The Game of Trading Jobs for Emissions

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Abstract

Following the international debate on the implications of international trade for global climate policy, this paper analyses the role of international trade in the growth of GHG emissions and introduces the important topic of the economic benefits related to emission generation. We use a multiregional input-output model and the World Input-Output Database to decompose the change in the evolution of GHG emissions in the period 1995-2008. We find that *i)* the evolution of emissions is mainly driven by the growth in the level of domestic final demand; *ii)* trade plays a secondary but relevant role in the growht of GHG emissions; *iii)* technological change contributes notably to offset the other two factors. We have also assessed the employment and greenhouse gas (GHG) generated worldwide by the production of exports. We show that, international trade should not be ignored when assessing the options for reducing global GHG emissions, since 24% of global GHG emissions are linked to trade. When doing that, it should bear in mind that 20% of the employment around the world is generated by international trade.

Keywords: Trade; Employment; GHG Emissions; Consumption-Based Approach; Multiregional Input-Output Model.

1. Introduction

In the last few decades world economies have experimented a rapid and profound process of globalization that has favoured the flow of goods, services and production factors around the world. This phenomenon becomes clear when we look at the statistics of international trade. According to the World Trade Organization, between 1995 and 2010 world trade volume tripled in nominal terms to exceed €14 trillion (30% of world GDP). The term globalization is usually associated to different economic concepts such as liberalization, specialization, outsourcing or competitiveness that contribute to shape the distribution and division of production and consumption activities across world regions.

The consequences of the growth in international trade can be observed in many dimensions of modern societies. For instance, by exporting goods and services countries can obtain economic benefits, such as the creation of new jobs (Rueda-Cantuche et al., 2012). On the other hand, exporting countries have to tackle the environmental consequences of producing those same exported goods (Muradian et al., 2002). This relation between increasing trade flows, employment generation and environmental degradation is well known for the problem of climate change (Wber et al., 2008).

In the last years, a group of emerging economies has led employment generation worldwide. At the same time, while developed countries have stabilized their emissions of greenhouse gases (GHG), the emissions of the emerging countries have increased significantly and global emissions have grown by almost 30% between 1995 and 2008 (WIOD, 2012). It has been argued that, to some extent, these trends could be related, among other factors, to the increasing exports of developing countries and to the growing market share of those countries in the final demand of developed economies (Le Quere, 2009; Raupach, 2007; Peters et al., 2009). Recently it has been estimated that the CO_2 emissions from the production of traded goods and services have increased from 20% of global emissions 26% in 2008. (Peters et al., 2011). However, it has not been assessed to what extent this growth in the emissions embodied in international trade has contributed to the total change in global emissions.

This triangle formed by trade, employment and emissions connects with the outstanding political debate about how to evaluate the relative contribution of different countries to climate change. The Kyoto Protocol establishes that each country would be responsible for the emissions generated within its national territory ("producer responsibility") (UNCCC, 1997; IPCC, 2006). According to this approach, countries could accomplish national emission reduction targets by "shifting" emissions to other countries via international trade. In contrast to this approach, the so-called "consumer responsibility" incorporates the trade on emissions into the accounting framework and postulates that each country should be responsible for all the emissions embodied in its final demand, regardless where they have been generated (Peters, 2008). In the last years a growing number of studies have focused on quantifying these transfers of emissions between countries via international trade (Wiedmann, 2009, Davis and Caldeira, 2009, Peters et al., 2011). However, no attention has been paid to the quantification of the economic consequences of trade in terms of jobs creation. This economic information is of special relevance for supporting the integration of international trade into climate change mitigation policies.

In this context, the main scope of the paper is to calculate the employment and GHG emissions generated by international trade of the world's main economies and to analyze to what extent trade drove the evolution of global GHG emissions in the period 1995-2008. The paper is structured as follow: section 2 describes the database and the methodology used, section 3 summarizes the main findings and section 4 discuses the results.

2. Database and methodology

We have conducted our analysis using the World Input-Output Database (WIOD). This database comprises a set of harmonized supply and use tables and symmetric I-O tables, valued at current and previous year prices, that includes data on international trade and satellite accounts related to environmental and socio-economic indicators. It comprises information from 1995 to 2009 for 35 industries, 60 products and 41 countries: 27 EU countries, 13 non-EU countries and the Rest of the World (RoW) as an aggregated region. Finally, the WIOD covers information in current and previous year prices. A detailed description o the database can be found at the website of the project (www.wiod.org).

In the rest of this section we show the methods for calculating the emissions and jobs embodied in international trade and analysing the drivers of the changes in both variables.

2.1 GHG emissions and employment embodied in trade

Multi-regional Input-Output models have been widely used to analyze the environmental consequences of trade (see Wiedman, 2009 and Wiedmann, et at., 2011 for a comprehensive revision of the literature and the existing databases). In our case, we will use a MRIO to calculate the emissions and employment embodied in international trade.

The methodology is described for the case of 3 regions with *n* sectors, but it can be applied to any number of regions and sectors.

The starting point of the model is the MRIO table. This table describes the flows of goods between all the individuals sectors and countries and the use of by final users. We can distinguish 3 main components in the MRIO table:

$$\mathbf{Z}=\begin{bmatrix}\mathbf{Z}^{11} & \mathbf{Z}^{12} & \mathbf{Z}^{12}\\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \mathbf{Z}^{23}\\ \mathbf{Z}^{31} & \mathbf{Z}^{32} & \mathbf{Z}^{33}\end{bmatrix}\quad \mathbf{f}=\begin{bmatrix}\mathbf{f}^{1}\\ \mathbf{f}^{2}\\ \mathbf{f}^{3}\end{bmatrix}=\begin{bmatrix}\mathbf{f}^{11}+\mathbf{f}^{12}+\mathbf{f}^{13}\\ \mathbf{f}^{21}+\mathbf{f}^{22}+\mathbf{f}^{23}\\ \mathbf{f}^{31}+\mathbf{f}^{32}+\mathbf{f}^{33}\end{bmatrix}\quad \mathbf{x}=\begin{bmatrix}\mathbf{x}^{1}\\ \mathbf{x}^{2}\\ \mathbf{x}^{3}\end{bmatrix}$$

where Z^{rs} gives the intermediate deliveries from country *r* to country *s*, where f^{rs} denotes the final demands in country *s* for goods produced by country *r*, and where x^{r} gives the gross output in country *r*. Finally, let assume that the MRIO table is extended to include a vector of sectoral emissions of GHG denoted by $\mathbf{g}^{r}$ and a vector of employment by sector $\mathbf{m}^{r}$:

$$\mathbf{g}=\begin{bmatrix}\mathbf{g}^{1}\\ \mathbf{g}^{2}\\ \mathbf{g}^{3}\end{bmatrix}\quad \mathbf{m}=\begin{bmatrix}\mathbf{m}^{1}\\ \mathbf{m}^{2}\\ \mathbf{m}^{3}\end{bmatrix}$$

The relation between $\mathbf{x}$, $\mathbf{Z}$ and $\mathbf{f}$ is defined by the accounting equation $\mathbf{x}=\mathbf{Zi}+\mathbf{f}$, where i is the column summation vector.

We can obtain the input coefficients $\mathbf{A}^{rs}=\mathbf{Z}^{rs}\left(\hat{\mathbf{x}}^{s}\right)^{-1}$, where $\left(\hat{\mathbf{x}}^{s}\right)^{-1}$ denotes the inverse of the diagonal matrix of the vector of total output. Likewise, the emissions coefficients and employment coefficients are defined as $\mathbf{e}^{r}=\left(\hat{\mathbf{x}}^{r}\right)^{-1}\mathbf{g}^{r}$ $\mathbf{d}^{r}=\left(\hat{\mathbf{x}}^{r}\right)^{-1}\mathbf{m}^{r}$ respectively.

