Pollution haven hypothesis in emissions embodied in world trade: The relevance of global value chains

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Abstract

Pollution haven hypothesis (PHH) occurs when the growth of international trade leads to an increase in emissions because countries specialize in producing polluting goods. The avoided emissions balance between a country with other countries of the world, i.e. the difference between the emissions embodied in exports in the country minus imports avoided by imports, allows us to evaluate if PHH occurs or not. A positive balance indicates that the country's trade increases global emissions. In contrast, a negative balance indicates that emissions trading by this country are reduced because the country specializes in less polluting products. However, the trade growth cannot be explained only by the increase of final goods and raw materials trade, it is also explained by the increasing fragmentation of production at different production stages and, therefore, trade in inputs that are part of successive stages of production. In this paper we propose a multi-regional input-output model (MRIO) that disaggregates the avoided emissions balance and allows us to analyze how much the trade in final goods or inputs linked to global value chains are responsible or not in the generation of PHH. The implementation of the multi-regional model proposed involves the use of World Input-Output Database (WIOD), which provides information on input-output tables for 3 and 7 regions between 1995 and 2009, with a disaggregation to 35 industries, well as information about energy goods consumption and CO_2 emissions by industry.

Keywords: Pollution Haven Hypothesis, Global Value Chain, multiregional input-output.

1. Introduction

Free trade of final goods, natural resources and parts and components is good for economic growth and for people in the market, but it could be bad for environment. Not because consumers in rich countries are responsible for the destruction of biodiversity in developing countries (Lenzen et al., 2012) and deforestation of the Amazon Rainforest (Karstensen et al., 2013). Not because this trade involves movement of raw materials from countries with natural resources towards countries that require these resources to produce, that in terms of petroleum represents the trading of 37% of their emissions in 2007 (Davis et al., 2011). Not because the emissions embodied in exports represent 20% of global CO2 emissions in 1990 and in 2008 reach represent 26% of global emissions (Peters et al., 2011), because firms have set their global value chains on the search of comparative advantages in each stage of the production and, for example, emissions embodied in processing exports represent 35% of virtual carbon in Chinese exports in 2011 (Dietzenbacher et al., 2012, Su et al., 2013). Behind the mentioned effects we can find a global GDP growth without precedents, which is multiplied by seven the last 50 years of XX century, associated with further increase in the growth of international trade (WTO, 2007), and requires a growing of resources demand and generates more waste. International trade would be inducer of environmental degradation but only on the extent that the welfare gains and productivity generated have accelerated global economic growth.

The fact that the virtual carbon, water and materials embodied in international trade grow faster than other economic indicators, like GDP and population (Peters et al., 2011) or international transport also grows faster than virtual carbon incorporated in those goods is an indication of the adverse effects of international trade on the environment (Cadarso et al., 2010, Cristea et al., 2013, Böhringer et al., 2013). In order to isolate the effect of international trade on the environment, in this paper we propose a multi-regional input-output methodology (MRIO) which allows evaluating, through a counterfactual, what would have happened in a world without international trade and if the growth of international trade have resulted in greater or lower environmental footprint and allows to identify the role of countries, industries and final demand agents. The appropriate identification of the factor content in international trade, value added, CO_2 emissions, soil or other, is important to assess its impact and the methodology based on the input-output framework is useful because prevents the double counting of intermediate inputs (Jonhson y Noguera, 2011, Trefler and Zhou, 2012).

The methodology proposed represents the generalization of the Balance of avoided emissions (BAE), proposed in López et al. (2013) for a bi-regional input-output model (BRIO), that differentiates between domestic emissions embodied in exports minus total avoided emissions in other countries via imports of final and intermediate goods, considering domestic emissions that each region generate depending on their role in global value chains. This balance is useful to assess the factor content in international trade and, therefore, we call from now balance of avoided factor content (BAFC). The cancelation of volume of trade in this (BAFC/BAE) implicate that we can evaluate how the impact on climate change from trade depends of advantages comparatives in emissions of different countries and the sectorial composition of trade, but not of trade´s volume (similarly, but alternatively of Jakob and Marschinski, 2012). Specifically, the application in this paper is made on the carbon embodied in trade but also may be done to the water or soil embodied in trade, or deforestation, ecological footprint, etc.

