_2 and equivalent C_2H_4. In particular, in all three cases, the effect of trade of intermediate goods is negative on the levels of emissions and, therefore, positive for the environment. In other words, any increase in inter-sectorial trade leads to lower emissions of equivalent CO_2, equivalent SO_2 and equivalent C_2H_4, although such effect for the case of equivalent SO_2 is lower. On the contrary, the effect of trade for final goods is positive in all the three aggregate measures of emissions, and, therefore, the effect on the environment is negative. Consequently, any increase in trade of final goods would generate higher emissions of equivalent CO_2, equivalent SO_2 and equivalent C_2H_4, leading to worse environmental situation. Nevertheless, from this two contrary effects, the effect of trade for intermediate goods is higher in the aggregate measure of equivalent CO_2 and equivalent C_2H_4, but the effect of trade for final goods is stronger in the case of emissions of equivalent C_2H_4. In sum, the overall effect of international trade in GHG emissions is negative, as increases in international trade finally lead to lower CO_2 equivalent emissions. In the same way, emissions of gases fostering ozone formation are also lowered by general increases in international trade. On the contrary, the effect of trade on C_2H_4 equivalent emissions affecting acidification is positive, as any increase in overall trade sharply increases SO_2 equivalent emissions.

5.5. Cross-Country Differences

Finally, in order to enrich previous results, some insights about the cross-regional differences in the world may contribute to the understanding of this interrelation between international trade and global emissions. In particular, the five regions that have been considered to assess these cross-country differences correspond to those of **Table 1**, named as EU members, NAFTA members (Canada, United States, and Mexico), ASIA members (China, Japan, South Korea, and Taiwan), BRIIAT members (Brazil, Russia, India, Indonesia, Australia, and Turkey), and the rest of the world (or RoW).