The accounting equation can now be written as the standard input-output model: $\mathbf{x}=\mathbf{Ax}+\mathbf{f}$. For arbitrary final demands $\mathbf{f}$ the solution to the this model is given by $\mathbf{x}=\mathbf{Lf}$, where $\mathbf{L}\equiv\left(\mathbf{I}-\mathbf{A}\right)^{-1}$ denotes the Leontief inverse. The emissions and the employment would be given by

$$\mathbf{g}=\hat{\mathbf{e}}\mathbf{x}=\hat{\mathbf{e}}\mathbf{Lf} \qquad (1)$$

$$\mathbf{m} = \hat{\mathbf{d}}\mathbf{x} = \hat{\mathbf{d}}\mathbf{L}\mathbf{f} \tag{2}$$

We can write (1) in its partitionate form as

$$\begin{bmatrix} \mathbf{g}^1 \\ \mathbf{g}^2 \\ \mathbf{g}^3 \end{bmatrix} = \begin{bmatrix} \mathbf{e}^1 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{e}^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{e}^3 \end{bmatrix} \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \mathbf{L}^{13} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \mathbf{L}^{23} \\ \mathbf{L}^{31} & \mathbf{L}^{32} & \mathbf{L}^{33} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix} \tag{3}$$

Finally, from (3) we can calculate the emissions embodied in the exports $\mathbf{gexp^1}$ and imports $\mathbf{gimp^1}$ of region 1:

$$\mathbf{gexp}^1 = \mathbf{e}^1\mathbf{L}^{11}\left(\mathbf{f}^{12} + \mathbf{f}^{13}\right) + \mathbf{e}^1\mathbf{L}^{12}\mathbf{f}^{2} + \mathbf{e}^1\mathbf{L}^{13}\mathbf{f}^{3} + \mathbf{e}^2\mathbf{L}^{21}\left(\mathbf{f}^{12} + \mathbf{f}^{13}\right) + \mathbf{e}^3\mathbf{L}^{31}\left(\mathbf{f}^{12} + \mathbf{f}^{13}\right) \tag{4}$$

$$\mathbf{gimp}^1 = \mathbf{e}^2\mathbf{L}^{21}\mathbf{f}^{1} + \mathbf{e}^2\mathbf{L}^{22}\mathbf{f}^{21} + \mathbf{e}^2\mathbf{L}^{23}\mathbf{f}^{31} + \mathbf{e}^3\mathbf{L}^{31}\mathbf{f}^{1} + \mathbf{e}^3\mathbf{L}^{32}\mathbf{f}^{21} + \mathbf{e}^3\mathbf{L}^{33}\mathbf{f}^{31} \tag{5}$$

In a similar way, we can calculate the emissions embodied in imports and exports of the other 2 regions. Moreover, applying expressions (4) and (5) to (2) we would obtain embodied employment in trade.

2.2 Decomposition of the change in the emissions and employment

The Structural Decomposition Analysis is a technique that uses the information from input-output tables to decompose the change of a variable over time in its determinants, in order to analyze and understand historical changes in socio-economic or environmental indicators (see Su and Ang, 2012 for a review of the literature).

The changes in the emissions between two points in time (indicated by subscript 0 an 1) are given by $\Delta\mathbf{m} = \mathbf{m_1} - \mathbf{m_0}$, where subscripts indicate the years. Following Dietzenbacher and Los (1998) we will use the average of the polar decompositions. The two polar decompositions are:

$$\Delta\mathbf{m} = (\Delta\hat{\mathbf{e}})\mathbf{L_1}\mathbf{f_1} + \hat{\mathbf{e}}_\mathbf{0}(\Delta\mathbf{L})\mathbf{f_1} + \hat{\mathbf{e}}_\mathbf{0}\mathbf{L_0}(\Delta\mathbf{f}) = (\Delta\hat{\mathbf{e}})\mathbf{L_0}\mathbf{f_0} + \hat{\mathbf{e}}_\mathbf{1}(\Delta\mathbf{L})\mathbf{f_0} + \hat{\mathbf{e}}_\mathbf{1}\mathbf{L_1}(\Delta\mathbf{f}) \tag{6}$$

And the average of the polar decompositions[1]

$$\Delta\mathbf{m} = \frac{1}{2}\{(\Delta\hat{\mathbf{e}})(\mathbf{L_1 f_1} + \mathbf{L_0 f_0}) + [\hat{\mathbf{e}}_\mathbf{0}(\Delta\mathbf{L})\mathbf{f_1} + \hat{\mathbf{e}}_\mathbf{1}(\Delta\mathbf{L})\mathbf{f_0}] + (\hat{\mathbf{e}}_\mathbf{0}\mathbf{L_0} + \hat{\mathbf{e}}_\mathbf{1}\mathbf{L_1})(\Delta\mathbf{f})\} \tag{7}$$

Different variations of Equation (7) have been used in the literature to analyse the effects of different factors in the change of GHG emissions. However, to our knowledge, none of them includes the change in the trade structures within the determinants of the decomposition. In our case we will adapt the classical structural decomposition to decompose the change in GHG emissions into 6 factors: domestic emission coefficients, domestic technology, foreign technology, domestic final demand, foreign final demand, and trade structure trade.

The first term in (7) can be written as

$$\frac{1}{2}(\Delta\hat{\mathbf{e}})(\mathbf{x_1} + \mathbf{x_0}) = \begin{bmatrix} \Delta\mathbf{e}^1 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \Delta\mathbf{e}^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \Delta\mathbf{e}^3 \end{bmatrix} \begin{bmatrix} 1/2(\mathbf{x}_\mathbf{1}^1 + \mathbf{x}_\mathbf{0}^1) \\ 1/2(\mathbf{x}_\mathbf{1}^2 + \mathbf{x}_\mathbf{0}^2) \\ 1/2(\mathbf{x}_\mathbf{1}^3 + \mathbf{x}_\mathbf{0}^3) \end{bmatrix} \tag{8}$$

For rewriting the second term in (7) we use $\Delta\mathbf{L} = \mathbf{L_1}(\Delta\mathbf{A})\mathbf{L_0} = \mathbf{L_0}(\Delta\mathbf{A})\mathbf{L_1}$. We have then

$$\frac{1}{2}[\hat{\mathbf{e}}_\mathbf{0}(\Delta\mathbf{L})\mathbf{f_1} + \hat{\mathbf{e}}_\mathbf{1}(\Delta\mathbf{L})\mathbf{f_0}] = \frac{1}{2}\hat{\mathbf{e}}_\mathbf{0}\mathbf{L_0}(\Delta\mathbf{A})\mathbf{x_1} + \hat{\mathbf{e}}_\mathbf{1}\mathbf{L_1}(\Delta\mathbf{A})\mathbf{x_0} \tag{9}$$

Next we split $\Delta\mathbf{A}$ into separate parts as follows

$$\Delta\mathbf{A} = \begin{bmatrix} \Delta\mathbf{A}^{11} & \mathbf{0} & \mathbf{0} \\ \Delta\mathbf{A}^{21} & \mathbf{0} & \mathbf{0} \\ \Delta\mathbf{A}^{31} & \mathbf{0} & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \Delta\mathbf{A}^{12} & \mathbf{0} \\ \mathbf{0} & \Delta\mathbf{A}^{22} & \mathbf{0} \\ \mathbf{0} & \Delta\mathbf{A}^{32} & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} & \Delta\mathbf{A}^{13} \\ \mathbf{0} & \mathbf{0} & \Delta\mathbf{A}^{23} \\ \mathbf{0} & \mathbf{0} & \Delta\mathbf{A}^{33} \end{bmatrix} \tag{10}$$

The following step is to split the change in the input coefficients (equation (10)) into the change in the technological coefficients and the change in the trade coefficients. To this end, we define the country-specific technology matrix for country *s* as $\mathbf{A}^s = \mathbf{A}^{1s} + \mathbf{A}^{2s} + \mathbf{A}^{3s}$. The

[1] To keep out of the analysis the effects of changes in prices and in exchange rates, we will use MRIO tables at previous year prices for t=1 and tables at current prices for t=0.