A positive sign of BAFC is indicates that international trade would have been a pollution haven for firms, which under different legislation, have been dedicated to satisfying consumption requirements of an increasing world population, inducing the carbon leakage phenomenon via competitiveness (Borghesi, 2011; Antimiani et al., 2012), a weak carbon leakage (Peters and Hertwich, 2008). We would have a pollution haven hypothesis (PHH), in the path of Copeland and Taylor (2004), and international trade, would be responsible, in conjunction with economic growth, of the deterioration of the Earth. In our case, considering virtual carbon, incorporates both direct and indirect domestic emissions embodied in trade, which explain most of virtual carbon embodied in trade, responsible of the environmental degradation (López et al., 2013) and is important too because the trade of non-energy-intensive goods is an important part of the growth in emissions embodied in international trade (Peters et al., 2011).

Other previous studies have calculated the balance of avoided emissions using bi-regional models, Dietzenbacher and Mukhopadhyay (2007), Peters et al. (2007), Ackerman et al. (2007), and multi-regional models (Zhang, 2012). The papers based on bi-regional models are adequate when we want to measure the impact of international trade between two regions, because considered only emissions / factor content between two countries considered but do not take account the origin of imports and could be using more polluting suppliers (Ackerman et al., 2007). The multiregional framework is adequate to assess the factor content in the different stages of production that compose global value chains (Turner et al., 2007, Peters et al., 2010, or Kanemoto et al., 2012), be they factors associated with the environment (Steen-Olsen et al., 2012, Moran et al., 2013), associated with value added (Johnson and Noguera, 2012) or work by skill levels.

The analysis is done for 3 and 7 regions of the world (UE, NAFTA, China, East-Asia, BRIIAT and the Rest of the world), between 1995 and 2009, using the information provided by WIOD database. The relevance of these studies is that, beyond exists multilateral agreement such as the Kyoto Protocol, mitigation policies occur among main world regions (Chen y Chen, 2011). In this sense, in The President´s Climate Action Plan (2013) of EEUU can read about the historical agreement reached into USA and China to phase down the consumption and production of HFCs or recognized the needs to do agreement with China and Indian to development clean coal electricity technology and to improve the carbon sequestration. Other case, are the negotiating about a free trade agreement the United States and the European Union that occurs in 2013.

This paper is organized as follows: In section 2 we development the methodology of (BAFC/BAE) and we comment the databases that we used. Section 3 presents the main results. Finally, in section 4 we conclude and discussed the results.

2. Methodology

The trade balance of an economy measures the difference between the value of goods and services exported to other economies and the value of goods and services imported from other economies. The aggregate trade balance may be disaggregated by commodities or industries. Whether we measure the trade balance in value or quantity terms, its information unambiguous. The trade balance of a can be positive, negative, or zero. For the global economy as a whole, the trade balance is zero, since the exports of one country are the imports of another country and planet Earth does not (yet) trade with other planets[1]. The trade volume, however, has grown significantly in recent decades, not only in absolute terms but also in relation to the level of global production.

Whereas the trade balance in value terms is calculated according to a standardised procedure, there is no standard definition of a balance reflecting the content of factor use or emissions[2] embodied in trade. Kanemoto (2012) and Dietzenbacher and Serrano (2012) discuss the peculiarities and assumptions of the different balances: the balance of responsibilities (RB), balance of embodied emissions in a bilateral input-output model (EEBT) and the balance of emissions or factor content in a multiregional model (MRIO-B) which assigns the emissions to the final consumption of countries. What all these balances have in common is the utilisation of the input-output methodology for the calculations, which permits the incorporation of factor content, virtual carbon or embodied factor content in exported and imported goods, although the results differ depending on the underlying assumptions. However, another common trait of these approaches is the fact that at the global level they sum up to zero (Kanemoto et al., 2012) and therefore they cannot help us answer the question whether this trade is damaging to the environment, or, in other words, whether the growth of international trade leads to an increase in global emissions or not. The balances mentioned above can be used to identify countries with an “emission deficit” (this is the case for most advanced economies) or an “emission surplus” (this is the case for most emerging and developing economies). They can also be used to identify the industries which are responsible, in direct or indirect terms, for these emissions (Munskgaard and Pedersen, 2001, Peters and Herwith, 2008, Gallego and Lenzen, 2008 or Cadarso et al., 2012).