Figure 8. Changes in production driven by reductions in overall trade

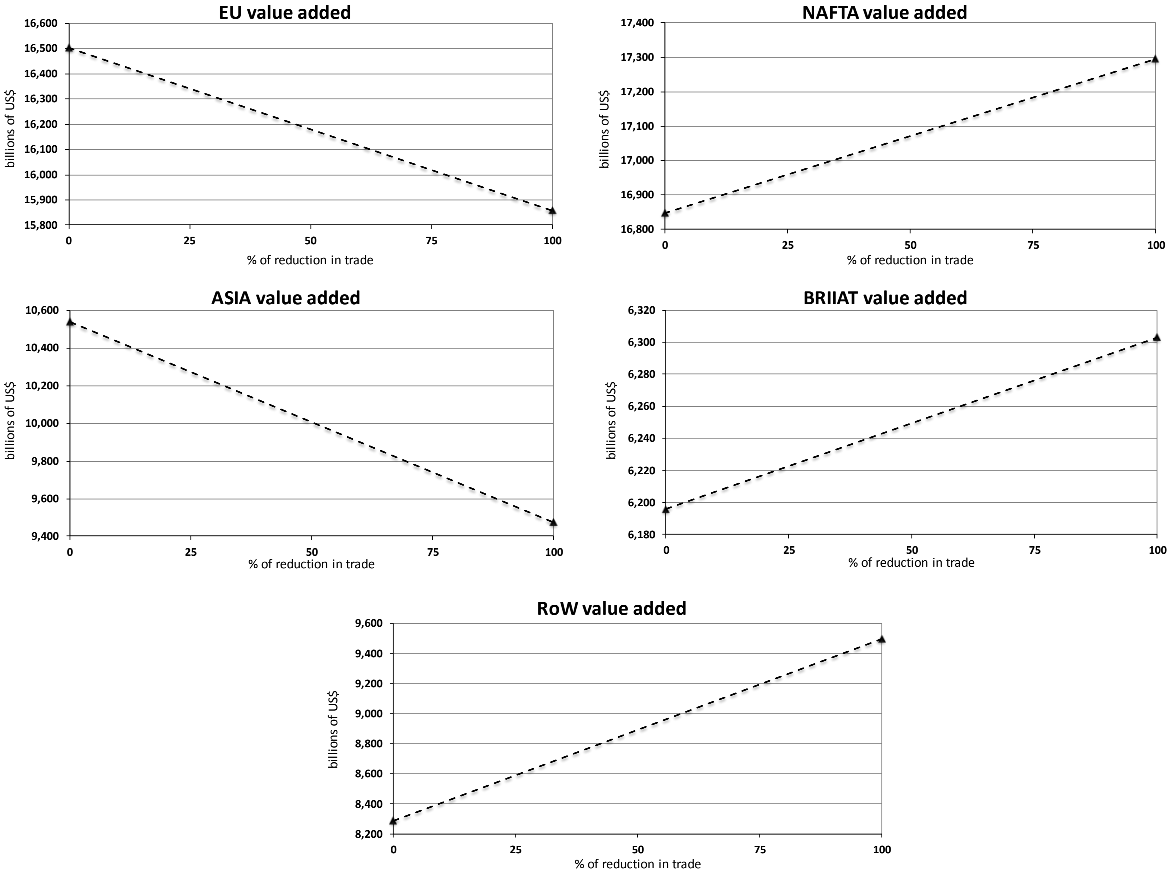


Source: own elaboration

First, **Figure 8** illustrates the changes in the production of the five big areas considered driven by reductions in overall international trade. As it was discussed in **Section 5.3**, the global production in the world was reduced by 1,055 billion US$ due to a 100% reduction of overall international trade. However, this decrease was not driven homogeneously by all regions in the same proportion. Moreover, this overall decrease in total production was in fact the results of some regions increasing their production but some others reducing a lot more their own. In numerical terms, considering the case of a 100% reduction of overall international trade, production would have been reduced by 1,869 billion US$ in the European Union (a 5.3% less), and reduced by 3,746 billion US$ in the case of ASIA (a 13.9% less). On the contrary, production would have increased by 1,200 billion US$ (3.9%)

in the case of NAFTA, by 491 billion US$ (1.7%) in the case of BRIIAT, and by 2,867 billion US$ (17.2%) in the Rest of the World.

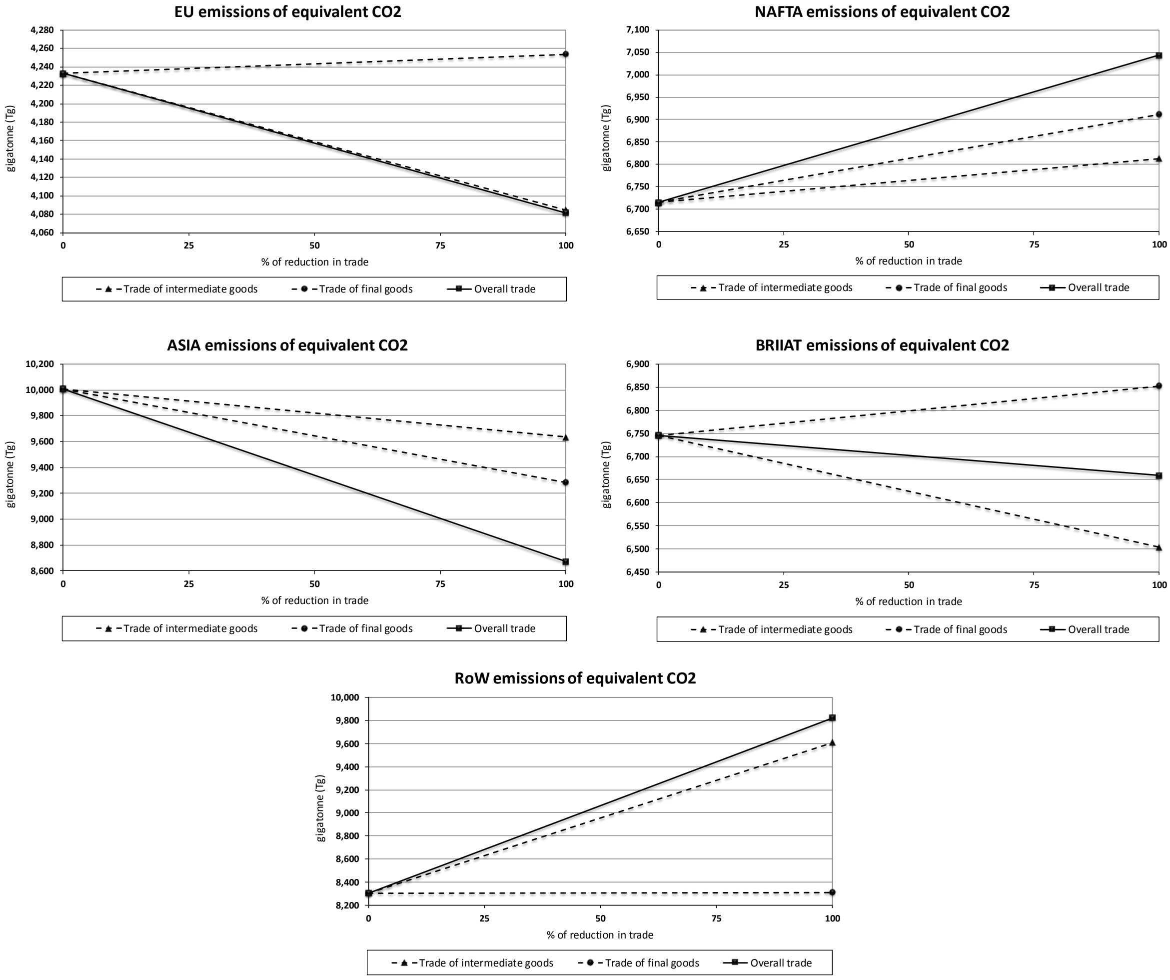
Figure 9. Changes in value added driven by reductions in overall trade



