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# The relevance of multi-country input-output tables in measuring emissions trade balance of countries: the case of Spain

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## Abstract

As part of national accounts, input-output tables are becoming crucial statistical tools to study the economic, social and environmental impacts of globalization and international trade. In particular, global input-output tables extend the national dimension to the international dimension by relating individual countries' input-output tables among each other, thus providing an opportunity to balance the global economy as a whole. Concerning emissions of greenhouse gases, the relative position that countries hold among their main trade partners at the global level is a key issue in terms of international climate negotiations. With this purpose, we show that (official) Multi-country input-output tables are crucial to analyse the greenhouse gas emission trade balance of individual countries. Spain has a negative trade emissions balance for all three gases analysed, being the most negative balances those associated to the bilateral trade with China, Russia, United States and the rest of the European Union as a whole.

*MSC:* 91F.

*Keywords:* WIOD, Emissions Trade Balance, Spain, GHG footprint, GHG.

## 1. Background and statistical context

The latest meeting of the Group of Experts on National Accounts of the United Nations Economic Commission for Europe (UNECE, 7-9 July 2015), was devoted to data collection and compilation methods in respect to global production activities. It was jointly

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organized with Eurostat and the Organization for Economic Co-operation and Development (OECD). The meeting was attended by representatives from more than thirty countries worldwide and representatives from the European Commission (EC), International Monetary Fund (IMF), OECD, the United Nations Conference on Trade and Development (UNCTAD), United Nations Statistics Division (UNSD) and World Trade Organization (WTO), among others.

According to the experts at this UNECE meeting, in order to measure global production and global value chains it is no longer sufficient to look only at what a firm does, but to also to consider how the firm does its activities and with whom. For instance, linking business statistics and trade statistics on a micro level should provide new dimensions to the data as long as new balancing challenges at the macro level data (e.g. national accounts). Indeed, statisticians have not always been able to keep up to date with business practices and must find ways to be forward looking and provide the information that meets future policy needs. Traditional measures of trade in goods and services have to be progressively supplemented with information on income and financial flows. Foreign direct investment statistics (FDI) should be further developed and complemented with foreign affiliate statistics (FATS) in order to improve their clarity, usefulness and coverage, and to provide better insights into global value chains.

In this respect, the UNECE Report emanating from this meeting supported new global initiatives, such as the extensions to Trade in Value Added and Global Input-Output Tables (OECD), the construction of the European Multi-Country Input-Output Framework (EC and Eurostat) as well as the elaboration of a new Handbook on a System of Extended International and Global Accounts (UNSD).

Hence, there is no doubt that globalization is currently affecting the way statisticians are measuring national production of countries and international statistical organizations are indeed very busy working on it in order to meet the policy needs at the worldwide level. As national accounts and input-output tables became an integral part of the production activities of national statistical institutes in the past, very soon multi-country and international input-output tables will become a crucial statistical tool to measure global production, trade in value added, environmental footprints and/or employment effects of export activities with official statistics (e.g. carbon footprint estimated by Eurostat).

Bearing all this in mind, we would like to illustrate in this paper the usefulness of global/world input-output tables in measuring the greenhouse gas footprints of individual countries and its external emission trade balance with respect to others. Hopefully, these types of indicators will soon become regularly produced in the future by statisticians using official global input-output tables instead of using other databases produced as one-off projects (e.g. World Input-Output Database, WIOD – www.wiod.org).

This paper is structured in five sections. Following this background, there is an introductory section on the related literature on greenhouse gases emissions footprints. Next, the third section introduces the methodology and the database. The fourth section presents the results obtained and discusses them. The fifth section concludes.

## 2. Introduction to GHG footprints

Greenhouse gas emissions (GHG) are considered to be one of the main causes of climate change. This is the reason why governments are increasingly making efforts to implement policies aiming to reduce GHG emissions. National climate policies are mainly driven by international negotiations and these are strongly linked to the amount of emissions produced within a country or the so called producer's responsibility principle. Within this context, exporting (producing) countries are responsible for their GHG emissions, irrespective of where the demand for such products comes from.

On the other hand, the interest in the so called consumer's responsibility principle has been growing since Leontief (1970) described the environmental impacts of the final consumer as a negative externality of the production process. This concept has been endorsed by the OECD's Green Growth Strategy (2011). According to this principle, the GHG emissions are allocated according to countries' domestic demand of goods and services, irrespective of where they were produced. Different approaches have been used to analyse this new concept of responsibility, such as general balance models, dynamic models and the analysis of structural decomposition, i.e. Peters and Hertwich (2006), Peters (2008) Peters et al. 2011), Druckman and Jackson (2009), Davis and Caldeira (2010), Zhou and Imura (2011) and Edens et al. (2011), Kanemoto et al. (2012), among others.

Among others, Rueda-Cantuche and Amores (2010) noted that developed countries may reduce their emissions produced but at the same time, they may increase their consumption-based emissions. This is due to the different technologies used in the production processes of developing countries, generally less clean than those of the developed countries. In the end, some environmental policies might result in a global increase in GHG emissions. At the national level, the difference between the production-based emissions and the consumption-based emissions lead to the so called emission trade balance (ETB) of a country or of a certain industry. This analysis will determine the surplus/deficit that a country/industry has. It is expected that developing countries have surpluses and developed countries, deficits.

Within this context, the aim of this paper is to calculate the Emission Trade Balance (ETB) of Spain in 2008 at a worldwide level and bilaterally with respect to 39 countries, 35 industries and one additional region as the "rest of the world" for the three main GHGs ($CO_2$, $N_2O$ and $CH_4$). In order to do so, we have used multi-regional input-output analysis (MRIO) and the World Input-Output Database (WIOD) (Dietzenbacher et al., 2013).

Input-output analysis (IOA) has been generally used to study environmental problems (Miller and Blair, 2009). Particularly, there are numerous related studies devoted to the analysis of polluting GHG emissions, i.e. Minx et al., (2009), Su et al. (2010), Chen et al., (2010), Liang et al. (2010), Chang et al. (2010), Zhu et al., (2012) and Mattila et al. (2013), among others.

Likewise, there are also many studies about GHG emissions associated with the international trade of specific countries, such as China, (Liang et al., 2007, Liu et al., 2009, Zhao et al., 2009, Xu et al., 2011, Hongtau et al., 2010, Chen et al., 2010 a, b, Chen and Zhang 2010); Finland (Maenpaa and Siikavirta 2007); Ireland (Llop and Tol, 2012); Italy (Cellura et al., 2013, Mongelli et al.,2006); Japan (Nansai et al., 2009); the United Kingdom (Wiedman et al., 2010, Druckman and Jackson 2009)) and Turkey (Tunç et al., 2007).

The work of Musksgaard and Pedersen (2001) for Denmark was the first one that linked the input-output methodology to the consumer's responsibility principle related to GHG emissions. It was followed by Ahmad and Wyckoff (2003) for OECD countries and Peters and Hertwich (2006) for the Norwegian economy and for three different gases ($CO_2$, $NO_2$ and $SO_2$).

IOA has also been applied to study GHG emissions associated to consumption in the case of Spain. Tarancón and del Rio (2007) used a combination of IOA with sensitivity analyses; Cadarso et al. (2010) study the effect of international trade of the Spanish emissions balace under DTA assumption; Sánchez-Choliz, and Duarte (2004), Serrano and Roca (2008a, 2008b), Serrano and Dietzenbacher (2010) used IOA assuming domestic technology in monetary terms while Arto (2009) and Arto et al., (2012) do the same but in physical terms; Lopez et al. (2013) analyse the existence of pollution haven hypothesis in a bi-regional input-output model and Cadarso et al. (2012) defined a shared responsibility criterion to analyse the impact of international trade in $CO_2$ emissions on an industrial basis, such as the food industry in Lopez et al. (2015).

But none of them has used a homogeneous multi-country IO database such as WIOD (Dietzenbacher et al., 2013), nor has the analysis been carried out with high industry resolution and bilateral trade flows as in the present study. This work covers 35 industries and 41 different geographical areas for each of the three GHGs considered. Therefore, the originality and interest of this work lies in the details and the extension of the results in terms of higher industry breakdown, homogeneity of the multi-country database, country coverage and pollutants covered ($CO_2$, $CH_4$ and $N_2O$) rather than the topic itself, which has already been addressed in the literature.

## 3. Methodology and database

### 3.1. Input-output analysis

Input-output analysis revolves around the so called input-output tables, which reflect the supply and demand of the economy in terms of products, industries and final users. By using the so called Leontief quantity model (Rueda-Cantuche, 2011), the total output of an economy can be broken down into final and intermediate demand, as indicated in (1):

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{y} \tag{1}$$

where $\boldsymbol{x}$ is the total industry output vector for $n$ industries $(n \times 1); \boldsymbol{Z} = \boldsymbol{A}\boldsymbol{x}$ is a matrix describing the intermediate uses of industries; $\boldsymbol{A}$ is a matrix $(n \times n)$ of input-output coefficients showing the inputs needed per unit of output by each industry; and $\boldsymbol{y}$ stands for a final demand vector $(n \times 1)$ showing the sum of consumption, investment and exports of all goods and services. Within this framework, we use industry by industry IO tables from the WIOD database (Dietzenbacher et al., 2013) with the same number of industries and commodities ($n$).