Our objective is to define and construct a multireginal model which may be used to evaluate the importance of global value chains of the different countries involved in trade on the evolution of the emissions associated with trade. To this end, we must first define a new balance of emissions. Our point of departure is the definition of a balance of domestic embodied emissions or factor content (BDEE/BDFC) as presented in López et al. (2013) for the case of a biregional model, which permits us to study the effect of a country’s trade pattern on emissions, which we extend to the case of a multiregional model. This is a balance which considers, for each region i, the domestic emissions embodied in exports and the emissions embodied in imports, as the sum of domestic emissions contributed by every region, of the

[1] However, trade balances usually contain a “statistical discrepancy” because not all trade flows can be observed.

[2] Although most of the literature on this subject is dedicated to the balance of emissions, there are some studies which deal with the implications of international trade on the use of production factors (land, water, biodiversity, deforestation, employment, value added etc.). These studies use similar methods to compute a balance of factor content rather than a balance of emissions.

production required to satisfy the final demand with those goods traded internationally. The result for the global economy is a balance of zero.

The balance of avoided factor content/emissions (BAE/BAFC) is the difference between emissions linked to exports (EEX) and emissions avoided by imports (EAM) to evaluate whether international trade increases or decreases emissions at a global level (Dietzenbacher & Mukhopadhyay, 2007, Peters, 2007, Akerman, 2007, Zhang, 2012 and López et al, 2013). In the balance of avoided emissions defined the volume of trade are cancelled in the four types of balances considered: RP, EETB, MRIO-B or BDFC. The results of the (BAE) depend of the environmental comparative advantage of the implicate countries and the volume of trade by sectors, but not the total of trade. The comparative advantage or specialization by sectors in the different countries is determined by two factors. First, technology used in the factory located in the emerging and development country. Second, differences in energy and environmental intensity that exist along the chain of suppliers between the countries of origin and destination.

In contrast to the balance of avoided factor content, the measure of carbon leakage, the difference between the emissions associated with the imports that the advanced economies receive from less advanced economies, and the emissions associated with the production in the advanced economies, is a measure which considers the time period and the total carbon incorporated in international trade (IPCC, 2007; Peters et al., 2008; Monjon and Quirion, 2010; Monjon and Quirion, 2011; Kuik and Hofkes, 2010). However, it is not suitable for evaluation the way in which the growth of trade endangers the environmental at the global level, since the reduction of domestic emissions in advanced economies may be induced by an improvement in their energy efficiency and environmental technology rather than a reduction in the level of production (Jakob and Marschinski, 2012 and López et al., 2013).

2.1 Domestic balance of factor content (BDFC)

The computation of the emission balance in a MRIO model – in contrast to a BRIO model – assumes a reassignment of the emissions between countries since an important share of the traded goods belongs to the global value chains of production, which is evaluated in Peters et al. (2012), Andrew y Peters (2013) and in Su and Ang (2011). For this computation we need to define a multiregional model for r regions (in our case r=3)[3]:

$$X = (1 - A)^{-1}Y = LY$$

$$\begin{pmatrix} x^1 \\ x^2 \\ x^3 \end{pmatrix} = \begin{pmatrix} L^{11} & L^{12} & L^{13} \\ L^{21} & L^{22} & L^{23} \\ L^{31} & L^{32} & L^{33} \end{pmatrix} \begin{pmatrix} \hat{y}^{11} & \hat{y}^{12} & \hat{y}^{13} \\ \hat{y}^{21} & \hat{y}^{22} & \hat{y}^{23} \\ \hat{y}^{31} & \hat{y}^{32} & \hat{y}^{33} \end{pmatrix} \quad (1)$$