Source: own elaboration

Secondly, **Figure 9** illustrates the different changes in value added in the different regions in the world coming from reductions in overall international trade. As discussed in **Section 5.3**, a total reduction in overall trade would lead to a situation in which 56 billion US$ more were generated to the global value added. In particular, this increase would be mainly driven by 448 billion US$ in the NAFTA (increasing by 2.7%), 107 billion US$ in the BRIIAT (1.7%) and 1,211 billion US$ in the Rest of the World (14.6%), and it would be partially mitigated by the decreases in the European Union and in ASIA, in amounts of -646 billion US$ (-3.9%) and -1,064 billion US$ (-10.1%) respectively.

Figure 10. Emissions of equivalent CO_2 (in gigatonnes, or Tg) by regions



Source: own elaboration

Thirdly, **Figure 10** shows the effect of trade reductions on equivalent CO_2 emissions for each case of the five big areas of the world considered. In particular, the aggregated information for these five regions corresponds to that displayed in **Figure 5** for the entire world. As was discussed in **Section 5.3**, the effects of trade of intermediate goods and the effect of trade of final goods on global CO_2 equivalent emissions had an opposite. However, being the negative effect of trade of intermediate inputs on emissions a bit higher in absolute terms, the resulting effect of overall trade on emissions was in the end negative; meaning the any increase in overall trade would in fact reduce equivalent CO_2 emissions. Nevertheless, as illustrated in **Figure 10**, this aggregate result comes from the combination of very diverse results regarding each of the areas of the world. First, it is worth mentioning that the effect of reductions in overall trade on equivalent CO_2 emissions has not a common sign for all regions. In particular, reducing overall international trade would lead to a reduction in the emissions generated by the areas of the European Union, ASIA and BRIIAT, in amounts of 151 (3.6%), 1,338 (13.4%) and 87 gigatonnes of equivalent CO_2 (1.3%) respectively. On the contrary, this reduction would increase emissions in NAFTA and in the Rest of the World, by amounts of 329 (4.9%) and 1,521 gigatonnes of equivalent CO_2 (18.3%). Secondly, the effect of reductions in trade for intermediate goods on emissions would be negative for the areas of European Union (-3.5%), ASIA (-3.7%) and BRIIAT (-3.6%) and positive for the areas of NAFTA (1.5%) and Rest of the World (15.7%); just the same sign of the effect of overall trade. Thirdly, however, the effect of international trade for final goods would have no correlation with the same effect for intermediate goods. More precisely, the effect of reductions in trade for final goods on emissions would be positive for all regions in the world (with an increase of 0.5% for the European Union, 2.9% for NAFTA, 1.6% for BRIIAT and 0.1% for the Rest of the World) except for ASIA (-7.2%). In sum, as discussed in **Section 5.1** and **Section 5.2**, the combination of these effects would lead to an overall reduction of 392 gigatonnes of equivalent CO_2 in the case of a total reduction in trade for final goods and an increase of 640 gigatonnes of equivalent CO_2 in the case of a total reduction in trade for intermediate goods. As mentioned in **Section 5.3**, the final effect of the total reduction in overall trade would increase by 274 gigatonnes global emissions of equivalent CO_2.

6. Further implications

In sum, the results of this study show that actual levels of international trade do in fact avoid 274 gigatonnes of equivalent CO_2 and 3,706 kilotonnes of equivalent SO_2, although they foster the emission of 4,829 kilotonnes extra of equivalent SO_2. These results, moreover, have taken into account the effect of international inter-sectorial trade and industry-to-consumer international trade, and disaggregated information has been considered to give a wider perspective on the issue of trade and emissions. Nevertheless, it is important to highlight in this section some considerations about the disposable data and the applied methodology that can affect the validity and significance of the obtained results. All these considerations, which go beyond the scope of this study, could in fact constitute points of departure for future research, as the deepening in all of them could enrich much the understanding of the interrelation between trade and the environment.

First, due to availability of information in the WIOD, it is important to notice that this study does not consider a complete Environmentally Extended and Multiregional Input-Output Table (EE-MRIO) with disaggregated information for all countries in the world. In particular, as explained in **Section 4**, of the approximately 197 independent and recognized countries in the world, the WIOD only considers 40 countries. In order to include information for the remaining countries, the WIOD considers an extra territory named Rest of the World (RoW) that consists in the aggregation of data for all sectors of all remaining countries. Although most part of the largest economies in the world are considered independently (accounting then for more than 85% of world gross domestic product), the database misses a segregated information for 157 countries. These counties that are not included in disaggregated form include, for instance, some important economies like Switzerland, Saudi Arabia, Argentina, and Nigeria, ranking in the list of the world's largest economies of 2015 in positions 19, 20, 21, and 24 respectively. Consequently, this issue presents an important limitation for the study and its objective of analyzing reductions in overall international trade. All these 157 countries are considered, therefore, as a block, and the effect of trade across these countries on emissions is not considered in the study. On the other hand, the methodological approach of this study could be replicated in the future for updated and more disaggregated world datasets.