Reordering (1), it yields

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y} \tag{2}$$

where $\boldsymbol{I}$ is the identity matrix and $(\boldsymbol{I} - \boldsymbol{A})^{-1}$, the so called Leontief inverse matrix that shows the total requirements of the economy for the production of goods and services to satisfy a certain level of final demand. Moreover, with appropriate emission levels ($\boldsymbol{s}$) per unit of total industry outputs ($\boldsymbol{x}$), $\boldsymbol{c} = \boldsymbol{s}\hat{\boldsymbol{x}}^{-1}$ (where ^ denotes diagonalization of the vector $\boldsymbol{x}$), the Leontief model can serve to estimate the absolute levels of emissions for the production of a certain level of total output needed to satisfy changes in final demand, e.g. emissions of the car industry to produce vehicles due to changes in households demand. It is important to note that this paper is focused on the production phase of emissions alone and it does not include those emissions derived from the use phase of a product (e.g. households driving cars). That is:

$$\boldsymbol{s} - \hat{\boldsymbol{c}}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y} \tag{3}$$

### *3.2. Multi-regional input-output analysis*

Multi-regional input-output analysis is based on a set of interconnected input-output tables of various countries (Miller and Blair, 2009). While equation (3) refers to one single country with $n$ industries, we will express hereafter the same equation for a three-region model with $n$ industries in each region, namely: Spain ($u$), rest of the EU ($r$) and rest of the world ($w$). The result is a fully fledged input-output table with three times $n$ industries and its main components are described below.

$$\boldsymbol{A} = \begin{pmatrix} \boldsymbol{A}_{uu} & \boldsymbol{A}_{ur} & \boldsymbol{A}_{uw} \\ \boldsymbol{A}_{ru} & \boldsymbol{A}_{rr} & \boldsymbol{A}_{rw} \\ \boldsymbol{A}_{wu} & \boldsymbol{A}_{wr} & \boldsymbol{A}_{ww} \end{pmatrix} \qquad \boldsymbol{Y} = \begin{pmatrix} \boldsymbol{y}_{uu} & \boldsymbol{y}_{ur} & \boldsymbol{y}_{uw} \\ \boldsymbol{y}_{ru} & \boldsymbol{y}_{rr} & \boldsymbol{y}_{rw} \\ \boldsymbol{y}_{wu} & \boldsymbol{y}_{wr} & \boldsymbol{y}_{ww} \end{pmatrix}$$

$$\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1} = \begin{pmatrix} \boldsymbol{L}_{uu} & \boldsymbol{L}_{ur} & \boldsymbol{L}_{uw} \\ \boldsymbol{L}_{ru} & \boldsymbol{L}_{rr} & \boldsymbol{L}_{rw} \\ \boldsymbol{L}_{wu} & \boldsymbol{L}_{wr} & \boldsymbol{L}_{ww} \end{pmatrix} \qquad \hat{\boldsymbol{C}} = \begin{pmatrix} \hat{\boldsymbol{c}}_{u} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \hat{\boldsymbol{c}}_{r} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \hat{\boldsymbol{c}}_{w} \end{pmatrix}$$

Matrix $\boldsymbol{A}$ and vector $\boldsymbol{y}$ stand for input-output coefficients and final uses, respectively. The subscript on the left corresponds to the exporting region and the subscript on the right refers to the importing region. Doing so, these two elements include bilateral exports and bilateral imports of intermediate and final uses, too. Besides, each of the submatrices of the $\boldsymbol{A}$ matrix has $n$ rows and $n$ columns, so the fully-fledged matrix $\boldsymbol{A}$ is of order $(3n \times 3n)$. For one single final demand category, the matrix $\boldsymbol{Y}$ is therefore of order $(3n \times 3)$.

Moreover, it is straightforward that the Leontief inverse is a square matrix of the same dimension as $\boldsymbol{A}$, being eventually matrix $\hat{\boldsymbol{C}}$ a diagonal matrix with three diagonalized vectors of $n$-dimension each. The latter corresponds to different emission coefficients by country of origin (or region), which is quite relevant for our analysis. These emission coefficients have been calculated as the total emissions of each country and industry over their corresponding total output, both provided by the WIOD database (Dietzenbacher et al., 2013).

With these new matrices, we re-define equation (3) but also allowing for a fully-fledged decomposition of the final demand by region. Subsequently, equation (4) is split up into as many components as number of regions the model has (i.e. three). As a matter of fact, the sum of all the elements of each component is nothing else but the footprint of each of the regions (e.g. carbon footprint). As in Lopez et al., (2013), Cadarso et al., (2012) or Skelton (2013), we have estimated matrices of emissions (see equation 5), where the sum by rows allocate the responsibility to industries that supply intermediate and final goods and the sum by columns allocate the responsibility to agents/industries that consume them. More precisely, the focus of our analysis is based on the sum of the elements of each row in each of the three fully-fledged matrices of equation (5), which yields three vectors of emissions.

$$
\begin{aligned}
\hat{\boldsymbol{C}}(\boldsymbol{I}-\boldsymbol{A})^{-1}\begin{pmatrix}\boldsymbol{y}_u & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{y}_r & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{y}_w\end{pmatrix} &= \\
= \begin{pmatrix}\hat{\boldsymbol{c}}_u & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \hat{\boldsymbol{c}}_r & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \hat{\boldsymbol{c}}_w\end{pmatrix}
\begin{pmatrix}\boldsymbol{L}_{uu} & \boldsymbol{L}_{ur} & \boldsymbol{L}_{uw}\\ \boldsymbol{L}_{ru} & \boldsymbol{L}_{rr} & \boldsymbol{L}_{rw}\\ \boldsymbol{L}_{wu} & \boldsymbol{L}_{wr} & \boldsymbol{L}_{ww}\end{pmatrix}
\begin{pmatrix}\boldsymbol{y}_{uu} & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{y}_{ru} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{y}_{wu}\end{pmatrix} \\
+ \begin{pmatrix}\hat{\boldsymbol{c}}_u & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \hat{\boldsymbol{c}}_r & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \hat{\boldsymbol{c}}_w\end{pmatrix}
\begin{pmatrix}\boldsymbol{L}_{uu} & \boldsymbol{L}_{ur} & \boldsymbol{L}_{uw}\\ \boldsymbol{L}_{ru} & \boldsymbol{L}_{rr} & \boldsymbol{L}_{rw}\\ \boldsymbol{L}_{wu} & \boldsymbol{L}_{wr} & \boldsymbol{L}_{ww}\end{pmatrix}
\begin{pmatrix}\boldsymbol{y}_{ur} & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{y}_{rr} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{y}_{wr}\end{pmatrix} \\
+ \begin{pmatrix}\hat{\boldsymbol{c}}_u & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \hat{\boldsymbol{c}}_r & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \hat{\boldsymbol{c}}_w\end{pmatrix}
\begin{pmatrix}\boldsymbol{L}_{uu} & \boldsymbol{L}_{ur} & \boldsymbol{L}_{uw}\\ \boldsymbol{L}_{ru} & \boldsymbol{L}_{rr} & \boldsymbol{L}_{rw}\\ \boldsymbol{L}_{wu} & \boldsymbol{L}_{wr} & \boldsymbol{L}_{ww}\end{pmatrix}
\begin{pmatrix}\boldsymbol{y}_{uw} & \boldsymbol{0} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{y}_{rw} & \boldsymbol{0}\\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{y}_{ww}\end{pmatrix}
\end{aligned}
\tag{4}
$$

Being:

$$\begin{pmatrix} \boldsymbol{y}_u & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{y}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{y}_w \end{pmatrix} = \begin{pmatrix} \boldsymbol{y}_{uu}+\boldsymbol{y}_{ur}+\boldsymbol{y}_{uw} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{y}_{ru}+\boldsymbol{y}_{rr}+\boldsymbol{y}_{rw} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{y}_{wu}+\boldsymbol{y}_{wr}+\boldsymbol{y}_{ww} \end{pmatrix}$$

Properly extended, equation (4) becomes into:

$$\begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{wu} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{wu} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{wu} \end{pmatrix} + \begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{wr} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{wr} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{wr} \end{pmatrix} + \begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{ww} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{ww} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{ww} \end{pmatrix}$$

and summing row-wise:

$$\begin{aligned} &\begin{pmatrix} \boldsymbol{g}_{uu}^{dom} \\ \boldsymbol{g}_{ru}^{imp} \\ \boldsymbol{g}_{wu}^{imp} \end{pmatrix} + \begin{pmatrix} \boldsymbol{g}_{ur}^{exp} \\ \boldsymbol{g}_{rr}^{dom} \\ \boldsymbol{g}_{wr}^{exp} \end{pmatrix} + \begin{pmatrix} \boldsymbol{g}_{uw}^{exp} \\ \boldsymbol{g}_{rw}^{exp} \\ \boldsymbol{g}_{ww}^{dom} \end{pmatrix} = \\ &= \begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{wu} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{wu} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{uu} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{ru} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{wu} \end{pmatrix} \begin{pmatrix} \mathbf{1} \\ \mathbf{1} \\ \mathbf{1} \end{pmatrix} \\ &+ \begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{wr} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{wr} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{ur} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{rr} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{wr} \end{pmatrix} \begin{pmatrix} \mathbf{1} \\ \mathbf{1} \\ \mathbf{1} \end{pmatrix} \\ &+ \begin{pmatrix} \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_u\boldsymbol{L}_{uw}\boldsymbol{y}_{ww} \\ \hat{\boldsymbol{c}}_r\boldsymbol{L}_{ru}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rr}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_r\boldsymbol{L}_{rw}\boldsymbol{y}_{ww} \\ \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wu}\boldsymbol{y}_{uw} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{wr}\boldsymbol{y}_{rw} & \hat{\boldsymbol{c}}_w\boldsymbol{L}_{ww}\boldsymbol{y}_{ww} \end{pmatrix} \begin{pmatrix} \mathbf{1} \\ \mathbf{1} \\ \mathbf{1} \end{pmatrix} \end{aligned} \tag{5}$$

with the following definitions (only some of them are presented as illustrative purposes):

(a) $\hat{\boldsymbol{c}}_u\boldsymbol{L}_{uu}\boldsymbol{y}_{uu}$ stands for the emissions produced in Spain derived from the Spanish final demand of domestically produced commodities (e.g. purchase of a Spanish car by a Spanish resident);

(b) $\hat{\boldsymbol{c}}_u\boldsymbol{L}_{ur}\boldsymbol{y}_{ru}$ represents the emissions produced in Spain for the production of an exported commodity that will be used by the rest of the EU ($r$) to produce something else that Spain will import (e.g. exports of Spanish electronic components for the production of Czech cars that will be imported by Spain).