trade coefficients are defined as $\mathbf{T}^{rs} = \mathbf{A}^{rs} \div \mathbf{A}^{s}$, where $\div$ indicates Hadamard (elementwise) division. For each intermediate input, the corresponding $\mathbf{T}^{rs}$ indicates the fraction that is imported from country r ($\neq s$) or is produced domestically (if $r = s$). Hence, we may write $\mathbf{A}^{rs} = \mathbf{T}^{rs} * \mathbf{A}^{s}$, where * is used to denote Hadamard (elementwise) multiplication. This yield the following expression for the change in $\mathbf{A}$:

$$\Delta\mathbf{A} = \frac{1}{2}\begin{bmatrix} (\mathbf{T}_0^{11} + \mathbf{T}_1^{11})\Delta\mathbf{A}^1 & \mathbf{0} & \mathbf{0} \\ (\mathbf{T}_0^{21} + \mathbf{T}_1^{21})\Delta\mathbf{A}^1 & \mathbf{0} & \mathbf{0} \\ (\mathbf{T}_0^{31} + \mathbf{T}_1^{31})\Delta\mathbf{A}^1 & \mathbf{0} & \mathbf{0} \end{bmatrix} + \tag{11.1}$$

$$\frac{1}{2}\begin{bmatrix} \mathbf{0} & (\mathbf{T}_0^{12} + \mathbf{T}_1^{12})\Delta\mathbf{A}^2 & \mathbf{0} \\ \mathbf{0} & (\mathbf{T}_0^{22} + \mathbf{T}_1^{22})\Delta\mathbf{A}^2 & \mathbf{0} \\ \mathbf{0} & (\mathbf{T}_0^{32} + \mathbf{T}_1^{32})\Delta\mathbf{A}^2 & \mathbf{0} \end{bmatrix} + \tag{11.2}$$

$$\frac{1}{2}\begin{bmatrix} \mathbf{0} & \mathbf{0} & (\mathbf{T}_0^{13} + \mathbf{T}_1^{13})\Delta\mathbf{A}^3 \\ \mathbf{0} & \mathbf{0} & (\mathbf{T}_0^{23} + \mathbf{T}_1^{23})\Delta\mathbf{A}^3 \\ \mathbf{0} & \mathbf{0} & (\mathbf{T}_0^{33} + \mathbf{T}_1^{33})\Delta\mathbf{A}^3 \end{bmatrix} + \tag{11.3}$$

$$\frac{1}{2}\begin{bmatrix} \Delta\mathbf{T}^{11}(\mathbf{A}_0^1 + \mathbf{A}_1^1) & \Delta\mathbf{T}^{12}(\mathbf{A}_0^2 + \mathbf{A}_1^2) & \Delta\mathbf{T}^{13}(\mathbf{A}_0^3 + \mathbf{A}_1^3) \\ \Delta\mathbf{T}^{21}(\mathbf{A}_0^1 + \mathbf{A}_1^1) & \Delta\mathbf{T}^{22}(\mathbf{A}_0^2 + \mathbf{A}_1^2) & \Delta\mathbf{T}^{23}(\mathbf{A}_0^3 + \mathbf{A}_1^3) \\ \Delta\mathbf{T}^{31}(\mathbf{A}_0^1 + \mathbf{A}_1^1) & \Delta\mathbf{T}^{31}(\mathbf{A}_0^2 + \mathbf{A}_1^2) & \Delta\mathbf{T}^{33}(\mathbf{A}_0^3 + \mathbf{A}_1^3) \end{bmatrix} \tag{12}$$

Finally we have the last term in (7)

$$\frac{1}{2}(\hat{\mathbf{e}}_0\mathbf{L}_0 + \hat{\mathbf{e}}_1\mathbf{L}_1)(\Delta\mathbf{f}) \tag{13}$$

Expression (13) includes $\Delta\mathbf{f}$ which can be rewritten in the same fashion as $\Delta\mathbf{A}$. That is, the final demands of country s as $\mathbf{f}^{s} = \mathbf{f}^{1s} + \mathbf{f}^{2s} + \mathbf{f}^{3s}$. The trade coefficients are defined as $\mathbf{t}^{rs} = \mathbf{f}^{rs} \div \mathbf{f}^{s}$, so that we can write $\mathbf{f}^{rs} = \mathbf{t}^{rs} * \mathbf{f}^{s}$. Note that for each product of the final demand vector, the corresponding element $\mathbf{f}^{rs}$ indicates the fraction that is imported from country r ($\neq s$) or is produced domestically (if $r = s$). This yields

$$\Delta\mathbf{f} = \frac{1}{2}\begin{bmatrix} (\mathbf{t}_0^{11} + \mathbf{t}_1^{11})\Delta\mathbf{f}^1 & \mathbf{0} & \mathbf{0} \\ (\mathbf{t}_0^{21} + \mathbf{t}_1^{21})\Delta\mathbf{f}^1 & \mathbf{0} & \mathbf{0} \\ (\mathbf{t}_0^{31} + \mathbf{t}_1^{31})\Delta\mathbf{f}^1 & \mathbf{0} & \mathbf{0} \end{bmatrix} + \tag{14.1}$$

$$\frac{1}{2}\begin{bmatrix} \mathbf{0} & \left(\mathbf{t}_0^{12}+\mathbf{t}_1^{12}\right)\Delta\mathbf{f}^2 & \mathbf{0} \\ \mathbf{0} & \left(\mathbf{t}_0^{22}+\mathbf{t}_1^{22}\right)\Delta\mathbf{f}^2 & \mathbf{0} \\ \mathbf{0} & \left(\mathbf{t}_0^{32}+\mathbf{t}_1^{32}\right)\Delta\mathbf{f}^2 & \mathbf{0} \end{bmatrix} + \qquad (14.2)$$

$$\frac{1}{2}\begin{bmatrix} \mathbf{0} & \mathbf{0} & \left(\mathbf{t}_0^{13}+\mathbf{t}_1^{13}\right)\Delta\mathbf{f}^3 \\ \mathbf{0} & \mathbf{0} & \left(\mathbf{t}_0^{23}+\mathbf{t}_1^{23}\right)\Delta\mathbf{f}^3 \\ \mathbf{0} & \mathbf{0} & \left(\mathbf{t}_0^{33}+\mathbf{t}_1^{33}\right)\Delta\mathbf{f}^3 \end{bmatrix} + \qquad (14.3)$$

$$\frac{1}{2}\begin{bmatrix} \Delta\mathbf{t}^{11}\left(\mathbf{f}_0^1+\mathbf{f}_1^1\right) & \Delta\mathbf{t}^{12}\left(\mathbf{f}_0^2+\mathbf{f}_1^2\right) & \Delta\mathbf{t}^{13}\left(\mathbf{f}_0^3+\mathbf{f}_1^3\right) \\ \Delta\mathbf{t}^{21}\left(\mathbf{f}_0^1+\mathbf{f}_1^1\right) & \Delta\mathbf{t}^{22}\left(\mathbf{f}_0^2+\mathbf{f}_1^2\right) & \Delta\mathbf{t}^{23}\left(\mathbf{f}_0^3+\mathbf{f}_1^3\right) \\ \Delta\mathbf{t}^{31}\left(\mathbf{f}_0^1+\mathbf{f}_1^1\right) & \Delta\mathbf{t}^{31}\left(\mathbf{f}_0^2+\mathbf{f}_1^2\right) & \Delta\mathbf{t}^{33}\left(\mathbf{f}_0^3+\mathbf{f}_1^3\right) \end{bmatrix} \qquad (15)$$

We are now able to combine the different parts of the decomposition. We have

$$\Delta\mathbf{m} = \begin{bmatrix} \Delta\mathbf{m}^1 \\ \Delta\mathbf{m}^2 \\ \Delta\mathbf{m}^3 \end{bmatrix} \qquad (16)$$

For country 1, the change in its GHG emissions ($\Delta\mathbf{m}^1$) can be decomposed in the following six factors:

1. the change in emission coefficients of country 1: $\frac{1}{2}\Delta\mathbf{e}^1\left(\mathbf{x}_1^1+\mathbf{x}_0^1\right)$ (see equation (8));

2. the change in technology in country 1: the first n elements of (9) combined with (11.1);

3. the change in technology abroad: the first n elements of (9) combined with (11.2) and of of (9) combined with (11.3);

4. the change in the final demands in country 1: the first n elements of (13) combined with (14.1);

5. the change in the final demands abroad: the first n elements of (13) combined with (14.2) and (13) combined with (14.3);

6. the change in the trade structure: the first n elements of of (9) combined with (12) and (13) combined with (15)

Analogously, we can decompose the changes in the emissions of the other regions.