Secondly, it is important to note that this study is based on the use of monetary Input-Output Tables, this is, tables capturing only monetary flows across sectors and regions and not physical Input-Output Tables capturing physical flows of goods. This distinction is crucial and presents an important limitation to the study. More precisely, as it was discussed in **Section 3**, the methodology defines the shifts in international trade as the substitution of certain foreign goods, final or intermediate, for the equivalent amount of domestically produced goods. However, this substitution is only carried out in monetary terms and not in physical terms, and, consequently, the procedure does not take into account price differences across countries. Obviously, price differences could alter previous results considerably. For instance, considering developed areas as the European Union to have higher prices than the rest of the world, the mere shift of EU consumers and firms shifting from foreign goods to domestic goods could rise nominal EU production more if these price differences are considered that if they are not. Consequently, this sharp increase in nominal production (to which emissions in the WIOD are associated) would lead also to a higher level of emissions within the borders of the European Union. In sum, the present study could be enriched by taken into account price differences, probably by the deflation of imports and exports across counties in reference to the prices of a certain benchmark economy, as carried out in **Arto et al. 2014a** for the case of Spain.

Additionally, one important element that this study does not include is the generation or the elimination of jobs as a consequence of changes in the international trade scheme, an issue that is very present in the debate about the pollution haven hypothesis. In particular, the methodology that has been developed and described in this study would easily incorporate such socioeconomic factor just by considering labor as an extra industry-specific output like pollution generated or overall production. Such incorporation of employment into the methodology of Input-Output Analysis was, for instance, carried out by **Arto et al. 2014b**, analyzing how a tradeoff exists between outsourcing production and pollution and retaining job positions. Nevertheless, it is important to mention that the approach of this last study on emissions is similar to that of ‘emissions embodied in trade’, although in this case, it would correspond to an analysis of the ‘jobs embodied in trade’. As mentioned previously for the case of emissions, such approach would not give response to the question about how big is the impact that international trade has on jobs nowadays, as a counterfactual in the case of autarky would still be missing. In addition, incorporating labor in the present study would allow having a general idea of how changes in international trade would lead to changes and imbalances in employment generation in the world and in specific regions. Furthermore, it could be studied if there could be a tradeoff between the improvement of the environmental situation and the generation of employment, both factors driven by shifts in international trade.

Finally, the last consideration that deserves a special attention in this study is the environmental impact of transportation and the strong correlation between the economic activity in these sectors and the overall trading activity. More precisely, transportation has been considered so far in this study as one of the many productive industries within the sector of services. The WIOD considers, in fact, three industries of transportation within each region in the world, corresponding to ‘Inland Transportation’ (sector c23), ‘Water Transportation’ (sector c24), and ‘Air Transportation’ (c25), and there is data available on the levels of emissions generated by each of these industries. Nevertheless, this information only accounts for the overall emissions generated by transportation firms established in each country, and it does not provide any detail of how much their production and emissions are split into intra-national or international transport. In this way, the procedure described in this study accounts for the general increases and decreases in the activity of this sectors, as it does with all the other existing industries considered when applying international trade reductions. However, the methodological approach here presented cannot take into account how reductions in trade and the subsequent increases in domestic production, could, on the one hand, reduce emission coming from international transportation and, on the other, increase those emissions coming from transportation within the same country.

Table 9. Emission by overall transportation between 1995 and 2009 (in percentage of total emissions)

	1995	1997	1999	2001	2003	2005	2007	2009	Average
CO2	9.3%	9.6%	10.0%	9.8%	9.6%	10.0%	10.0%	9.8%	**9.8%**
CH4	3.0%	3.1%	3.1%	3.1%	3.1%	3.0%	2.8%	2.5%	**3.0%**
NO2	0.8%	0.9%	1.0%	1.0%	1.0%	1.0%	0.9%	0.9%	**0.9%**
NOX	27.0%	26.5%	25.7%	26.9%	26.7%	19.9%	20.7%	23.2%	**24.5%**
SOX	3.5%	3.8%	3.8%	4.3%	4.2%	3.5%	2.9%	2.9%	**3.7%**
CO	44.6%	41.7%	74.2%	31.9%	21.9%	63.0%	58.1%	14.9%	**44.9%**
NMVOC	42.6%	40.2%	51.9%	23.0%	12.8%	42.2%	9.6%	4.6%	**32.5%**
NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Source: own elaboration