(c) $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uw} \boldsymbol{y}_{wu}$ shows the emissions produced in Spain for the production of an exported commodity that will be used by the rest of the world ($w$) to produce something else that Spain will import (e.g. exports of Spanish electronic components for the production of American cars that will be imported by Spain).

(d) $\boldsymbol{g}_{uu}^{dom}$ is the sum of (a), (b) and (c); the sum of emissions emitted in Spain coming from the final demand of Spanish residents.

(e) $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{ru} \boldsymbol{y}_{uu}$ stands for the emissions produced in EU countries ($r$) derived from the imported intermediate inputs needed to satisfy the Spanish final demand of domestically produced commodities (e.g. purchase of a Spanish car by a Spanish resident that involves imports of electronic components from the Czech Republic);

(f) $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rr} \boldsymbol{y}_{ru}$ shows the emissions produced in EU countries ($r$) to satisfy the Spanish final demand of commodities produced in the EU (e.g. imports of German cars by Spanish residents);

(g) $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rw} \boldsymbol{y}_{wu}$ shows the emissions produced in EU countries ($r$) to produce an intermediate export to a non-EU country that will serve as input to produce something to be exported to Spain (e.g. purchase of a Japanese car by a Spanish resident that involves imports of electronic components from the Czech Republic);

(h) $\boldsymbol{g}_{ru}^{imp}$ is the sum of (e), (f) and (g); the sum of emissions emitted in the rest of Europe coming from the final demand of Spanish residents.

(i) $\boldsymbol{g}_{wu}^{imp}$ is, analogously, the sum of emissions emitted in the rest of the world coming from the final demand of Spanish residents.

(j) $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uu} \boldsymbol{y}_{ur}$ shows the emissions produced in Spain to satisfy the EU final demand of Spanish commodities (e.g. imports of a Spanish car by a German resident);

(k) $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{ur} \boldsymbol{y}_{rr}$ shows the emissions produced in Spain derived from the imported inputs of the rest of the EU needed to satisfy their own final demand of domestically produced commodities (e.g. purchase of a German car by a German resident that involves imports of electronic components from Spain);

(l) $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uw} \boldsymbol{y}_{wr}$ shows the emissions produced in Spain derived from the imported intermediate inputs of the rest of the world needed to satisfy the final demand of EU residents (e.g. purchase of a Japanese car by a German resident that involves imports of electronic components from Spain);

(m) $\boldsymbol{g}_{ur}^{exp}$ is the sum of (j), (k) and (l); the sum of emissions emitted in Spain coming from the final demand of EU residents.

(n) $\boldsymbol{g}_{uw}^{exp}$ is, similarly, the sum of emissions emitted in Spain coming from the final demand of the rest of the world.

Therefore, the total emissions produced in the region $u$, is:

$$\boldsymbol{g}_{uu}^{dom} + \boldsymbol{g}_{ur}^{exp} + \boldsymbol{g}_{uw}^{exp} \tag{6}$$

and the total of emissions caused by the final demand of region $u$ (carbon footprint), is:

$$\boldsymbol{g}_{uu}^{dom} + \boldsymbol{g}_{ru}^{imp} + \boldsymbol{g}_{wu}^{imp} \tag{7}$$

The difference between the two is the so called Emission Trade Balance (ETB), which can be calculated here by the difference between the emissions actually produced in Spain (6) and the Spanish footprint (7).

In a bilateral model (i.e. dropping region $w$ in equations 6 and 7), the ETB yields:

$$\boldsymbol{g}_{ur}^{exp} - \boldsymbol{g}_{ru}^{imp}$$

which is equal to (from equation 5):

$$\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uu} \boldsymbol{y}_{ur} + \hat{\boldsymbol{c}}_u \boldsymbol{L}_{ur} \boldsymbol{y}_{rr} - \hat{\boldsymbol{c}}_r \boldsymbol{L}_{rr} \boldsymbol{y}_{ru} - \hat{\boldsymbol{c}}_r \boldsymbol{L}_{ru} \boldsymbol{y}_{uu}$$

And therefore,

$$\hat{\boldsymbol{c}}_u (\boldsymbol{L}_{uu} \boldsymbol{y}_{ur} + \boldsymbol{L}_{ur} \boldsymbol{y}_{rr}) - \hat{\boldsymbol{c}}_r (\boldsymbol{L}_{rr} \boldsymbol{y}_{ru} - \boldsymbol{L}_{ru} \boldsymbol{y}_{uu})$$

where the expressions in parentheses are indeed the sum of intermediate and final exports and imports, respectively. Thus, the ETB (positive or negative) highly depends on both the trade balance and the different pollution (emission) intensity of goods traded in both regions (Rueda-Cantuche, 2011; López et al., 2013).

Furthermore, multi-country input-output tables also allow a detailed separate analysis about trade on intermediate and final goods and services and thus, global value chains in the emissions balance. For instance, the total emissions generated in the country of reference due to Spanish imports of final goods and services ($\boldsymbol{g}_{ru}^{imp}$) can be decomposed into:

(a) Emissions generated in the country of reference for the production of the final goods and services exported to Spain (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rr} \boldsymbol{y}_{ru}$;

(b) Emissions generated in the country of reference for the production of the intermediate inputs that will be exported to Spain for the domestic production of a final good or service demanded by Spanish residents (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{ru} \boldsymbol{y}_{uu}$;

(c) Emissions generated in the country of reference for the production of the intermediate inputs that will be exported to a third country for the domestic production of a final good or service to be exported to Spain (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rw} \boldsymbol{y}_{wu}$;

And similarly, the total emissions produced in Spain due to imports of the country of reference ($\boldsymbol{g}_{ur}^{exp}$) can be split up into:

(a) Emissions produced in Spain for exports of final goods and services - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uu} \boldsymbol{y}_{ur}$;

(b) Emissions produced in Spain for exports of intermediate goods and services to the country of reference for the production of final goods in the same country - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{ur} \boldsymbol{y}_{rr}$;

(c) Emissions produced in Spain for exports of intermediate goods and services to a third country that will use them for the production of goods and services to be exported to the country of reference - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uw} \boldsymbol{y}_{wr}$;

Tables A.2, A.3 and A.4 in the Annex report all these results of the analysis for the three gases, which are described and commented in Section 4.

### 3.3. Database

The data used in this paper come from the World Input-Output Database (WIOD), as described in Dietzenbacher et al. (2013). This is a free database financed by the European Union and developed with the aim to analyse the effects of globalization on trade patterns, environmental pressures and the socioeconomic development of a large group of countries. The data include world input-output tables for the 27 European Union countries and 13 other non-EU economies and also the corresponding national IO tables. The WIOD database currently covers the period 1995-2011 and includes 35 industries and 59 commodities (see Table A.1 of the Annex I). However, data on energy and emissions have not been updated up to 2011 yet so we had to carry out our analysis with environmental data up to 2009. The selection of the year 2008 was eventually done in order to avoid the use of a year where the economic crisis was hitting hard the European economy.

## 4. Results and discussion

The description of the results is divided into three blocks. The first block reflects the position of the Spanish emission trade balance (ETB) with the rest of the world for all the three GHG considered. In a second step, the results are broken down into types of gases, countries and polluting industries, describing the situation of Spain with respect to the countries with the largest positive or negative ETB.

### 4.1. Emission Trade Balance of GHG in Spain: general overview

Spain produced 316.6 million tons of $CO_2$ equivalents in 2008 (7 tons per capita) and its final demand led to 494 million tons of $CO_2$ equivalents elsewhere in the same year (10.8 tons per capita). The emission trade balance of Spain of GHG resulted therefore in -177.7 million tons of $CO_2$ equivalents (3.9 tons per capita, a bit over the EU27 average,