[3] $X = AX + Y, \begin{pmatrix} x^1 \\ x^2 \\ x^3 \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & A^{13} \\ A^{21} & A^{22} & A^{23} \\ A^{31} & A^{32} & A^{33} \end{pmatrix} \begin{pmatrix} x^1 \\ x^2 \\ x^3 \end{pmatrix} + \begin{pmatrix} \hat{y}^{11} & \hat{y}^{12} & \hat{y}^{13} \\ \hat{y}^{21} & \hat{y}^{22} & \hat{y}^{23} \\ \hat{y}^{31} & \hat{y}^{32} & \hat{y}^{33} \end{pmatrix}$

Where X is a matrix of world´s total output. A is a matrix of input coefficients, A^{rr} is the matrix of domestic production coefficients of country *r* and A^{rs} is the matrix of imported coefficients from country *r* to country *s*. The matrix of final demand is *Y*, that included the diagonalized vector $\hat{y}^{rr}$of domestic final consumptions and the diagonalized vector $\hat{y}^{rs}$ is final exports of country *r* to country *s*. L^{rs} is the inverse matrix of Leontief of country *r* and L^{rs} is the imported inverse matrix of Leontief of county *r* to country *s*.
Now we define the diagonal matrix of emissions intensities *F* and ($f_r = F_r/x_r$), or direct emissions (F_r) per produced unit (x_r). Now we defined the matrix *P* of multiplier of the content factor. Where P^{rs} shows total, direct and indirect, factor content/emissions in country *r* embodied in a unit of production to final demand in country *s* (or in the same country if is P^{rr}.

$$P = \begin{pmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{pmatrix} = \begin{pmatrix} f^1 & 0 & 0 \\ 0 & f^2 & 0 \\ 0 & 0 & f^3 \end{pmatrix} \begin{pmatrix} L^{11} & L^{12} & L^{13} \\ L^{21} & L^{22} & L^{23} \\ L^{31} & L^{32} & L^{33} \end{pmatrix} (2)$$

The next expression (F^X) is useful to calculate factors embodied in the production of the world economic, that can split up into different elements of final demand or input:

$$F^X = F(1-A)^{-1}Y = FLY = PY$$

$$\begin{pmatrix} F^{11} & F^{12} & F^{13} \\ F^{21} & F^{22} & F^{23} \\ F^{31} & F^{32} & F^{33} \end{pmatrix} = \begin{pmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{pmatrix} \begin{pmatrix} \hat{y}^{11} & \hat{y}^{12} & \hat{y}^{13} \\ \hat{y}^{21} & \hat{y}^{22} & \hat{y}^{23} \\ \hat{y}^{31} & \hat{y}^{32} & \hat{y}^{33} \end{pmatrix} =$$

$$\begin{pmatrix} P^{11}\hat{y}^{11} + P^{12}\hat{y}^{21} + P^{13}\hat{y}^{31} & P^{11}\hat{y}^{12} + P^{12}\hat{y}^{22} + P^{13}\hat{y}^{32} & P^{11}\hat{y}^{13} + P^{12}\hat{y}^{23} + P^{13}\hat{y}^{33} \\ P^{21}\hat{y}^{11} + P^{22}\hat{y}^{21} + P^{23}\hat{y}^{31} & P^{21}\hat{y}^{12} + P^{22}\hat{y}^{22} + P^{23}\hat{y}^{32} & P^{21}\hat{y}^{13} + P^{22}\hat{y}^{23} + P^{23}\hat{y}^{33} \\ P^{31}\hat{y}^{11} + P^{32}\hat{y}^{21} + P^{33}\hat{y}^{31} & P^{31}\hat{y}^{12} + P^{32}\hat{y}^{22} + P^{33}\hat{y}^{32} & P^{31}\hat{y}^{13} + P^{32}\hat{y}^{23} + P^{33}\hat{y}^{33} \end{pmatrix}$$

(3)

Where F^{rs} includes all the emissions from country *r* required to satisfy country *s*'s demand and F^{rr} to satisfy the domestic demand of country *r*'s.