These six determinants can be combined in several ways. Since our objective is to analyze the role of trade in the change of GHG emissions, we propose aggregate them into the following three factors:

1. the change in domestic technology would include both the changes in the emission coefficients[2] of the country analysed and the changes in its technology (factors 1 and 2)

2. the change in domestic final demands (i.e. changes in the final demand of the country analysed) (factor 4)

3. the changes related to trade, including all the changes that are directly or indirectly favoured by trade, namely the change in technology abroad (factor 3), the change in the final demands abroad (factor 5), and the change in the trade structure (factor 6).

3. Results

The following sections summarize the results of the decomposition of the change in the emissions of world's main economies between 1995 and 2008, and the quantification of the emissions and employment embodied in international trade

3.1. Main drivers of the change in GHG emissions

In 2008, world's GHG emissions total 39.3 Giga tonnes of CO_2 equivalents ($GtCO_2e$). China is the country that emits most GHG in the world (21%, 8.4 $GtCO_2e$), followed by USA (16%, 6.4 $GtCO_2e$), the EU (13%, 5.2 $GtCO_2e$), Russia (6%, 2.3 $GtCO_2e$) and India (6%, 2.3 $GtCO_2e$). These five regions account for more than 60% of global GHG emissions. Between 1995 and 2008, the world GHG emissions increased by 29%, releasing additional 8.9 $GtCO_2e$.

[2] Note that changes in emissions coefficients are ultimately linked to changes to more or less efficient/clean technologies.

Data by country reveals that China is the country that most contributed to this increase (3.8 $GtCO_2e$), succeeded by India (0.8 $GtCO_2e$), USA (0.4 $GtCO_2e$) and Brazil (0.24 $GtCO_2e$). In the EU, the emissions of GHG slightly decreased by 0.3% (-0.17 $GtCO_2e$).

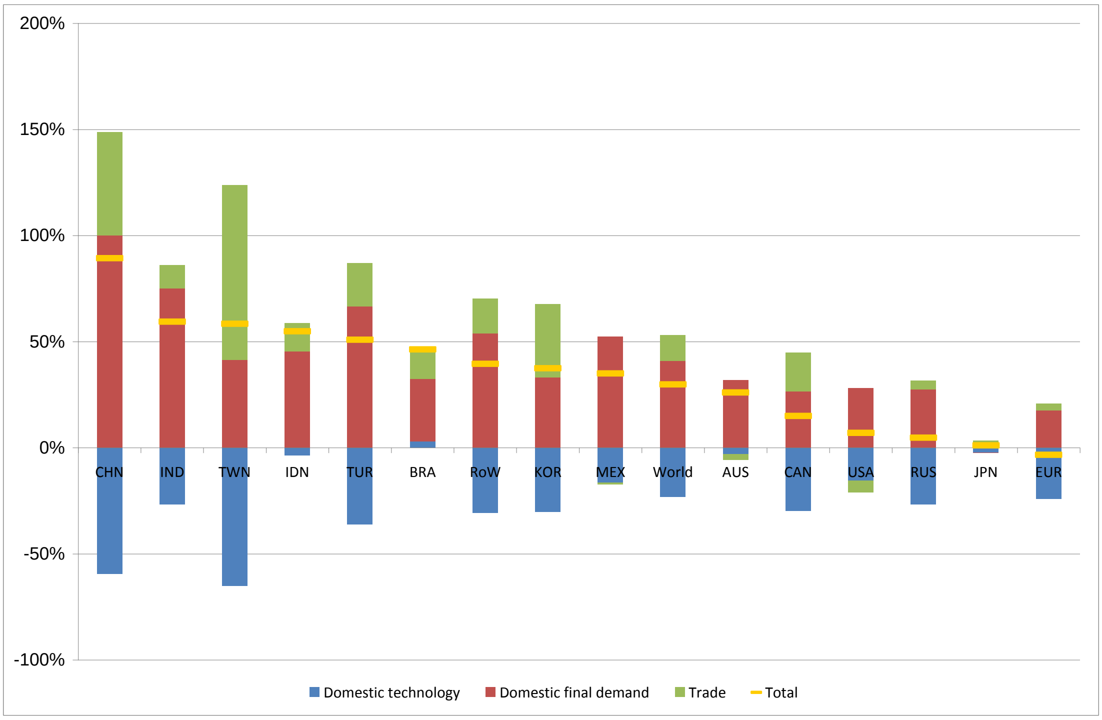
According to data reported in Figure 1, the change in the domestic final demand was the main driver for the growth in global GHG emissions, contributing to an increase of 41% (12.7 $GtCO_2e$) compared to 1995. Changes linked to international trade caused a growth of 12% (3.7 $GtCO_2e$) in GHG emissions, while technological change contributed to reduce the emissions by 23% (-7.3 $GtCO_2e$).

At the country level, between 1995 and 2008 the evolution of emissions is mainly driven by the growth in the level of domestic final demand. In China, domestic final demand contributed to double the emissions. The changes in the emissions of India, Turkey and Mexico were also mostly affected by the growth in their domestic final demand.

Trade plays a secondary but relevant role in the change of GHG emissions. International trade was particularly relevant for the evolution of the emissions in the Asian economies. In China, the country with the highest growth in emissions due to trade (2.1 $GtCO_2e$), trade contributed to increase the emissions by 50%; while in Taiwan and Korea the contribution of trade rose to 82% and 35% respectively. Finally, in Japan trade was also the main driver for the change in the emissions, but in this case its contribution limited to 3%. On the other hand, in only 3 of the world's main economies, namely United States, Australia and Mexico, trade contributed to reduce the emissions.

Technological change contributes notably to offset the effects of domestic final demand and trade on emissions. In China the changes in domestic technology reduced the emissions by 2.6 $GtCO_2e$ (-59% compared to 1995). Taiwan was the country in which technology contributed most to reduce the emissions. The EU is the only main economies that shows a reduction in the emissions during the period analysed (-3%). In this case, technological change totally offset the positive effect on emissions of the domestic final demand and the international trade.

Figure 1. Main drivers of the change in GHG emissions, 1995-2008



3.2 GHG generated by trade

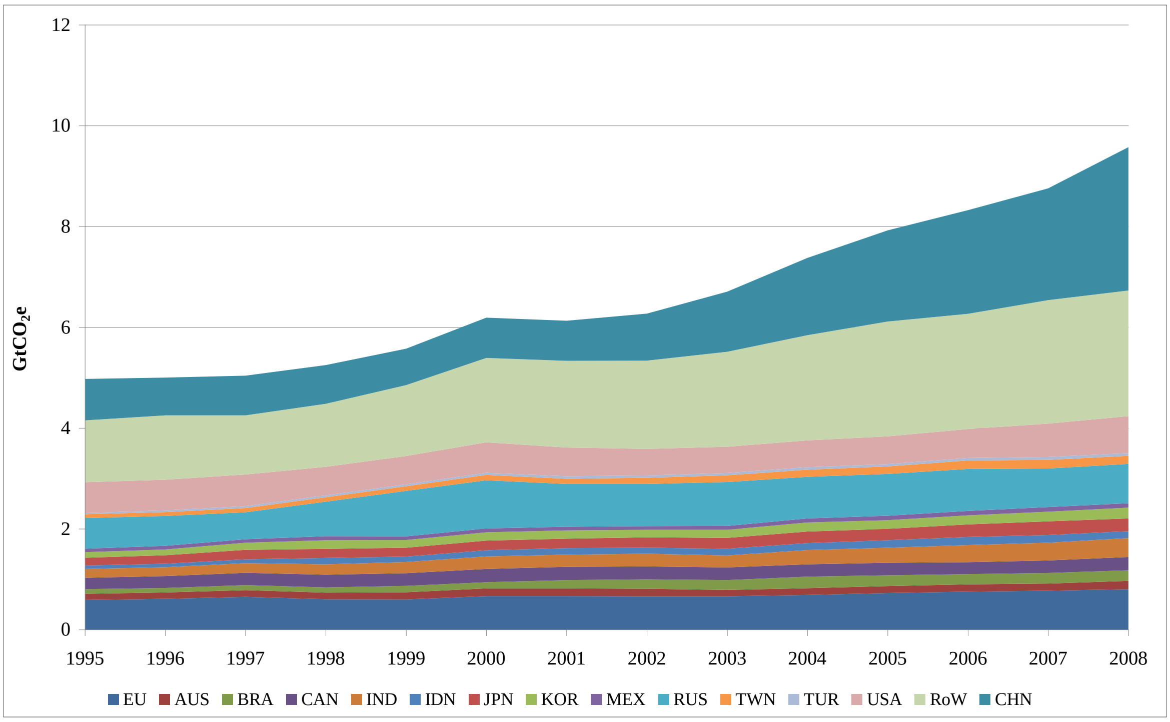
Between 1995 and 2008, the volume of global GHG emissions linked to trade almost doubled, passing from 4.8 $GtCO_2e$ (16% of total emissions) to 9.6 $GtCO_2e$ (24% of total emissions) (Figure 2).