***Table 1:*** *Emission Trade Balance of GHG of Spain (thousand tonnes $CO_2$-equivalent).*

| | GHG produced from Spanish exports of final goods and services | GHG footprint from Spanish final demand of goods and services | Emission Trade Balance of GHG |
|---|---:|---:|---:|
| FRA | 10 943.0 | 8 558.1 | 2 384.9 |
| PRT | 6 244.9 | 4 417.3 | 1 827.6 |
| GRC | 1 123.0 | 283.2 | 839.8 |
| GBR | 7 513.9 | 6 692.0 | 822.0 |
| SWE | 1 141.8 | 863.7 | 278.1 |
| CYP | 131.7 | 29.5 | 102.2 |
| SVN | 246.5 | 150.2 | 96.3 |
| LUX | 123.0 | 69.9 | 53.1 |
| MLT | 60.9 | 28.1 | 32.8 |
| LVA | 76.5 | 53.9 | 22.5 |
| ESP | 225 484.1 | 225 484.1 | 0.0 |
| EST | 65.8 | 153.3 | −87.5 |
| AUT | 771.1 | 860.7 | −89.5 |
| LTU | 137.6 | 334.7 | −197.1 |
| MEX | 1 471.8 | 1 699.5 | −227.7 |
| HUN | 363.4 | 740.0 | −376.6 |
| IRL | 575.0 | 977.3 | −402.3 |
| BGR | 212.9 | 632.1 | −419.2 |
| SVK | 182.9 | 604.5 | −421.6 |
| DNK | 602.7 | 1 051.8 | −449.0 |
| FIN | 421.2 | 894.0 | −472.8 |
| ROM | 527.8 | 1 071.1 | −543.3 |
| CZE | 590.4 | 1 272.6 | −682.2 |
| TUR | 996.9 | 1 805.8 | −808.9 |
| AUS | 613.3 | 1 471.7 | −858.3 |
| BEL | 2 059.2 | 3 005.9 | −946.7 |
| ITA | 5 963.5 | 7 289.4 | −1 325.9 |
| POL | 1 446.0 | 2 990.5 | −1 544.5 |
| JPN | 1 207.2 | 2 930.1 | −1 723.0 |
| CAN | 1 122.8 | 2 870.1 | −1 747.3 |
| TWN | 187.4 | 1 938.2 | −1 750.7 |
| IDN | 200.4 | 2 078.1 | −1 877.7 |
| KOR | 574.7 | 2 659.8 | −2 085.1 |
| NLD | 1 733.8 | 4 044.6 | −2 310.8 |
| DEU | 8 209.0 | 12 685.0 | −4 476.0 |
| BRA | 892.1 | 5 810.3 | −4 918.2 |
| IND | 582.6 | 6 947.2 | −6 364.6 |
| USA | 6 766.3 | 13 686.8 | −6 920.5 |
| RUS | 1 616.6 | 20 659.2 | −19 042.6 |
| RoW | 21 055.7 | 79 113.2 | −58 057.5 |
| CHN | 2 385.8 | 65 456.3 | −63 070.4 |
| Total EU27 | 276 951.8 | 285 237.5 | −8 285.8 |
| Total | 316 625.3 | 494 363.6 | −177 738.3 |

*Source:* Own elaboration based on data from WIOD (Dietzenbacher et al., 2013).

i.e. 3.2 tons per capita). Spain is the fifth EU country with the largest negative emission trade balance, behind Germany, France, United Kingdom and Italy.

Moreover, Spanish exports of final goods and services to France lead to around 11 million tons of $CO_2$ equivalent of GHG while Spanish exports to Germany and UK induce 8.2 million and 7.5 million tons of $CO_2$ equivalents of GHG, respectively. On the other hand, the final demand of Spanish residents (GHG footprint) leads to 65.5 million tons of $CO_2$ equivalent of GHG in China; followed by Russia and US with 20.7 and 13.7 million tons of $CO_2$ equivalents (see Table 1).

As a result, the largest positive balances are found in France (24 millions of tons of $CO_2$ equivalents) and Portugal (18.3 millions of tons of $CO_2$ equivalents). With respect to the largest negative emission trade balances of Spain, China presents the biggest negative balance (63 million tons of $CO_2$ equivalents) followed by Russia and US (19 million and 6.9 million of tons of $CO_2$ equivalents, respectively).For further analysis hereafter, we will limit the analysis to the countries with the largest negative/positive emission trade balance of Spain.

This implies that the GHG emissions originated from the consumption of Spanish residents is bigger than those generated in Spain as a consequence of the foreign demand. As shown in Table 1 and in the Annex II (Figure A.1), China is the country with the biggest negative emission trade balance with respect to Spain, even well above the sum of the EU-27.

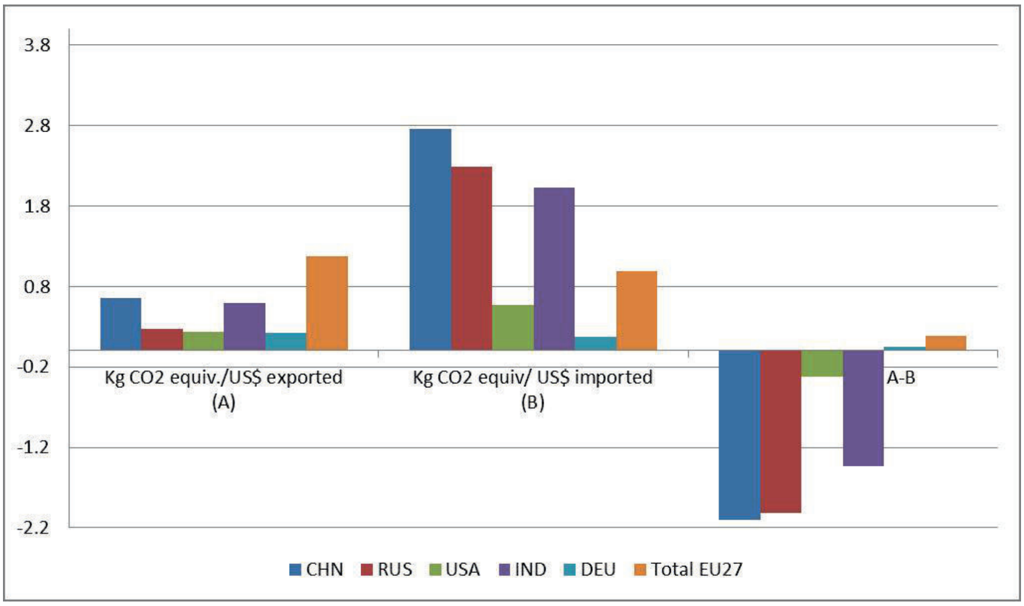

*Figure 1: Comparison of GHG emissions per US dollar in Spain. (Kg $CO_2$-equivalents/US dollar).*

*Source:* Based on data from WIOD (Dietzenbacher et al., 2013).

Figure 1 shows GHG emissions per dollar exported (A) and imported (B) by Spain, and the difference between both values (A-B) across some relevant countries and the EU-27 average. Generally speaking, Spanish exports generate less GHG emissions per dollar than Spanish imports, except in the case of the EU-27 average (e.g. Germany). Note that the value of GHG emissions per dollar caused by the production of Chinese and Russian products exported to Spain (i.e. Spanish imports) are remarkably higher than those originated in Spain due to the demand of Spanish products by China and Russia.

### 4.2. Emission trade balance of GHG in Spain by country of destination

Table A.2 of the Annex I lists, on the one hand, the five countries that contribute most to the negative Spanish ETB in $CO_2$ emissions, i.e. China, Russia, Germany, the United States and Indonesia. They amount to 47% of the total emissions originated outside Spain due to the imports of Spanish residents. As in Lopez et al. (2013), China is also the country that contributes most to the negative bilateral ETB of Spain. Spanish imports from China account for 25% of the total $CH_4$ and $CO_2$ emissions associated with Spanish imports and 14% of $N_2O$. On the other hand, we show the two countries – France and Portugal – with the largest positive ETB. The emissions associated with the Spanish exports to France and Portugal amounts to 18% of the total emissions produced in Spain to satisfy the total final demand.

Figures A.2, A.3 and A.4 of the Annex II present the results of the bilateral trade emissions of Spain with respect to the rest of the world for the three gases considered: $CO_2$, $CH_4$ and $N_20$, separately. The ETB for $CO_2$ is positive for 11 countries, which are all EU members. The most prominent positive balances are those of France and Portugal. For $CH_4$ the situation is similar. The balance is positive for 16 EU countries (e.g. Germany, Italy and Great Britain) and Japan. Finally, in the case of $N_2O$, the balance is positive for 8 EU countries, Japan and Turkey. As a last remark, 7 EU countries have positive ETB for the three gases, being Great Britain and Portugal the ones that contribute most to the Spanish positive trade balance on GHG emissions (see Figures A.2, A.3 and A.4 of the Annex II).

### 4.3. Emission trade balance of GHG in Spain by polluting industry

Hereafter, we identify the industries that contribute most to the GHG emissions produced in other countries different from Spain, particularly in those countries where the Spanish carbon footprint is the largest. Analogously, we identify the industries (and countries) that contribute most to the GHG emissions produced in Spain as a result of its imports from other countries. Those GHG emissions are concentrated in seven industries, as it is shown in Tables A.2, A.3 and A.4 of the Annex I.

In Spain, it is interesting to highlight that Electricity is barely traded but nonetheless it is one of the most important sectors in terms of virtual carbon in trade. The reason is that electricity is generally used to produce goods and services that are eventually traded. In particular, emissions from the Electricity, Gas and Water Supply activities amount to more than half (53.5%) of the $CO_2$ footprint of Spain in China (column B1 in Table A.2), being 86.6% caused by Spanish imports of Chinese final goods (38.4%, column C1 in Table A.2) and Chinese intermediate goods (48.2%, column D1 in Table A.2). All other emissions (13.4%, column E1 in Table A.2) were due to emissions generated in China for the production of intermediate goods that are exported to third countries, which in turn produce final goods that are consumed by Spanish residents. These results agree with those of Cadarso et al. (2008, 2012). The distribution of $CO_2$ footprints between final and intermediate goods is similar to other polluting industries (e.g. chemicals, non-metallic mineral and basic metals). However, they do not weight the same as the electricity industry. Cadarso et al.'s results (2008, 2012) suggested that this might be due to the reallocation of production between countries.

The same industry-wide distribution pattern is associated to the emissions of $CH_4$ and $N_2O$ gases derived from the Spanish demand for final goods produced in China. Particularly, Mining and Quarrying is responsible for almost half (48.1%) of the $CH_4$ emissions and also the Electricity (38.4%) and Chemicals (36.9%) industries for $N_2O$ emissions.

It is also remarkable that the Agriculture, Hunting, Forestry and Fishing industry is responsible for 26.2% (column B1 of Table A.3) of the $CH_4$ emissions and 75.6% of the $N_2O$ emissions (column B1 of Table A.4). More than half of these emissions are in both cases caused by the production of Chinese final goods demanded by residents in Spain, being only one third intermediate imported inputs for the domestic production of goods and services demanded by Spanish residents as final goods (columns C1 and D1 in Tables A.3 and A.4 of Annex I).