The domestic balance of embodied factor content/emissions (BDFC) of region i tells us the difference between the domestic emissions associated with the exports of region i minus the emissions embodied in all the international stages of production of the imports of region j, of intermediate as well as final goods, which satisfy the final demand in both regions. In case we have a multiregional model with only two regions, the balance of domestic factor content/embodied emissions of region 1 (BDFC/BDEE), which trades with region 2, would be given by equation (4) and the opposite would be true for the balance of region 2 with region 1.

$$BDFC^{1-2} = F^{E12} - F^{M12} = \underbrace{(P^{11}\hat{y}^{12} + P^{12}\hat{y}^{22} + P^{12}\hat{y}^{21})}_{4.1} - \underbrace{(P^{21}\hat{y}^{12} + P^{21}\hat{y}^{11} + P^{22}\hat{y}^{21})}_{4.2}$$
$$= \underbrace{(P^{11}\hat{y}^{12} - P^{22}\hat{y}^{21})}_{4.3} + \underbrace{(P^{12}\hat{y}^{22} - P^{21}\hat{y}^{11})}_{4.4} + \underbrace{(P^{12}\hat{y}^{21} - P^{21}\hat{y}^{12})}_{4.5}$$

(4)

Where BDFC means the difference between the emissions associated with exports (F^E) and those associated with imports (F^M). Reading the resulting matrices by rows, we can quantify the direct embodied emissions by the exporting country for final and intermediate goods (Cadarso et al., 2012). Enabling the identification of whether they are final or intermediate goods by the fragmentation of the various components of final demand: when trade is destined for consumption of final goods in region 2 ($\hat{y}^{12}$), enter as intermediate goods in region 2 are processed and ultimately intended for final demand in that region ($\hat{y}^{22}$), or region 2 finally transform them into other good that is exported back to region 1 ($\hat{y}^{21}$).

The balance of this balance may be positive or negative and the result will be the sum of the successive balances. The term 4.3 shows the balance of emissions linked to trade in final goods into the two regions considers. The term 4.4 shows the balance of emissions linked to trade in intermediate inputs that belong to the last stage of international production, as when they enter the country these inputs become embodied in the production of final goods that are sold domestically. Expression 4.5 is the balance of emissions linked to any other round of international production between country 1 and 2 required to produce final goods in both countries.

The generalization of this balance to a multiregional model under the assumption that the number of regions is n and that r, s, t, p are regions would mean that the world balance of factor contents (WBDFC) in a MRIO would be:

$$WBDFC = F^E - F^M = \sum^{n}_{\substack{rst,\\ r\neq s\neq t}} P^{rs}\hat{y}^{st} - \sum^{n}_{\substack{rst,\\ r\neq s\neq t}} P^{rt}\hat{y}^{ts} = 0 \qquad (5)$$

It is interesting to compare the BDFC with the other balances used in the literature (Kanemoto et al., 2012). The BDFC is similar to the EEBT in far as it only considers the domestic emissions of the country in question, differentiating between final goods and imports according to the formulation of Kanemoto et al. (2012), and it differs in that it is calculated on the basis of a MRIO which incorporates all domestic stages of the production of the imports which go to the final demand in the countries in question. That is to say, it includes bidirectional trade, but it does not include multidirectional trade, of three or more international stages of production, if they do not end in the final demand of the countries in question.

On the other hand, the BDFC has in common with the MRIO-B that both consider all the stages of production, but whereas the MRIO-B assigns the emissions of inputs to the agents of final demand, the BDFC assigns these emissions to the countries which trade in those goods. In relation to the balance of responsibilities (RB), there is a cancelation of emissions, which does not occur in BDFCE, such that it is ultimately equivalent in form to the bilateral balances and MRIO is compatible with monetary trade balances. The existing differences between the three balances in a MRIO table are owed to the different way of assigning the responsibilities for those emissions: in the BDFC the responsibility is assigned to the agent of the country of intermediate and final demand and which buy and sell these goods (the same as in EEBT), whereas in the MRIO-B and RB the responsibility is assigned to the agents of final demand in those countries.

2.2 Balance of avoided factor content (BAFC)

The Pollution Haven Hypothesis occurs when the domestic emissions linked to exports (EEX) by a country are larger than emissions avoided by imports (EAM) (Dietzenbacher &

Mukhopadhyay (2007), Peters, 2007 and Zhang (2012). The balance of avoided factor content/emissions (BAFC) proposed considered domestic emissions in exports and emissions in imports associate to in all global value chains.