China is the country with the highest growth in the embodied emissions in exports and is also the world's largest exporter of emissions. Between 1995 and 2008, Chinese exports of GHG increased by a factor of 3.5, from 0.8 $GtCO_2e$ to 2.8 $GtCO_2e$ (42% of the growth in the global trade on emissions). In 2008 China exported 225 $GtCO_2e$, this figure represents 30% of the total GHG embodied in international trade.

In this same period, the emissions exported by the RoW doubled from 1.2 $GtCO_2e$ to 2.5 $GtCO_2e$ (26% of global exports). In 2008, the EU exported 0.8 $GtCO_2e$ (16% of its domestic emissions) compared with 0.6 $GtCO_2$ in 1995. The EU exports 8.4% of the worldwide emissions embodied in international trade, Russia contributes to 8.1% and USA to 7.7%.

India also contributed notably to the increase in the emissions embodied in international trade. Between 1995 and 2008 the emissions exported by India rose by 0.2 $GtCO_2e$. Taiwan is the country that exports the highest share of its domestic emissions (50%), followed by Canada (38%), Korea (35%), China (34%), Russia (33%) and Australia (30%).

Figure 2: Emissions embodied in exports, 1995 and 2008. ($GtCO_2e$)

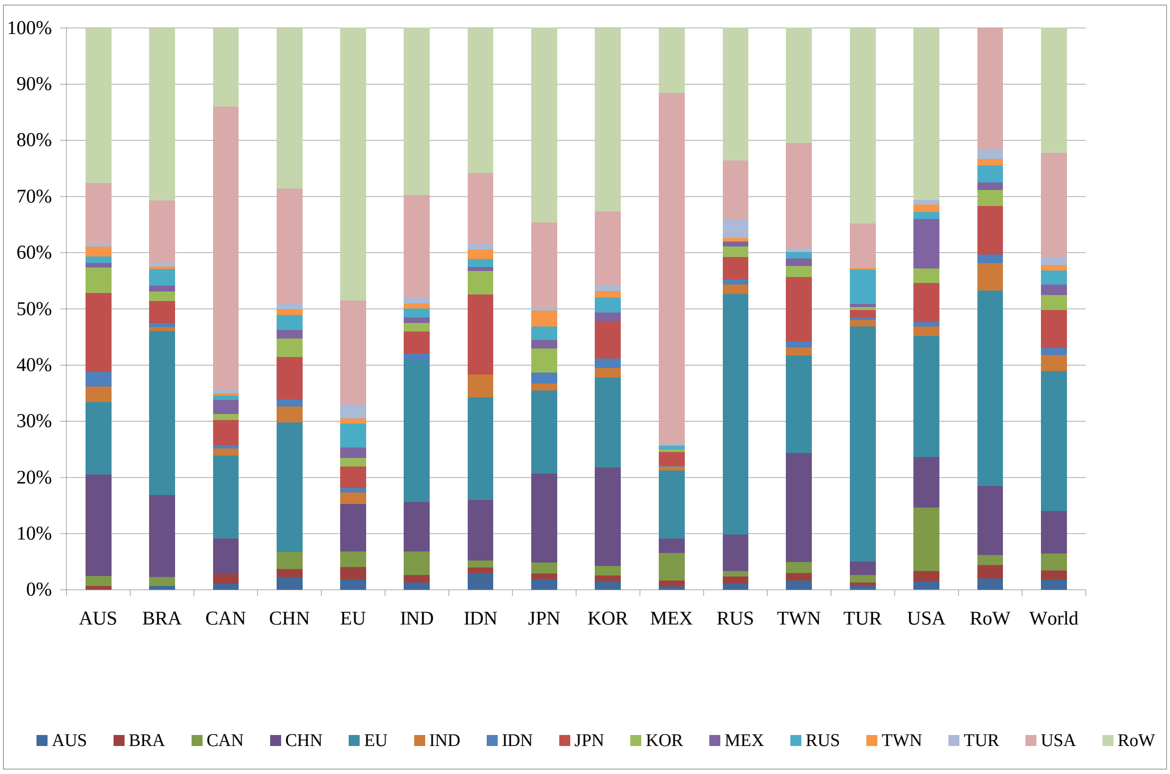


Note: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; EU: European Union; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RoW: Rest of the World; RUS: Russia; TWN: Taiwan; USA: United States of America.

Figure 3 depicts for the main world economies the destination (importer) country of exported emissions in 2008. The EU turned out to be the main destination for the global emissions generated by international trade (25% of total emissions traded) followed by the USA (18%), China (8%) and Japan. (7%). The EU and USA are the destination regions for respectively 23% and 21% of the Chinese exports of GHG emissions. The main importer regions of emissions from the RoW are the EU (35), USA (21%), China (12%) and Japan (9%). Half of the emissions exported by the EU are addressed to the RoW, 18% to USA and 8% to China. The main trade partners of the USA in terms of exports of GHG are the RoW (31%), the EU

(22%), Canada (11%), China (9%) and Mexico (9%). USA imports 62% of the emissions exported by Mexico and 50% of Canadian exports of GHG.

Figure 3: Emissions embodied in exports: shares by destination country, 2008



The emission trade balance allows analyzing to what extent a country is a net exporter or importer of emissions. If the emissions embodied in the exports of one country are larger than those embodied in its imports the country will be a net emission exporter and, therefore, it will have an emission surplus. Otherwise, the country will be a net importer and will show an emission deficit.

According to data reported Figure 4, the evolution of the emission trade balance shows an increasing gap between countries that produce emissions and countries that consume the exported goods. In 2008, the EU is the region with the largest emission deficit: 1.5 $GtCO_2e$ (0.8 in 1995). This deficit is equivalent to 31% of the emissions generated within the EU (16% in 1995). The emission trade balance of USA shows an increase in the deficit from 0.4 $GtCO_2e$ in 1995 (6% of its national emissions) to 1 $GtCO_2e$ in 2008 (16% of its domestic emissions). In Japan the emission deficit has decrease from 0.5 $GtCO_2e$ (40% of its emissions) to 0.4 $GtCO_2e$ (32% of its national emissions).

The emission surplus of China is supporting the growth in the emission deficit of the EU and USA. In 2008 China is the world's largest net exporter of emissions, with a surplus of 2.1 $GtCO_2e$ (25% of its total emissions). This surplus has increased by a factor of 3 since 1995. Russia (0.5 $GtCO_2e$), the RoW (0.4 $GtCO_2e$) India (0.1 $GtCO_2e$) follow China in the rank of the net emissions exporters.