The second country with the largest negative bilateral ETB (with respect to Spain) is Russia, both for $CO_2$ and $CH_4$, although their weight in the total emissions associated with the Spanish imports is much lower than in the case of China: 7.5% for $CO_2$ and 12.8% for $CH_4$. In both cases more than 90% of the emissions are explained by a few industries. The most polluting industry in each case is the same as in China: the Electricity industry for $CO_2$ emissions and Mining and Quarrying activities for $CH_4$ emissions. Incidentally, Mining and Quarrying is also the second most polluting industry in terms of $CO_2$ emissions. Although the pattern of types of goods associated with these emissions is somewhat different to China, 70.5% of the emissions associated with the Spanish imports from Russia are caused by the demand for intermediate goods. Besides, Inland Transport industry is responsible for 14.7% and 28.5% of $CO_2$ and $CH_4$, respectively, due to pipeline transport services. Differently from China, the relevance of the $CO_2$ and $CH_4$ emissions generated in Russia for the production of intermediate goods that will be used by a third country to produce other final goods that Spanish residents will consume, is much higher (over 20%, column E1 in Tables A.2 and A.3).

The third country with the largest negative ETB for $CO_2$ emissions is Germany, which, however, has a very small but negative $N_2O$ ETB, and a positive $CH_4$ ETB. The most polluting industries in terms of $CO_2$ emissions are the same as those for China plus air transportation services. The relative importance of the contribution of industries to the overall total of emissions is however more spread. The distribution between intermediate and final goods is also similar to that of China.

The list of industries contributing to the United States' (US) emissions associated with Spanish imports is much longer than for the other countries mentioned so far (China, Russia and Germany). Only six industries weight more than 5% in carbon dioxide emissions and they do not sum up even 30% of the overall total, being the most polluting industry the Gas, Water and Electricity supply activities. The distribution pattern between intermediate and final goods is similar to other countries except for Russia, reaching for instance, 78% (sum of columns D1 and E1 in Table A.2) in intermediate goods for Basic metals and fabricated metals. This value is much higher for Russia, i.e. 97%. For $N_2O$ and $CH_4$ emissions the main source is the Agriculture industry. This industry generates 81.9% and 44.8% of the total emissions of $N_2O$ and $CH_4$, respectively. Moreover, imports of US final goods are bigger than those of intermediate goods in this industry. As in China, Mining and Quarrying is another relevant emitter of $CH_4$ gases in the US exports to Spain.

In addition, Brazil is the most polluting country in terms of $N_2O$ and $CH_4$ emissions coming mainly from the imports of intermediate goods made by the Spanish agricultural industry. France's position is peculiar, since it has a positive ETB in $CO_2$ and $CH_4$ and it has, on the other hand, the third largest negative ETB in $N_2O$ emissions; mainly due to the imports of agricultural products (85%) and the imports of chemicals (12%).

Countries with the largest positive emission trade balance in their bilateral trade with Spain are Portugal and France for $CO_2$, Germany, Italy and United Kingdom (UK) for $CH_4$ and UK and Portugal for $N_2O$. In terms of $N_2O$ and $CH_4$ emissions, Spanish has a surplus in the trade balance of mining and quarrying and agriculture industries. This is mainly due to the fact that the Spanish economy is specialized in exporting agricultural products, while at the same time it does not import large amounts of related natural resources. Exported chemicals products play also a relevant role in terms of $N_2O$ emissions. The same applies to Other Social Services for $CH_4$ emissions.

$CO_2$ emissions of Spanish exports (with positive emission trade balance) are spread among several industries but mainly coming from the import demand of France and Portugal (neighboring countries). This demand is concentrated on electricity and demand for intermediate goods of basic and non-metallic minerals.

## 5. Conclusions

Many studies have addressed the calculation of the GHG footprint of Spain but to our knowledge, none or very few of them has used a homogeneous multi-country IO database, nor has the analysis been carried out with high industry resolution and bilateral country flows as it is done in this paper. Therefore, the originality and interest of this work lies on the details and the extension of the results in terms of higher industry breakdown, homogeneity of the multi-country database, country coverage and pollutants covered ($CO_2$, $CH_4$ and $N_2O$).

Spain produced 316.6 million tons of $CO_2$ equivalents in 2008 and its final demand led to 494 million tons of $CO_2$ equivalents elsewhere in the same year. The emission trade balance of Spain of GHG resulted therefore in -177.7 million tons of $CO_2$ equivalents. Spain is the fifth EU country with the largest negative emission trade balance, behind Germany, France, United Kingdom and Italy.

Moreover, Spanish exports of final goods and services to France, Germany and UK are those that contribute most to the GHG emissions produced by Spain. On the other hand, the final demand of Spanish residents (GHG footprint) leads to 65.5 million tons of $CO_2$ equivalent of GHG in China; followed by Russia and US with 20.7 and 13.7 million tons of $CO_2$ equivalents.

As a result, the largest positive balances are found in France (24 millions of tons of $CO_2$ equivalents) and Portugal (18.3 millions of tons of $CO_2$ equivalents), while the largest negative emission trade balances of Spain are found for China, Russia and US. The analysis also gives some details by polluting industry.

Finally, special attention should be devoted to the emissions trade balance between Spain and China. China is the country that produces more $CO_2$, $CH_4$ and $N_2O$ emissions due to Spanish imports. In particular, Chinese GHG emissions due to intermediate imported inputs by Spain are much more than those produced for exporting final goods and services to Spain (as in López et al., 2013). This result could be explained by the re-allocation of (less clean) production activities and international supply chains across the world (Cadarso et al., 2012). Interestingly, future work might be focused on whether this trend of re-allocation of production activities to less developed countries will continue in time. Policy options like stimuli of technology transfers and the spread use of cleaner technologies through standard regulations would also be worthwhile to investigate.

Reducing emissions of greenhouse gases (GHG) has become one of the main objectives of the current climate policies of countries. The relative position that countries hold among their main trade partners is also a key issue in terms of international climate negotiations and this paper hopefully contributes to raise the awareness of national statistical institutes and statistical international organizations about the necessary construction of official global multi-country input-output tables that would pave the way for further detailed studies on the economic, social and environmental impacts of globalization and international trade.

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## Annex I. Tables

***Table A.1:*** *WIOD Industries and Commodities.*[1]

| | WIOD Sectors |
|---|---|
| 1 | Agriculture, Hunting, Forestry and Fishing |
| 2 | Mining and Quarrying |
| 3 | Food, Beverages and Tobacco |
| 4 | Textiles and Textile Products |
| 5 | Leather, Leather and Footwear |
| 6 | Wood and Products of Wood and Cork |
| 7 | Pulp, Paper, Paper , Printing and Publishing |
| 8 | Coke, Refined Petroleum and Nuclear Fuel |
| 9 | Chemicals and Chemical Products |
| 10 | Rubber and Plastics |
| 11 | Other Non-Metallic Mineral |
| 12 | Basic Metals and Fabricated Metal |
| 13 | Machinery, Nec |
| 14 | Electrical and Optical Equipment |
| 15 | Transport Equipment |
| 16 | Manufacturing, Nec; Recycling |
| 17 | Electricity, Gas and Water Supply |
| 18 | Construction |
| 19 | Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel |
| 20 | Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles |
| 21 | Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods |
| 22 | Hotels and Restaurants |
| 23 | Inland Transport |
| 24 | Water Transport |
| 25 | Air Transport |
| 26 | Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies |
| 27 | Post and Telecommunications |
| 28 | Financial Intermediation |
| 29 | Real Estate Activities |
| 30 | Renting of M&Eq and Other Business Activities |
| 31 | Public Admin and Defence; Compulsory Social Security |
| 32 | Education |
| 33 | Health and Social Work |
| 34 | Other Community, Social and Personal Services |
| 35 | Private Households with Employed Persons |

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[1] Commodities and industries are the same provided that the World IOTs used are square.

## Legends to read Tables A.2, A.3 and A.4

A1: Total emissions generated in the country of reference due to Spanish imports of final goods and services (GHG footprints) - $\boldsymbol{g}_{ru}^{imp}$

B1: Cumulated share of A1 over the total amount of emissions (%)

C1: Share of emissions generated in the country of reference for the production of the final goods and services exported to Spain (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rr} \boldsymbol{y}_{ru}$

D1: Share of emissions generated in the country of reference for the production of the intermediate inputs that will be exported to Spain for the domestic production of a final good or service demanded by Spanish residents (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{ru} \boldsymbol{y}_{uu}$

E1: Share of emissions generated in the country of reference for the production of the intermediate inputs that will be exported to a third country for the domestic production of a final good or service to be exported to Spain (%) - $\hat{\boldsymbol{c}}_r \boldsymbol{L}_{rw} \boldsymbol{y}_{wu}$

A2: Total emissions produced in Spain due to imports of the country of reference - $\boldsymbol{g}_{ur}^{exp}$

B2: Cumulated share of A2 over the total amount of emissions (%)

C2: Share of emissions produced in Spain for exports of final goods and services - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uu} \boldsymbol{y}_{ur}$

D2: Share of emissions produced in Spain for exports of intermediate goods and services to the country of reference for the production of final goods in the same country - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{ur} \boldsymbol{y}_{rr}$

E2: Share of emissions produced in Spain for exports of intermediate goods and services to a third country that will use them for the production of goods and services to be exported to the country of reference - $\hat{\boldsymbol{c}}_u \boldsymbol{L}_{uw} \boldsymbol{y}_{wr}$