In order to give just a brief overview on the importance of this topic, **Table 9** summarizes the levels of emissions coming from overall transportation as a share in the total generation of emissions in the world. In addition, **Appendix 1** provides this information more in detail, considering also disaggregated information for inland, water and air transportation. As it possible to see, emissions coming from transportation are not trivial at all. For instance, overall transportation accounts for a 9.8% of global emissions of CO_2, and a 3% and 0.9% for the global emissions of CH_4 (totally driven by inland transport) and N_2O respectively. In particular, within the generation of CO_2, a 4.2% percent is driven by inland transportation, while a 2.7% is driven by water transportation and a 2.9% by air transportation. Moreover, overall transportation accounts for a big 24.5% in emissions of NO_x (mainly driven by inland transportation), a 44.9% in global emissions of CO (mainly driven by water transportation), and a 32.5% in the generation of NMVOC (mainly driven by water transportation as well).

Table 10. Emissions coming from reductions in trade and transport activity

	Units	No change in trade nor transport	100% reduction in overall trade and reduction in transport activity of				
			0%	25%	50%	75%	100%
Emissions of Eq. CO2	***gigatonnes (Tg)***	**36,005**	**36,279**	**35,576**	**34,873**	**34,170**	**33,467**
% change			0.8%	-1.2%	-3.1%	-5.1%	-7.0%
Emissions of Eq. SO2	***kilotonnes (Gg)***	**240,750**	**235,921**	**230,450**	**224,980**	**219,510**	**214,040**
% change			-2.0%	-4.3%	-6.6%	-8.8%	-11.1%
Emissions of Eq. C2H4	***kilotonnes (Gg)***	**66,356**	**70,062**	**63,952**	**57,841**	**51,731**	**45,620**
% change			5.6%	-3.6%	-12.8%	-22.0%	-31.2%

Source: own elaboration

In short, the lack of disaggregated information concerning how transport activity and transport emissions are intrinsically related to international trade levels presents a considerable limitation to this study, as the final estimation of the impact of international trade on the environment deeply depends on how international transportation is affected by trade. Nevertheless, with the support of results in **Section 5** and taking into account pollution generated by transport industries in **Table 9**, it is possible to compute a threshold in which the actual curve of emissions depending on trade reductions would take place. **Appendix 2** shows this construction for the cases of equivalent CO_2, SO_2 and C_2H_4 emissions, and such analysis is here synthetized in **Table 10**. As it is possible to see in the table, changes in emissions for all these aggregate measures of gases are very sensible to how the transportation sector would increase or reduce its activity as a result of changes in international trade. For instance, if transportation activity was not correlated with international trade activity, i.e. the sector was only devoted to intra-industry transportation, the increase in emissions coming from trade reduction would be of 0.8% for the case of equivalent CO_2, -2.0% for the case of equivalent SO_2, and 5.6% for equivalent C_2H_4. However, on the other hand, if this reduction in international trade lead to a 50% decrease in transport activity, global emissions of these aggregate measures of gases would change considerably. In fact, a reduction in trade would lead to a reduction in emissions for all of aggregate measures, corresponding respectively to reductions of 3.1%, 6.6% and 12.8%.

7. Conclusions

In response to the emerging awareness on the negative impact that current economic activity has on the environment, this study contributes to a better understanding of this issue by addressing the existing relationship between international trade and the emission of polluting gases. More precisely, the study considers how variations in international trade for final and intermediate goods can lead to very diverse changes in global emissions. Moreover, thanks to the methodological procedure that has been developed, the study gives an estimation of which is the real impact that international trade alone has on the emission of eight different types of gases, which altogether contribute to three dramatic environmental phenomena.

In particular, the results that have been obtained rise broad and compelling considerations. In the first place, for the three aggregate measures of polluting emissions, international trade of intermediate goods seems to have a negative effect on emissions and, therefore, a positive effect on the environment, as any increase in inter-sectorial trade seems to decrease emission levels. On the contrary, international trade for final goods seems to have a positive effect on emissions and a negative effect on the environment, as increases in trade of final goods for consumption considerably increase emissions of polluting gases. The combination of these two effects, however, rises very diverse results, as the positive effect of trade for intermediate goods is stronger in the cases of equivalent CO_2 and equivalent C_2H_4 emissions, but the negative effect of trade for final goods is stronger in the case of equivalent SO_2 emissions. In the end, results indicate that overall international trade has a positive impact by avoiding 274 gigatonnes of equivalent CO_2 and 3,706 kilotonnes of equivalent C_2H_4, but a negative impact on the environment by generating extra 4,829 kilotonnes of equivalent SO_2.