The formulation is clear BAFC biregional model and similar to a model EEBT, as global chains of production only occur between countries:

$$
\begin{aligned}
BAFC^{1-2} &= (F^{E1} + F^{E2}) - (F^{AM1} + F^{AM2}) \\
&= \left[\underbrace{(P^{11}\hat{y}^{12} + P^{12}\hat{y}^{22} + P^{12}\hat{y}^{21})}_{} + \underbrace{(P^{22}\hat{y}^{21} + P^{21}\hat{y}^{11} + P^{21}\hat{y}^{12})}_{}\right] \\
&\quad - \left[\underbrace{(P^{11}\hat{y}^{21} + P^{12}\hat{y}^{11} + P^{12}\hat{y}^{12})}_{} + \underbrace{(P^{22}\hat{y}^{12} + P^{21}\hat{y}^{22} + P^{21}\hat{y}^{21})}_{}\right]
\end{aligned}
$$

(6)

The expression of the world balance of avoided content factor (WBAFC) in a MRIO:

$$
WBAFC \quad = F^{E} - F^{AM} = \sum\nolimits^{n}_{\substack{rst, \\ r\neq s\neq t}} P^{rs}\hat{y}^{st} - \sum\nolimits^{n}_{\substack{rst, \\ r\neq s\neq r\neq t\neq s}} P^{rs}\hat{y}^{ts} = 0 \qquad (7)
$$

If the rest of the world has the same production technology and pollution that Country 1 expressions serious emissions avoided by imports (F^{AM+}):

$$
\begin{aligned}
F^{AM+} &= \begin{pmatrix} F^{11} & F^{12} & F^{13} \\ F^{21} & F^{22} & F^{23} \\ F^{31} & F^{32} & F^{33} \end{pmatrix} = \begin{pmatrix} f^{1} & 0 & 0 \\ 0 & f^{1} & 0 \\ 0 & 0 & f^{1} \end{pmatrix} \begin{pmatrix} L^{11} & L^{12} & L^{13} \\ L^{12} & L^{11} & L^{23} \\ L^{13} & L^{12} & L^{11} \end{pmatrix} \\
&= \begin{pmatrix} P^{11+} & P^{12+} & P^{13+} \\ P^{21+} & P^{22+} & P^{23+} \\ P^{31+} & P^{32+} & P^{33+} \end{pmatrix} \begin{pmatrix} \hat{y}^{11} \\ \hat{y}^{21} \\ \hat{y}^{31} \end{pmatrix} = \begin{pmatrix} P^{11+}\hat{y}^{11} + P^{12+}\hat{y}^{21} + P^{13+}\hat{y}^{31} \\ P^{21+}\hat{y}^{11} + P^{22+}\hat{y}^{21} + P^{23+}\hat{y}^{31} \\ P^{31+}\hat{y}^{11} + P^{32+}\hat{y}^{21} + P^{33+}\hat{y}^{31} \end{pmatrix}
\end{aligned}
$$

(8)

Where the elements (F^{AM1}) include emissions avoided by imports made by the country, in this case 1, involves replacing emission multipliers exporter by the importer (Lopez et al., 2013). However, when more countries are included in their study requires a more detailed subdivision, which also implies making decisions on the allocation of responsibilities between countries and stakeholders in trade[4].

$$
\begin{aligned}
BAFC^{1-Row} = {} & \underbrace{(P^{12}\hat{y}^{22} + P^{13}\hat{y}^{33}) - (P^{21+}\hat{y}^{11} + P^{31+}\hat{y}^{11})}_{9.1} \\
& + \underbrace{(P^{11}\hat{y}^{12} + P^{11}\hat{y}^{13}) - (P^{22+}\hat{y}^{21} + P^{33+}\hat{y}^{31}) - (P^{32+}\hat{y}^{21} + P^{23+}\hat{y}^{31})}_{9.2} \\
& + \underbrace{(P^{12}\hat{y}^{21} + P^{12}\hat{y}^{23}) - (P^{21+}\hat{y}^{12})}_{9.3} + \underbrace{(P^{13}\hat{y}^{31} + P^{13}\hat{y}^{32}) - (P^{31+}\hat{y}^{13})}_{9.4}
\end{aligned}
$$

[4] Similar to the development realize in a bi-regional model in López et al. (2013), we can replace the multiplier emissions by emission coefficient and get the direct/own factor content/emissions associated with international trade and the indirect emissions as the difference between total and direct.