***Table A.2:*** *Industries with larger $CO_2$ footprints and commodities. Thousands of tons $CO_2$, 2008.*

| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $CO_2$ EMISSIONS | A1 (Th. tons) $g_{ru}^{imp}$ | B1 (%) | C1 (%) Final | D1 (%) Interm. | E1 (%) Interm. |
|---|---|---|---|---|---|---|
| **CHN (-)** | TOTAL | 50 135 | 100.0 | 37.2 | 49.6 | 13.2 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 39 150 | 78.1 | 36.9 | 49.5 | 13.6 |
| | Electricity, Gas and Water Supply | 26 815 | 53.5 | 38.4 | 48.2 | 13.4 |
| | Basic Metals and Fabricated Metal | 5 826 | 11.6 | 32.9 | 51.7 | 15.5 |
| | Other Non-Metallic Mineral | 3 301 | 6.6 | 31.5 | 58.3 | 10.2 |
| | Chemicals and Chemical Products | 3 208 | 6.4 | 36.9 | 48.0 | 15.1 |
| **RUS (-)** | TOTAL | 14 450 | 100.0 | 4.4 | 69.7 | 25.9 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 13 482 | 93.3 | 4.8 | 70.5 | 24.7 |
| | Electricity, Gas and Water Supply | 5 850 | 40.5 | 5.5 | 69.2 | 25.2 |
| | Mining and Quarrying | 2 798 | 19.4 | 1.6 | 75.2 | 23.2 |
| | Inland Transport | 2 129 | 14.7 | 1.4 | 72.1 | 26.5 |
| | Basic Metals and Fabricated Metal | 1 868 | 12.9 | 3.0 | 69.4 | 27.6 |
| | Coke, Refined Petroleum and Nuclear Fuel | 836 | 5.8 | 22.9 | 59.7 | 17.5 |
| **DEU (-)** | TOTAL | 11 170 | 100.0 | 35.9 | 51.6 | 12.4 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 8 779 | 78.6 | 33.5 | 53.6 | 12.9 |
| | Electricity, Gas and Water Supply | 4 174 | 37.4 | 39.7 | 47.6 | 12.7 |
| | Basic Metals and Fabricated Metal | 2 087 | 18.7 | 23.3 | 60.9 | 15.8 |
| | Chemicals and Chemical Products | 1 160 | 10.4 | 33.3 | 53.3 | 13.4 |
| | Other Non-Metallic Mineral | 710 | 6.4 | 23.2 | 67.5 | 9.3 |
| | Air Transport | 647 | 5.8 | 38.3 | 54.1 | 7.6 |
| **USA (-)** | TOTAL | 10 084 | 100.0 | 29.7 | 50.8 | 19.5 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 7 332 | 72.7 | 32.2 | 49.1 | 18.7 |
| | Electricity, Gas and Water Supply | 2 981 | 29.6 | 31.5 | 47.8 | 20.8 |
| | Chemicals and Chemical Products | 1 256 | 12.5 | 44.7 | 38.0 | 17.3 |
| | Air Transport | 1 043 | 10.3 | 28.8 | 59.2 | 12.0 |
| | Coke, Refined Petroleum and Nuclear Fuel | 843 | 8.4 | 35.2 | 51.1 | 13.7 |
| | Inland Transport | 625 | 6.2 | 21.8 | 56.8 | 21.5 |
| | Basic Metals and Fabricated Metal | 585 | 5.8 | 22.0 | 49.9 | 28.1 |
| **IND (-)** | TOTAL | 5 178 | 100.0 | 35.4 | 45.2 | 19.4 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 4 095 | 79.1 | 68.5 | 47.7 | −16.2 |
| | Electricity, Gas and Water Supply | 2 550 | 49.2 | 40.7 | 41.3 | 17.9 |
| | Basic Metals and Fabricated Metal | 687 | 13.3 | 56.5 | 22.8 | 20.8 |
| | Mining and Quarrying | 573 | 11.1 | 64.5 | 10.8 | 24.7 |
| | Chemicals and Chemical Products | 286 | 5.5 | 55.4 | 23.6 | 21.0 |

| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $CO_2$ EMISSIONS | A2 (Th. tons) $g_{ur}^{exp}$ | B2 (%) | C2 (%) Final | D2 (%) Interm. | E2 (%) Interm. |
|---|---|---|---|---|---|---|
| **FRA (+)** | TOTAL | 8 735 | 100.0 | 47.0 | 46.4 | 6.6 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 7 162 | 82.0 | 45.0 | 48.3 | 6.8 |
| | Electricity, Gas and Water Supply | 2 120 | 24.3 | 51.2 | 41.9 | 6.9 |
| | Other Non-Metallic Mineral | 1 373 | 15.7 | 20.3 | 76.0 | 3.7 |
| | Coke, Refined Petroleum and Nuclear Fuel | 906 | 10.4 | 43.7 | 49.3 | 7.0 |
| | Basic Metals and Fabricated Metal | 905 | 10.4 | 37.8 | 51.9 | 10.3 |
| | Inland Transport | 724 | 8.3 | 44.3 | 47.1 | 8.6 |
| | Agriculture, Hunting, Forestry and Fishing | 608 | 7.0 | 86.8 | 10.0 | 3.3 |
| | Chemicals and Chemical Products | 526 | 6.0 | 51.0 | 40.0 | 9.0 |
| **PRT (+)** | TOTAL | 4 970 | 100.0 | 49.8 | 48.9 | 1.3 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 4 150 | 83.5 | 45.5 | 53.1 | 1.4 |
| | Electricity, Gas and Water Supply | 1 185 | 23.8 | 55.4 | 43.1 | 1.5 |
| | Other Non-Metallic Mineral | 720 | 14.5 | 22.8 | 76.3 | 0.9 |
| | Coke, Refined Petroleum and Nuclear Fuel | 553 | 11.1 | 30.9 | 68.0 | 1.1 |
| | Basic Metals and Fabricated Metal | 473 | 9.5 | 38.0 | 59.5 | 2.4 |
| | Agriculture, Hunting, Forestry and Fishing | 340 | 6.8 | 72.7 | 26.8 | 0.5 |
| | Inland Transport | 334 | 6.7 | 58.1 | 39.8 | 2.1 |
| | Chemicals and Chemical Products | 288 | 5.8 | 42.1 | 56.1 | 1.8 |
| | Air Transport | 256 | 5.1 | 60.2 | 38.8 | 1.0 |

***Table A.3:*** *Industries with larger $CH_4$ footprints and types of commodities. Tons $CH_4$, 2008.*

| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $CH_4$ EMISSIONS | A1 (tons) $g_{ru}^{imp}$ | B1 (%) | C1 (%) Final | D1 (%) Interm. | E1 (%) Interm. |
|---|---|---|---|---|---|---|
| **CHN (-)** | TOTAL | 542 790 | 100.0 | 40.0 | 48.3 | 11.7 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 534 042 | 98.4 | 40.1 | 48.3 | 11.6 |
| | Mining and Quarrying | 261 244 | 48.1 | 34.4 | 50.6 | 14.9 |
| | Agriculture, Hunting, Forestry and Fishing | 142 116 | 26.2 | 56.5 | 33.0 | 10.5 |
| | Other Community, Social and Personal Services | 130 682 | 24.1 | 33.4 | 60.3 | 6.2 |
| **RUS (-)** | TOTAL | 287 495 | 100.0 | 2.4 | 73.0 | 24.7 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 274 574 | 95.5 | 2.2 | 73.3 | 24.5 |
| | Mining and Quarrying | 146 779 | 51.1 | 1.6 | 75.2 | 23.2 |
| | Inland Transport | 81 814 | 28.5 | 1.4 | 72.1 | 26.5 |
| | Electricity, Gas and Water Supply | 45 980 | 16.0 | 5.5 | 69.2 | 25.2 |
| **BRA (-)** | TOTAL | 127 954 | 100.0 | 10.2 | 71.8 | 18.0 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 126 645 | 99.0 | 10.2 | 71.9 | 17.9 |
| | Agriculture, Hunting, Forestry and Fishing | 112 374 | 87.8 | 10.7 | 72.7 | 16.7 |
| | Mining and Quarrying | 8 006 | 6.3 | 2.6 | 70.3 | 27.0 |
| | Other Community, Social and Personal Services | 6 265 | 4.9 | 12.0 | 60.1 | 27.9 |
| **USA (-)** | TOTAL | 104 801 | 100.0 | 35.9 | 47.8 | 16.3 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 101 962 | 97.3 | 36.0 | 47.8 | 16.2 |
| | Agriculture, Hunting, Forestry and Fishing | 46 960 | 44.8 | 47.5 | 38.8 | 13.7 |
| | Mining and Quarrying | 37 936 | 36.2 | 27.8 | 53.0 | 19.3 |
| | Other Community, Social and Personal Services | 10 578 | 10.1 | 23.1 | 63.9 | 13.1 |
| | Inland Transport | 6 489 | 6.2 | 21.8 | 56.8 | 21.5 |
| **IND (-)** | TOTAL | 59 613 | 100.0 | 33.5 | 42.0 | 24.5 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 58 575 | 98.3 | 33.4 | 42.0 | 24.6 |
| | Agriculture, Hunting, Forestry and Fishing | 28 941 | 48.5 | 44.1 | 31.1 | 24.8 |
| | Mining and Quarrying | 16 850 | 28.3 | 10.8 | 64.5 | 24.7 |
| | Other Community, Social and Personal Services | 12 784 | 21.4 | 39.1 | 37.0 | 23.9 |
| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $CH_4$ EMISSIONS | A2 (tons) $g_{ur}^{exp}$ | B2 (%) | C2 (%) Final | D2 (%) Interm. | E2 (%) Interm. |
| **DEU (+)** | TOTAL | 56 511 | 100.0 | 83.3 | 9.6 | 7.1 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 53 102 | 94.0 | 85.7 | 7.8 | 6.4 |
| | Agriculture, Hunting, Forestry and Fishing | 48 682 | 86.1 | 90.2 | 4.5 | 5.4 |
| | Other Community, Social and Personal Services | 4 419 | 7.8 | 37.0 | 44.9 | 18.2 |
| **ITA (+)** | TOTAL | 34 812 | 100.0 | 70.0 | 25.0 | 4.9 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 31 434 | 90.3 | 73.6 | 21.7 | 4.6 |
| | Agriculture, Hunting, Forestry and Fishing | 26 808 | 77.0 | 80.6 | 15.2 | 4.2 |
| | Other Community, Social and Personal Services | 4 626 | 13.3 | 33.1 | 59.5 | 7.4 |
| **GBR (+)** | TOTAL | 35 302 | 100.0 | 77.3 | 14.5 | 8.3 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 32 730 | 92.7 | 80.3 | 11.8 | 7.9 |
| | Agriculture, Hunting, Forestry and Fishing | 28 958 | 82.0 | 86.5 | 6.3 | 7.2 |
| | Other Community, Social and Personal Services | 3 772 | 10.7 | 32.5 | 54.3 | 13.3 |