Furthermore, in the actual situation in which countries are facing constant negotiations to first foster production and commercial activity and later reduce global emissions, results obtained in this study suggest interesting and practical implications. International trade and the openness to the global market has been imputed to be one crucial trigger in the development of countries and, moreover, the present study suggests that international trade, at least for intermediate goods, has been one driver of environmental efficiency. However, on the other hand, results show that there exists an important misallocation of production for certain pollutants and certain types of products, as international trade shows to be also a driver of higher pollution in comparison with a situation of autarky for instance in the case of final goods. While technological differences across countries are well leveraged in the generation of certain pollutants, being mostly generated by the most environmentally efficient countries, for some other pollutants such opportunity coming from technological and cross-country differences is not considered, as production is biased towards highly polluting industries.

Finally, it is important to note that all these considerations could be useful in the design of policies to address both economic development and environmental improvement. Policymakers could take into account how trade of final goods and trade of intermediate goods has in fact a very different impact on emissions. If international trade for intermediate goods was fostered but trade for final goods was softly refrained, it could be expected to observe an important reduction in emissions. Such fact, for example, would lead regulators to treat differently both types of goods, fostering in consumers the purchase of final goods domestically produced, but moving businesses to use those foreign inputs that result more beneficial for the environment. In short, integrating these and previous considerations in realistic policies could foster both the preservation of the environment and economic growth.

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Appendix 1: Emissions generated by transportation

Summarized in **Table 11**, the historical emissions coming from the different types of transportation are considered. As it is possible to see, the sector of transportation represents a crucial polluting sectors for gases like CO_2, NO_x, CO and NMVOC; while its contribution to other pollutants like CH_4, NO2, SO_x and NH_3 is moderated. Moreover, there exists a remarkable asymmetry regarding the three types of transportation as, for instance, CH_4 is only generated by Inland Transport, and CO and NMVOC are mainly triggered by Water Transport.

Table 11. Emissions by transportation between 1995 and 2009 (in percentage of total emissions)

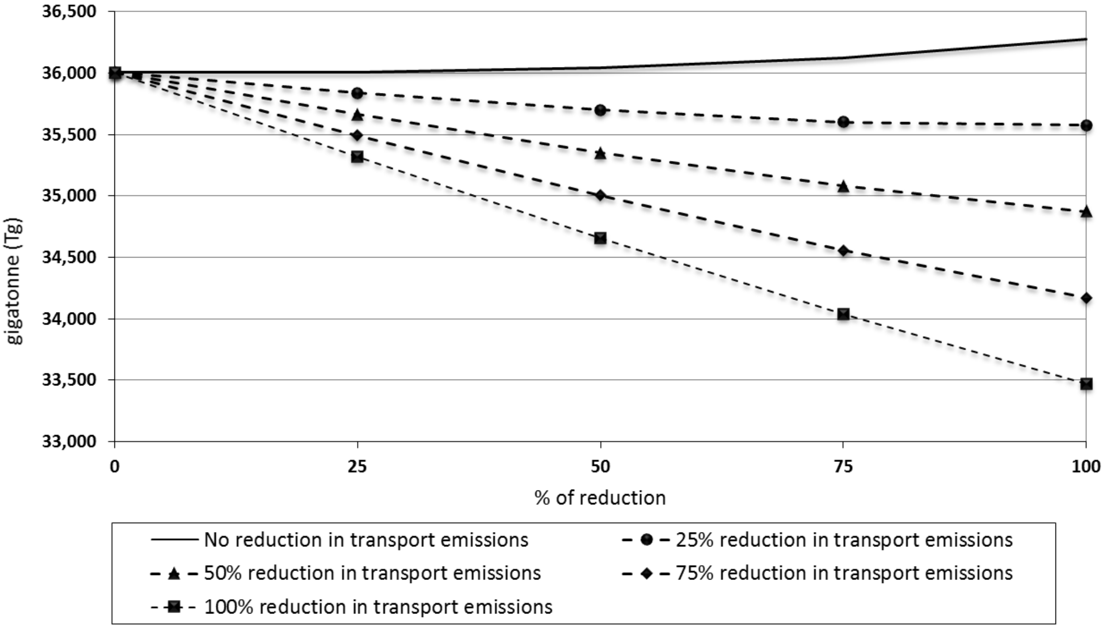
		1995	1997	1999	2001	2003	2005	2007	2009	Average
CO2	**Overall transport**	**9.3%**	**9.6%**	**10.0%**	**9.8%**	**9.6%**	**10.0%**	**10.0%**	**9.8%**	**9.8%**
	Inland transport	4.1%	4.1%	4.2%	4.2%	4.1%	4.2%	4.3%	4.3%	4.2%
	Water transport	2.6%	2.7%	2.8%	2.7%	2.7%	2.8%	2.9%	2.7%	2.7%
	Air transport	2.6%	2.9%	2.9%	3.0%	2.8%	3.0%	2.9%	2.8%	2.9%
CH4	**Overall transport**	**3.0%**	**3.1%**	**3.1%**	**3.1%**	**3.1%**	**3.0%**	**2.8%**	**2.5%**	**3.0%**
	Inland transport	3.0%	3.0%	3.1%	3.0%	3.1%	3.0%	2.8%	2.5%	3.0%
	Water transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Air transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NO2	**Overall transport**	**0.8%**	**0.9%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**0.9%**	**0.9%**	**0.9%**
	Inland transport	0.5%	0.5%	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.6%
	Water transport	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
	Air transport	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
NOX	**Overall transport**	**27.0%**	**26.5%**	**25.7%**	**26.9%**	**26.7%**	**19.9%**	**20.7%**	**23.2%**	**24.5%**
	Inland transport	19.5%	17.9%	17.5%	17.1%	16.2%	11.0%	11.3%	13.0%	15.4%
	Water transport	5.5%	6.1%	5.9%	6.6%	7.5%	6.7%	7.2%	7.5%	6.6%
	Air transport	1.9%	2.5%	2.2%	3.1%	3.1%	2.2%	2.1%	2.7%	2.5%
SOX	**Overall transport**	**3.5%**	**3.8%**	**3.8%**	**4.3%**	**4.2%**	**3.5%**	**2.9%**	**2.9%**	**3.7%**
	Inland transport	1.2%	1.0%	0.8%	1.2%	0.8%	0.2%	0.2%	0.3%	0.7%
	Water transport	2.2%	2.6%	2.8%	2.9%	3.3%	3.2%	2.6%	2.5%	2.8%
	Air transport	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%
CO	**Overall transport**	**44.6%**	**41.7%**	**74.2%**	**31.9%**	**21.9%**	**63.0%**	**58.1%**	**14.9%**	**44.9%**
	Inland transport	8.2%	8.1%	2.6%	8.6%	7.9%	4.2%	4.5%	8.8%	6.4%
	Water transport	34.1%	31.5%	71.2%	20.9%	11.6%	57.0%	51.8%	3.0%	36.5%
	Air transport	2.3%	2.1%	0.4%	2.5%	2.4%	1.8%	1.8%	3.1%	2.0%
NMVOC	**Overall transport**	**42.6%**	**40.2%**	**51.9%**	**23.0%**	**12.8%**	**42.2%**	**9.6%**	**4.6%**	**32.5%**
	Inland transport	4.9%	4.5%	2.7%	6.4%	5.5%	1.8%	2.4%	2.6%	3.8%
	Water transport	37.0%	34.8%	48.8%	15.6%	6.4%	39.9%	6.6%	1.3%	27.9%
	Air transport	0.7%	0.9%	0.4%	1.0%	0.9%	0.5%	0.6%	0.6%	0.7%
NH3	**Overall transport**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Inland transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Water transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Air transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Source: own elaboration