Figure 4. GHG emission trade balance, 1995 and 2008. ($GtCO_2e$)

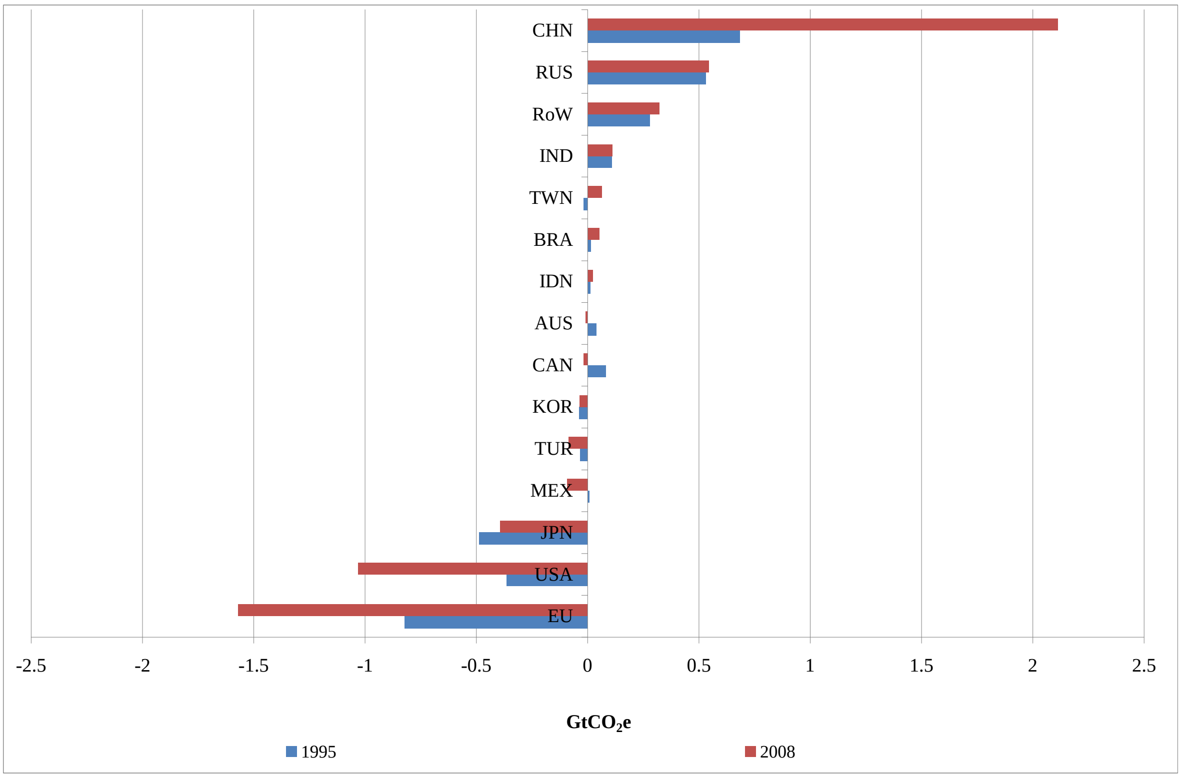


Table 1 columns 2nd and 3rd, depicts the share of GHG embodied in international trade by commodity and sector. On the one hand, the commodities which generated the largest part of the emissions embodied in trade were electrical and optical equipment (12.4%), mining and quarrying (11.6%), basic and fabricated metals (10.9%), chemical products (9.6%) and agricultural products (6.3%) (Table 1, 2nd column). This commodity rank does not match with the sector rank (Table 1, 3rd column). From a sector viewpoint, 28.7% of traded emissions were generated by electricity, gas and water supply, 13.6% by mining and quarrying, 12.6% by agriculture, 10% by basic and fabricated metals, and 7% by chemical products.

Table 1. GHG emission and employment embodied in exports: 2008.

	Share of GHG emissions embodied in exports		Share of employment emissions embodied in exports		Employment in exports / Emissions in exports (jobs / 1000 tCO_2e)	
	Good	Sector	Good	Sector	Good	Sector
Electrical and Optical Equipment	12.4%	0.8%	11.7%	4.1%	55	297
Mining and Quarrying	11.6%	13.6%	6.3%	6.6%	32	29
Basic Metals and Fabricated Metal	10.9%	10.0%	4.5%	2.9%	24	17
Chemicals and Chemical Products	9.6%	7.0%	4.3%	1.7%	26	14
Agriculture, Hunting, Forestry and Fishing	6.3%	12.6%	13.8%	34.9%	129	163
Coke, Refined Petroleum and Nuclear Fuel	5.8%	4.0%	2.0%	0.2%	20	3
Transport Equipment	4.6%	0.4%	4.0%	1.3%	51	189
Textiles and Textile Products	4.5%	0.7%	10.8%	5.1%	140	448
Machinery, Nec	4.4%	0.4%	3.8%	1.8%	51	278
Food, Beverages and Tobacco	4.3%	0.5%	8.7%	1.6%	118	180
Water Transport	3.3%	3.9%	1.0%	0.5%	18	7
Manufacturing, Nec; Recycling	2.8%	1.2%	4.5%	2.6%	94	127
Inland Transport	2.7%	4.0%	1.7%	3.6%	37	52
Renting of M&Eq and Other Business Activities	2.6%	0.8%	4.6%	4.2%	104	317
Other Non-Metallic Mineral	2.1%	3.5%	0.6%	0.7%	18	11
Air Transport	2.0%	2.2%	0.8%	0.3%	23	8
Rubber and Plastics	1.8%	1.2%	1.8%	1.9%	58	94
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	1.4%	0.3%	2.4%	3.4%	99	582
Electricity, Gas and Water Supply	1.3%	28.7%	0.1%	0.7%	6	1
Other Community, Social and Personal Services	1.0%	2.0%	2.4%	6.3%	141	188
Rest	4.5%	2.2%	10.3%	15.5%	135	423
Total	100.0%	100.0%	100.0%	100.0%	59	59

3.3. Employment generated by trade

The increase in the volume of international trade has also impacted the employment around the world. In 2008 international trade generated 605 million jobs worldwide (20% of total employment). The total employment generated by trade increased by 271 million jobs between 1995 and 2008.

China is the country that benefitted most from the increase in international trade: between 1995 and 2008, the number of workers devoted to exports doubled (from 112 million to 225 million) (Figure 5). In the RoW the number of jobs embodied in exports grew by 94 million to a total of 201 million workers. India (with 29 million of new jobs), the EU (11 million), Brazil (6.2), Indonesia (5.9) and Japan (2.7) also benefited notably from the growth in the number of jobs generated by exports.

In 2008 almost 29% of the total employment in China was generated by exports (16% in 1995). In this same year, the production of exports generated 201 million of jobs in the RoW, 63 million in India, 30 million in the EU and 17 million in Brazil.

In 2008, Taiwan (39%), China (29%) and Korea (24%), Row (23%) and Canada (21%). are the countries with the highest share of the total employment devoted to exports. In the rest of the countries analysed this share is bellow the world average (20%): 13% in the EU, 12% in Japan and 8% in USA.