***Table A.4:*** *Industries with larger $N_2O$ footprints and types of commodities. Tons $N_2O$, 2008.*

| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $N_2O$ EMISSIONS | A1 (tons) $g_{ru}^{imp}$ | B1 (%) | C1 (%) Final | D1 (%) Interm. | E1 (%) Interm. |
|---|---|---|---|---|---|---|
| **CHN (-)** | TOTAL | 12 652 | 100.0 | 51.5 | 37.7 | 10.9 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 12 268 | 97.0 | 52.0 | 37.2 | 10.8 |
| | Agriculture, Hunting, Forestry and Fishing | 9 561 | 75.6 | 56.5 | 33.0 | 10.5 |
| | Chemicals and Chemical Products | 1 183 | 9.3 | 36.9 | 48.0 | 15.1 |
| | Other Community, Social and Personal Services | 857 | 6.8 | 33.4 | 60.3 | 6.2 |
| | Electricity, Gas and Water Supply | 668 | 5.3 | 38.4 | 48.2 | 13.4 |
| **BRA (-)** | TOTAL | 6 326 | 100.0 | 10.7 | 72.5 | 16.8 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 6 216 | 98.3 | 10.7 | 72.7 | 16.7 |
| | Agriculture, Hunting, Forestry and Fishing | 6 216 | 98.3 | 10.7 | 72.7 | 16.7 |
| **FRA (-)** | TOTAL | 5 742 | 100.0 | 49.1 | 44.7 | 6.2 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 5 598 | 97.5 | 49.3 | 44.5 | 6.2 |
| | Agriculture, Hunting, Forestry and Fishing | 4 888 | 85.1 | 49.9 | 44.2 | 5.9 |
| | Chemicals and Chemical Products | 710 | 12.4 | 45.1 | 46.7 | 8.2 |
| **USA (-)** | TOTAL | 4 523 | 100.0 | 45.8 | 39.7 | 14.4 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 4 259 | 94.2 | 47.2 | 38.7 | 14.1 |
| | Agriculture, Hunting, Forestry and Fishing | 3 704 | 81.9 | 47.5 | 38.8 | 13.7 |
| | Chemicals and Chemical Products | 556 | 12.3 | 44.7 | 38.0 | 17.3 |
| COUNTRY OF REFERENCE | TOP INDUSTRIES WITH MORE $N_2O$ EMISSIONS | A2 (tons) $g_{ur}^{exp}$ | B2 (%) | C2 (%) Final | D2 (%) Interm. | E2 (%) Interm. |
| **GBR (+)** | TOTAL | 1 828 | 100.0 | 79.9 | 12.2 | 7.9 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 1 682 | 92.0 | 82.7 | 9.6 | 7.7 |
| | Agriculture, Hunting, Forestry and Fishing | 1 564 | 85.5 | 86.5 | 6.3 | 7.2 |
| | Chemicals and Chemical Products | 118 | 6.5 | 32.5 | 52.8 | 14.7 |
| **PRT (+)** | TOTAL | 1 713 | 100.0 | 70.5 | 28.9 | 0.6 |
| | TOTAL INDUSTRIES WITH MORE EMISSIONS | 1 589 | 92.8 | 69.0 | 30.4 | 0.6 |
| | Agriculture, Hunting, Forestry and Fishing | 1 475 | 86.1 | 72.7 | 26.8 | 0.5 |
| | Chemicals and Chemical Products | 115 | 6.7 | 42.1 | 56.1 | 1.8 |

# Annex II. Figures

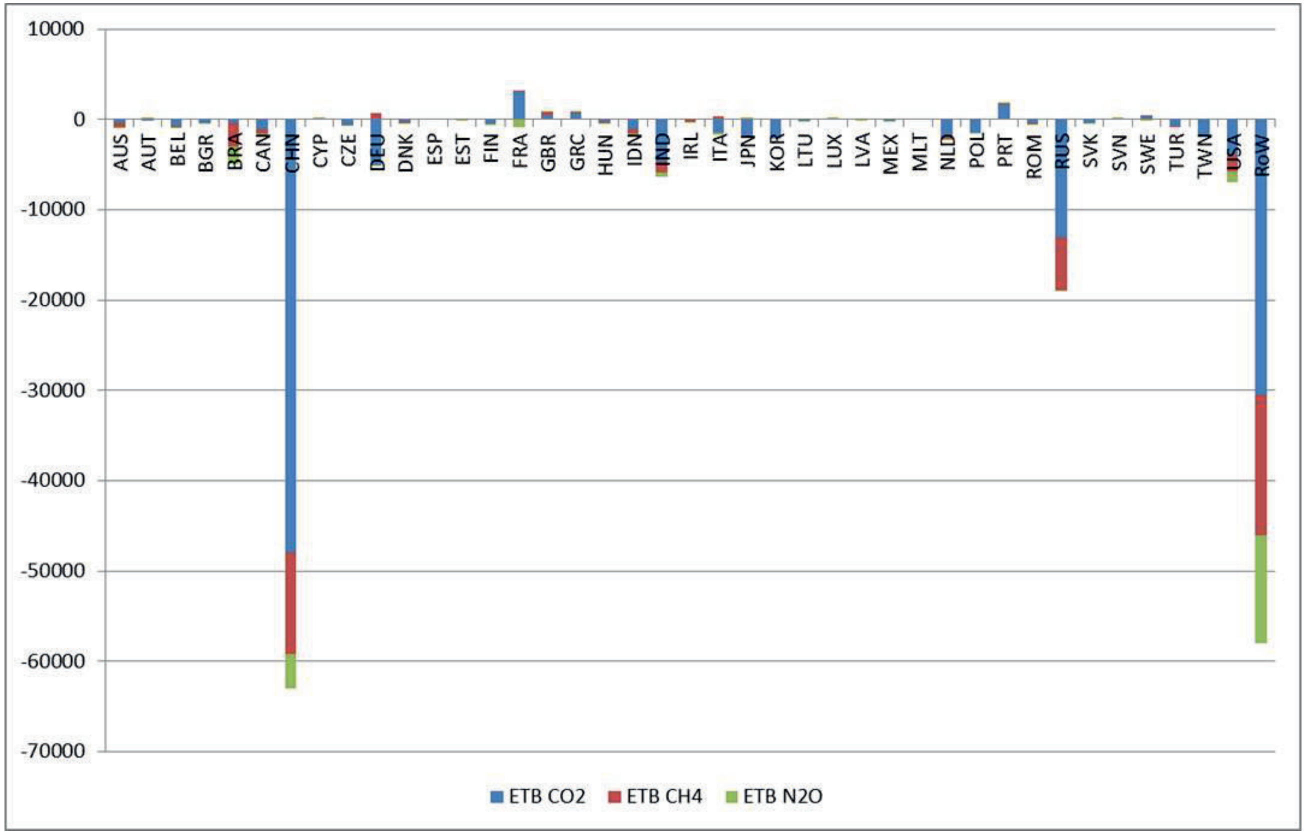

***Figure A.1:*** *GHG Global emission trade balance of Spain. 2008. Thousands of tons of $CO_2$-equivalents.*

*Source:* Based on data from WIOD (Dietzenbacher et al., 2013).