Appendix 2: Effect of transportation on global emissions

Changes in emissions coming from both reductions in overall trade and reductions in transport activity are shown in **Figure 11** for the particular case of equivalent CO_2. The continuous line refers to the results obtained by the standard procedure in which transportation activity reduction is not taken into account because of overall transport reductions, the same information provided in **Figure 5** of **Section 5.4**. On the other hand, discontinuous lines in the figure assume that reductions in overall trade activity would lead to reductions in overall transport activity and, therefore, in overall transport emissions. For instance, the discontinuous line with the triangular marker called '50% reduction in transport emissions' considers that every 2% reduction in overall international trade would lead to a 1% reduction in the emission coming from transportation. In sum, all five lines provide a threshold in which the actual level of emissions, depending on the reduction in overall international trade, would take place.

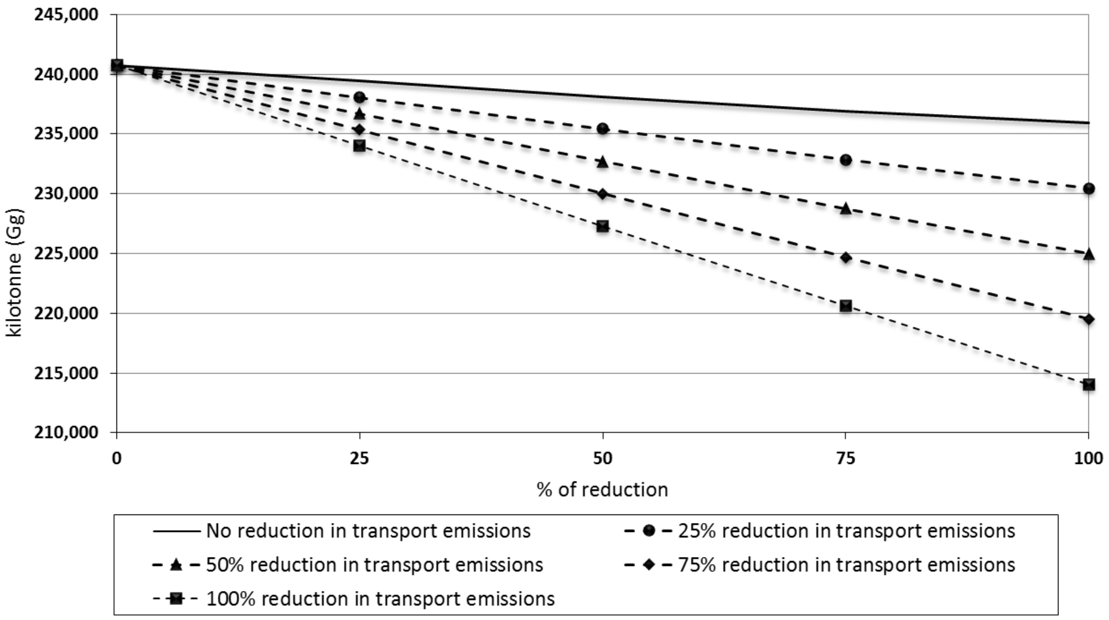
Figure 11. Reduction in equivalent CO_2 emissions coming from reductions in transport activity