Figure 5: Employment embodied in exports, 1995 and 2008 (Million jobs)

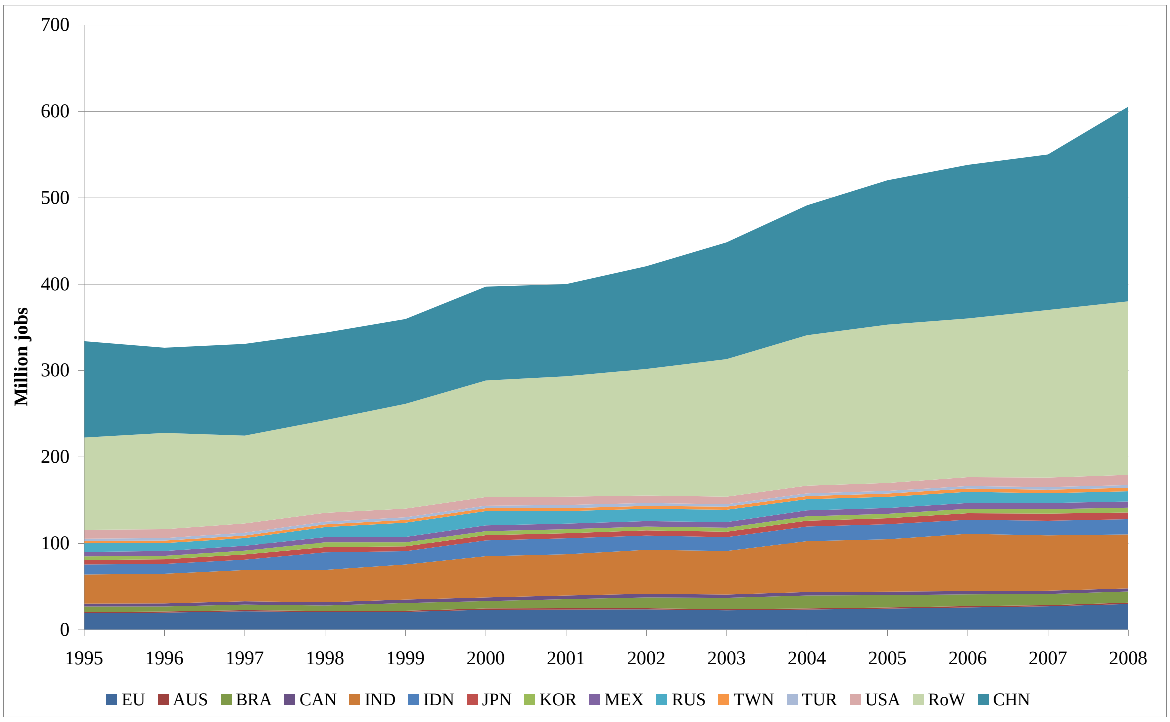


Figure 6 shows the share of the employment embodied in exports by country in relation to the importing region for the year 2008. The results in terms of employment embodied in trade are very similar to those of GHG emissions. The EU is the leading geographical area in creating jobs elsewhere through imports: almost 28% (165 million jobs) of the total employment generated by international trade was due to EU imports. China and India were the countries that most benefitted from EU imports, being the number of jobs generated in these countries 55 million and 18 million, respectively. USA generated 20% of the employment embodied in trade while China 7%.

The employment generated by trade in the RoW is mainly linked to the exports to the EU (36%), USA (21%) and Japan (8%). In China, the exports to the RoW generated 28% of the Chinese employment devoted to exports, while the exports to the EU and USA occupied 25% and 20% of the export-oriented labour force respectively.

Almost 50% of the employment generated by international trade in EU is linked to the exports to the RoW, 17% to USA and 10% to China. The main trade partners of the USA in terms of employments embodied in exports are the RoW (35%), the EU (23%), Canada (11%), China (8%) and Mexico (7%). Finally, the exports to the USA generate 59% of the jobs linked to trade in Mexico and 55% in Canada.

Figure 6: Employment embodied in exports: shares by destination country, 2008

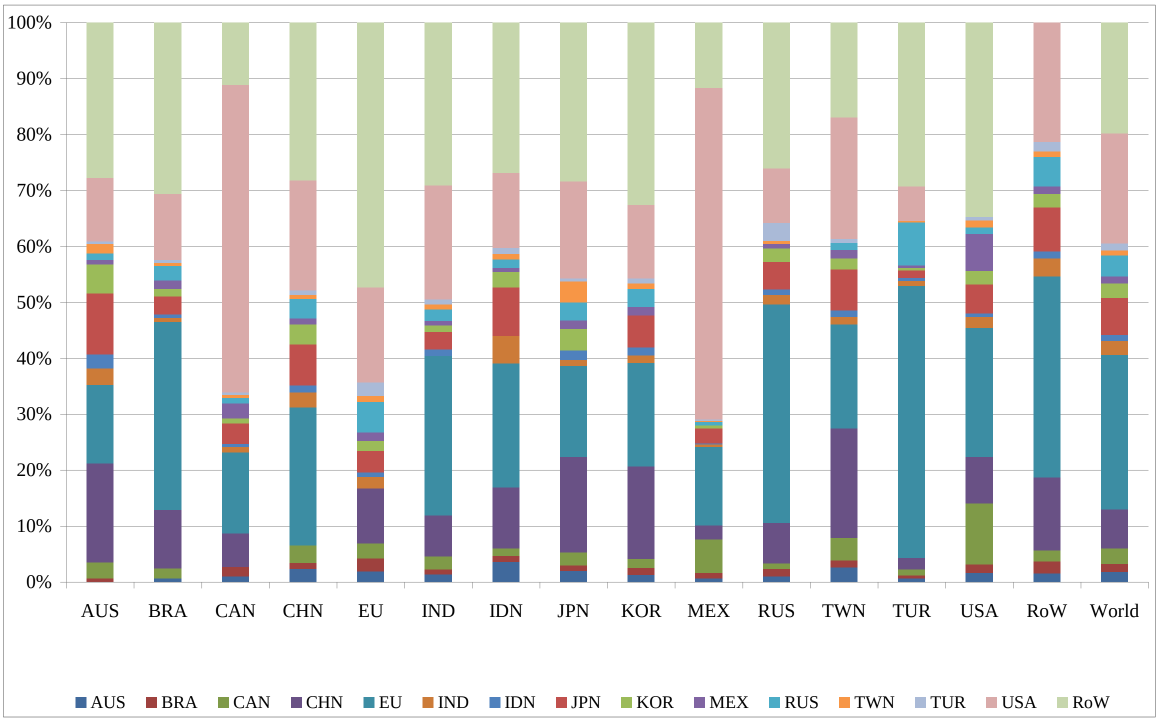


Table 1 columns 4th and 5th, show the share of the employment embodied in international trade by commodity and sector. The commodities which contributed to generate the largest part of the employment embodied in trade worldwide were agricultural products (13.8%), electrical and optical equipment (11.7%), textiles (10.8%), food, beverages and tobacco (8.7%), and mining and quarrying (6.3%). By sector, 34.9% of the employment embodied in exports is generated in agriculture, 6.6% in mining, 6.3% in other services, and 15.5% in a group of sectors in which services predominates.

4. Discussion

Our analysis reveals that the largest part of the increase in GHG has been driven by changes in the final demand. However, although international play a secondary role in the growth of GHG emissions, it should not be ignored when assessing the options for reducing global GHG emissions, since 24% of global GHG emissions are linked to trade. When doing that, it should bear in mind that 20% of the employment around the world is generated by international trade.