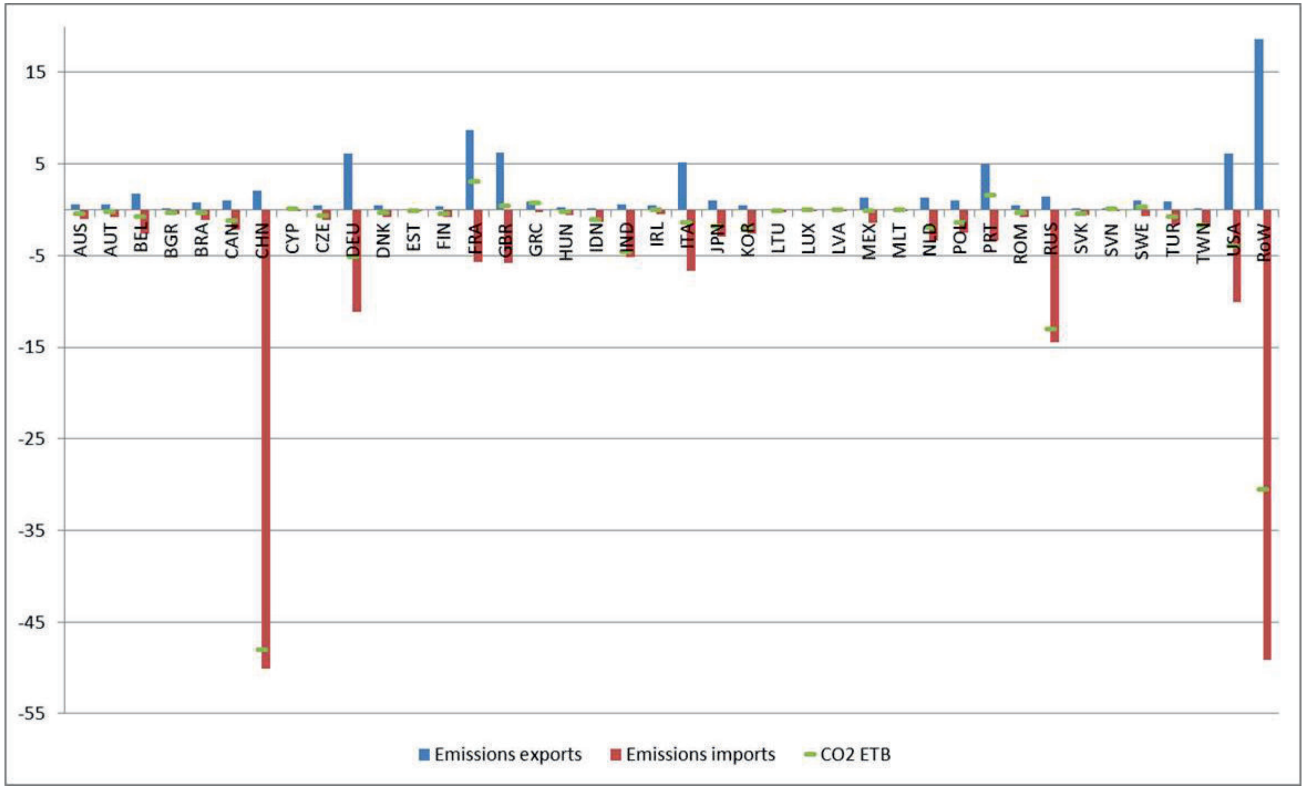

***Figure A.2:*** *Bilateral ETB of $CO_2$ (Millions of tons) in Spain, 2008, decomposed into emissions associated with imports and exports.*

*Source:* Based on data from WIOD (Dietzenbacher et al., 2013).

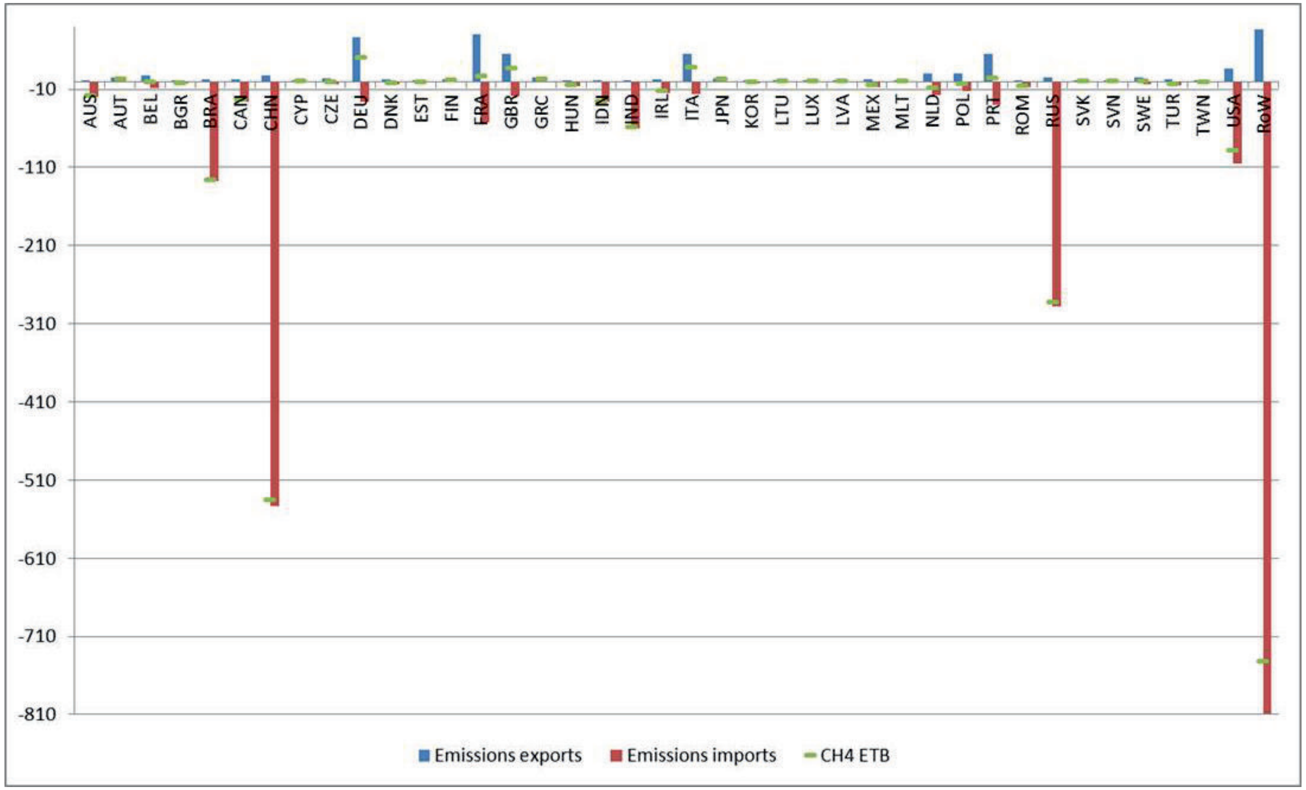

***Figure A.3:*** *Bilateral ETB of $CH_4$ (Thousands of tons) in Spain, 2008, decomposed into emissions associated with imports and exports.*

*Source:* Based on data from WIOD (Dietzenbacher et al., 2013).

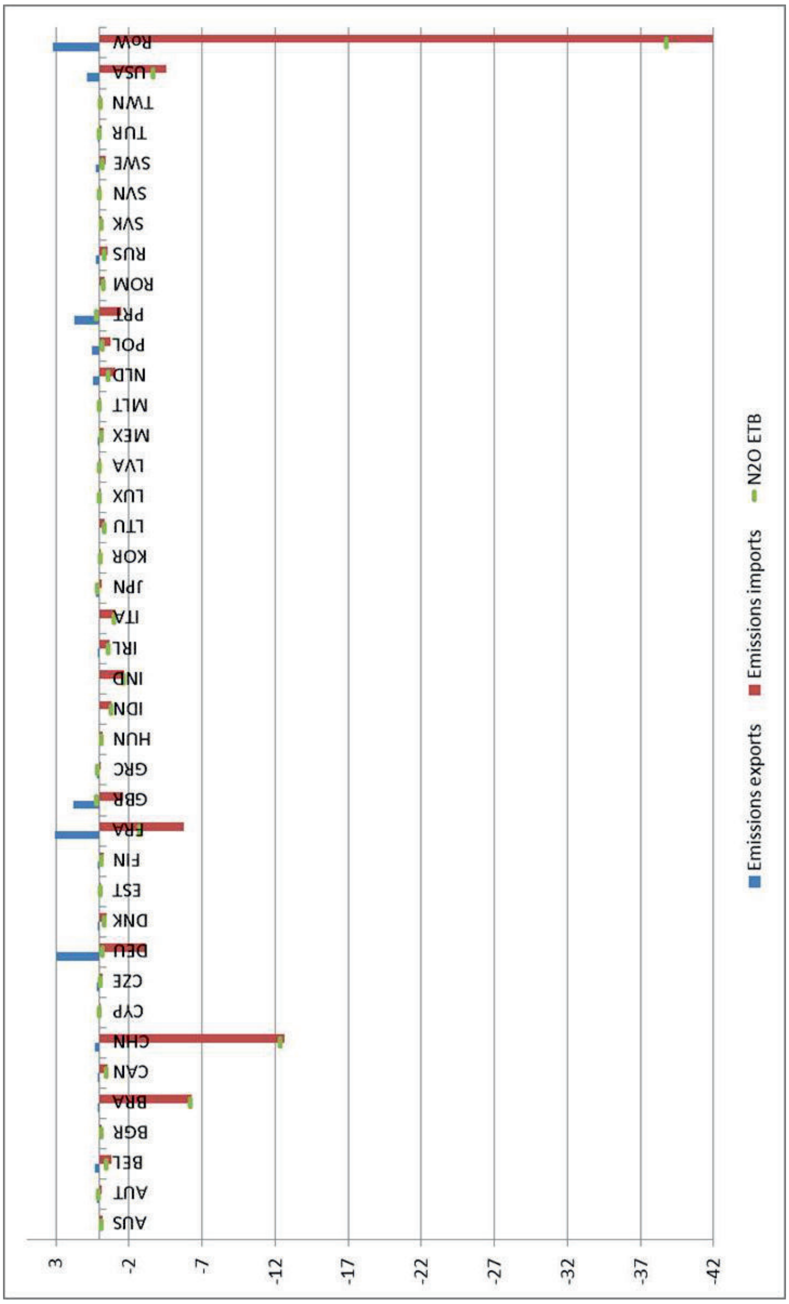

***Figure A.4:*** *Bilateral ETB of $N_2O$ (Thousands of tons) in Spain, 2008, decomposed into emissions associated with imports and exports.*

*Source:* Based on data from WIOD (Dietzenbacher et al., 2013).

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