Source: own elaboration

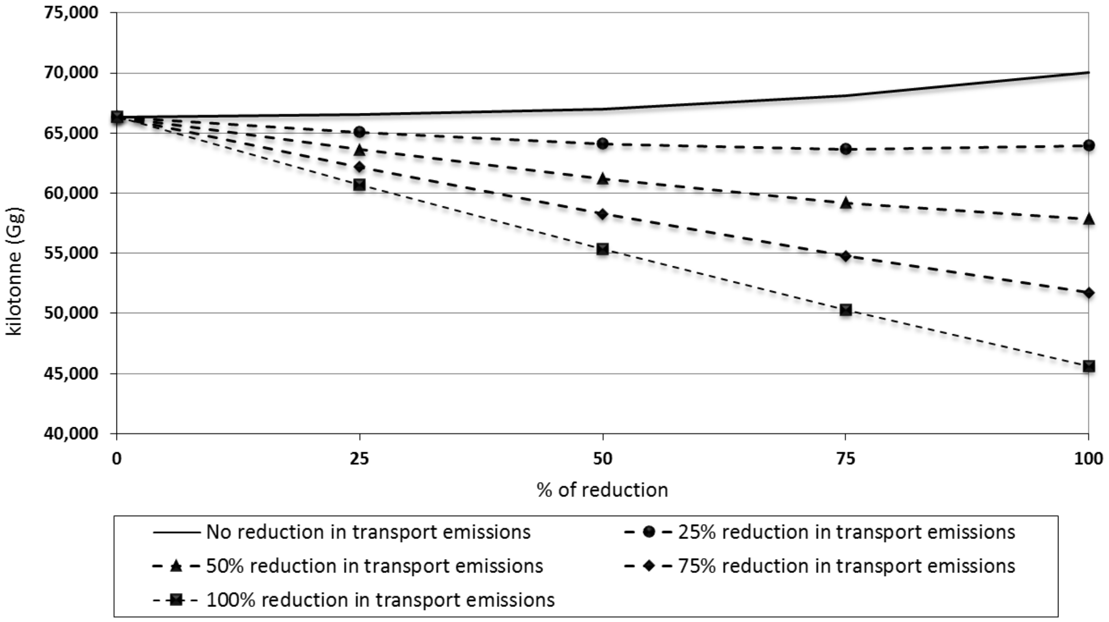
In a similar fashion, **Figure 12** gathers this information for the case of equivalent SO_2 emissions, while **Figure 13** refers to the emissions of C_2H_4 equivalent. As all three figures show, the resulting and final impact of international trade on emissions strongly depends on how transportation is affected by international trade.

Figure 12. Reduction in equivalent SO_2 emissions coming from reductions in transport activity



Source: own elaboration

Figure 13. Reduction in equivalent C_2H_4 emissions coming from reductions in transport activity



Source: own elaboration

In particular, for the case of equivalent CO_2 emissions, as shown in **Figure 11**, the current impact of international trade on the environment could range from the previously mentioned 274 gigatonnes of CO_2 equivalent avoided to the positive generation of 2,538 gigatonnes of CO_2 equivalent in the case of a 100% reduction in trade activity. Similarly, for the case of equivalent C_2H_4 emissions in **Figure 13**, the environmental impact of actual levels of international trade could be between the avoidance of 3,706 kilotonnes of C_2H_4 equivalent and the generation of 20,736 kilotonnes of C_2H_4 equivalent. On the other hand, as illustrated in **Figure 12**, the impact of trade on emissions of equivalent SO_2 would be in all cases positive, as any increase in overall international trade would lead to higher levels of this pollutant. In this case, however, this negative impact would range from the initial generation of 4,829 kilotonnes of SO_2 equivalent to the generation of 26,710 kilotonnes of SO_2 equivalent in the case of total reduction in transportation activity.