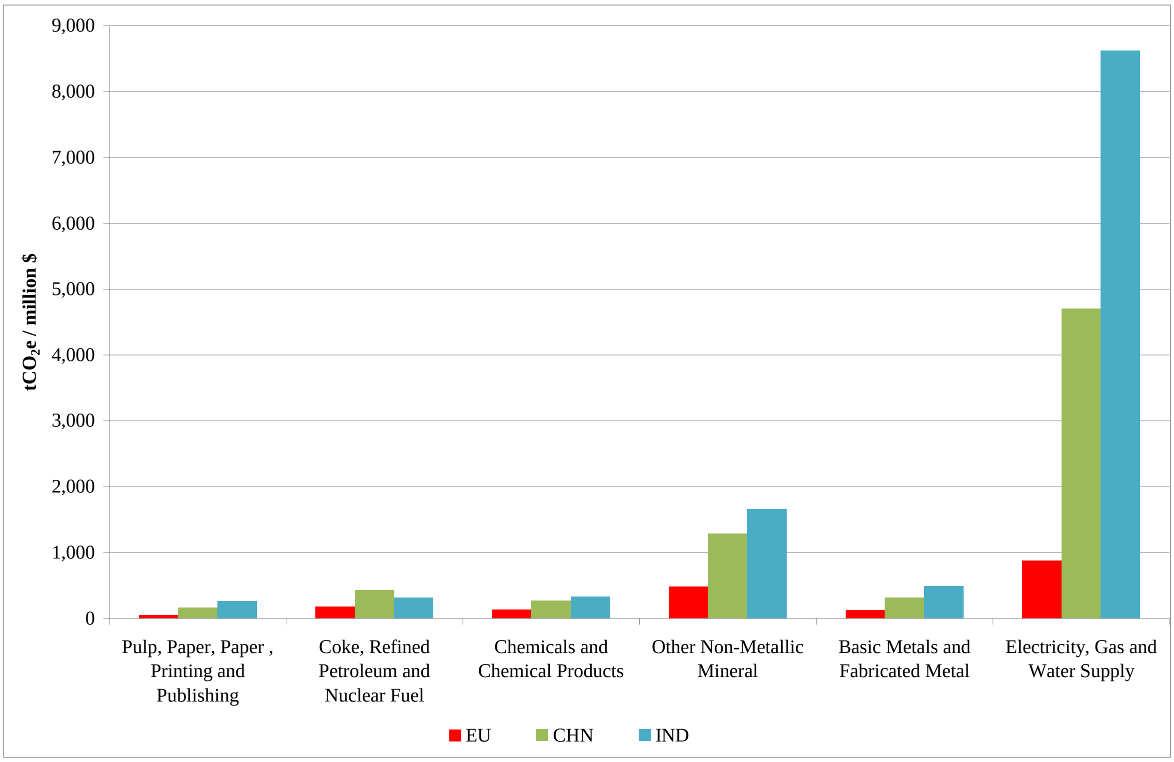
One way of incorporating international trade into fight against climate change could be by allocating reduction targets following the "consumer responsibility" principle. According to this approach, countries would be responsible for the emissions imported and should developed policy measures to abate those emissions. In such a case, they would probably concentrate their efforts on reducing the imports of those goods with highest emissions, without taking into account the economic impacts in the exporting countries. For instance, at the global level, the imports of electrical and optical equipment (which account for 12.4% of global trade in emissions) would be a candidate for the implementation of policy instruments, such as carbon taxes, to reduce the emissions imported. The effects of this type of policy measures in the employment of the exporting countries could be relevant, since the exports of electrical and optical equipment generates 11.7% of the total employment embodied in trade. In this case, for each 1000 tCO_2e reduced 55 jobs would be lost (see Table 1, column 6th).

From a global perspective, it would be better to prioritize measures oriented to those commodities with the greatest potential for reducing the emissions and the least impact on employment or, in other words, with the highest emissions intensities per job (Table 1, column 6th). For instance, trade of basic metals and fabricated metals represents 10.9% of global exports of GHG, but only 4.5% of the employment embodied in exports, and its ratio of employment to emissions is 24 jobs/1000 tCO_2e. One way of favouring the reduction of the emissions embodied in trade, minimizing the economic impact on exporting countries, would be sharing the responsibility within the trade partners.

On the other hand, there is a range of policy options based on the sectors involve in the production of the exports rather than on the commodities exported that should also be explored. For example, the reduction of the emissions on the electricity and gas sector could be very positive in environmental and economic terms. Although the emissions embodied in the exports of the products of the electricity and gas sector only represent 1.3% of traded emissions, almost 30% of the emissions embodied in international trade are generated by the electricity sector when producing the electricity and gas used for producing the exports. Moreover, the electricity sector shows the smallest elasticity of the employment to changes in the emissions (1 job/1000 tCO_2e), i.e. a drop in the consumption of electricity involving a reduction of 1000 tCO_2e would imply the lost of 1 job.

The reduction of the emissions embodied in exports at the sectoral level could be based on the improvement of the production technologies. Although technological change has contributed notably to offset the growth in GHG emissions in the last years, there is still room for progress in this direction. The change in the emissions due to the technological change is closely related to the reduction of the emission intensity of the economy, measured as the quotient between the emissions and the gross output. Figure 7 shows emissions intensities in the EU, China and India for the most emission intensive industries of the manufacturing sector. For all the sectors analyzed, in China and India the ratio of GHG emissions per unit of output is higher than in the EU. The gap existing between China and India with respect the EU could be interpreted as the improvement potential (in terms of cleaner technologies) of these emerging economies. This gap is especially relevant for the electricity sector.

Figure 7: Gap of the sectoral GHG emissions per unit of output in China and India with respect the EU, 2008. (tCO_2e/million $)



At the country level, the EU occupies a central position in the global exchange of employments and emissions. In the year 2008, the EU ranked 3rd in employment embodied in exports and 2nd in GHG embodied in exports. The EU was the region that generates the largest amount of employment abroad through imports (165 million jobs, 28% of the total employment generated by international trade) and was the largest GHG emissions importer around the world (2.4 $GtCO_2e$, 25% of traded emissions). The EU was the region with the largest emission deficit: 1.5 $GtCO_2e$, equivalent to 30% of the emissions generated within the EU. In addition, the EU is the leading region in the world in terms of clean technologies.

China and USA could be encouraged to play an important role in reducing the emissions embodied in international trade. China is the country that has contributed most to the growth in GHG emissions. Between 1995 and 2008, more than 40% of the increase in global GHG emissions took place in China. In 2008, 20% of the change in Chinese emissions was linked to international trade, and China exports 34% of its national emissions. China was the world largest net exporter of emissions, with a surplus of 2.1 $GtCO_2e$ (25% of its total emissions). In terms of employment, China was the country that benefitted most from the increase of international trade, 29% of Chinese total employment was linked to exports. In 2008, USA ranked 2nd in terms of GHG emissions and had the 2nd largest emissions trade deficit.

Finally, these results show the importance of policies oriented to share the emissions responsibilities embodied in trade between producers and consumers countries. If from one side, importing countries obtains environmental benefits by displacing emissions outside the national borders, on the other side, exporter countries benefits for employment generation. For this reason, it is even more important to extend the emissions reduction debate by including into the analysis the environmental benefits obtained by importing countries but also the economic benefits obtained by exporter countries.

5. Reference

Davis S., Caldeira K., 2010. Consumption-based accounting of CO2 emissions. Proceedings of the National Academy of Sciences of the USA, 107: 5687-5692.

Hertwich E.G., Peters G.P., 2009. Carbon footprint of nations: A global trade-linked analysis.Environmental Scinece and Technology 45: 6414-6420

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by te National Greenhouse Gas Inventories Programme (Institute for Global Environmental Strategies, Japan).

Le Quere, C., Raupach, M.R., Marland, G., Bopp, L., et al., 2009. Trends in the sources and sinks of carbon dioxide. Natural Geoscience 2:832-836

Muradian, R., O'Connor, M., Martinez-Alier, J., 2002. Embodied pollution in trade: Estimating the "Environmental load displacement"of industrialised countries. Ecological Economics 41: 51-65

Raupach M.R., 2007. Global and regional drivers of accelerating CO_2 emissions. Proceedings of the National Academy of Sciences 104: 10288-10293

Su, B., Ang, B.W., 2012. Structural decomposition analysis applied to energy and emissions: Some methodological developments. Energy Economics 34: 177-188

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecolocigal Economics 65: 13-23

Peters, G.P., Minx, J.C., Weber, C.L., Edenhofer, O., 2011. Growth in emission transfer via international trade from 1990 to 2008. Proceedings of the National Academy of Sciences of the USA 108: 8903-8908.

Peters, G.P., Marland, H., Hertwich, E.G, Saikku, L., Rautiainen, A., Kauppi, P., 2009. Trade, transport and sinks extend the carbon dioxide responsibility of countries. Climate Change 97: 379-388

Sousa, N., Rueda-Cantuche, J.M., Arto, I. and Andreoni, V, 2012. Extra-European exports and employment. Chief Economist Note, DG TRADE, European Commission: Brussels (forthcoming).

United Nations Framework convention on Climate Change, 1997. The Kyoto Protocol to the United Nations convention on Climate Change.

Weber, C.L., Peters, G.P., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36: 3572-3577

Wiedmann, T., 2009. A review of recent multi-region input-output models used for consumption-based emission and resource accounting. Ecological Economics 69: 211-222

Wiedmann, T., Wilting, M., Lenzen, M., Lutter, S., Viveka, P., 2011. Quo Vaqdis MRIO? Methodological, data and institutional requirements for multi-region input-output analysis. Ecological Economics 65: 15-26.