(9)

The term 9.1 shows the balance of emissions linked to trade in intermediate inputs that belong to the last stage of international production in the different regions considers (only domestic emissions in the two regions), as when they enter the country these inputs become embodied in the production of final goods that are sold domestically. The term 9.2 shows the balance of domestic emissions linked to trade in final goods. Expression 9.3 y 9.4 are the balance of avoided emissions linked to any other round of international production required to produce final goods. Expression 9.3 is the balance of avoided emissions linked to any other round of international production between country 1 and 2 required to produce final goods. Expression 9.4 is the balance of avoided emissions linked to any other round of international production between country 1 and 3 required to produce final goods. This is the case as they are emissions of country 1 that enter country 2 and are used to produce in this country and later on exported to one of this countries (the opposite will be true for imports)[5]. This balance captures emissions embodied in the consecutive rounds and steps of the production of a commodity caused by the fragmentation of production and the creation of global value chains.

3. Main results

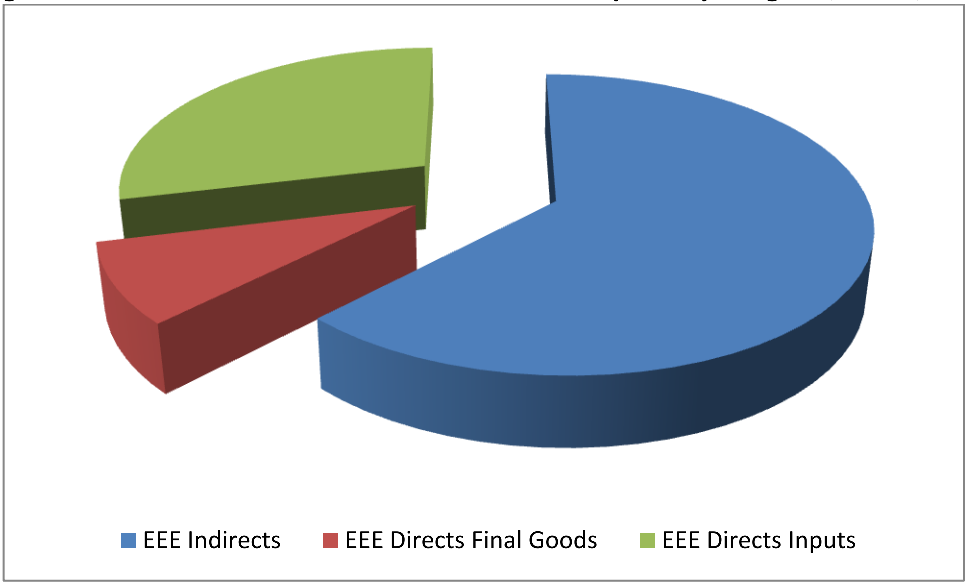
3.1 Direct versus indirect emissions embodied in trade

Virtual carbon in trade represents a 17% in 1995 and a 23.5% in 2009 of total emissions associated to productive activities in the global economy, when we aggregate the world in 7 regions. These results are lower than those obtained by Peters et al. (2011), 26% in 2008, however their calculations include international trade of 113 countries provided by GTAP and thus, greater volume of international trade than our calculations with 7 regions, becoming in domestic trade.

It is interesting to see how only 37.6% of virtual carbon in exports is directly incorporated by firms that export these goods, which represents 2.193.900 Kt CO_2 (Figure 1). The rest, 62.4% is due to the linkage effects generated along the entire production system and represent 3.648.149 Kt CO_2. In so far that emissions embodied in exports could be induced by a carbon leakage the negative impact on pollution would be more pronounced due to these linkage effects rather than direct effects. This would be an indirect carbon leakage, which can be “strong”, due to a mitigation policy in the country of origin, or “weak”, due to the trade growth (Peters, 2008). The emissions distribution between intermediate and final goods is higher for the first, because inputs trade is more important (67.1%) and also because they have a higher pollution intensity that represents 76.7% of direct emissions embodied in trade.

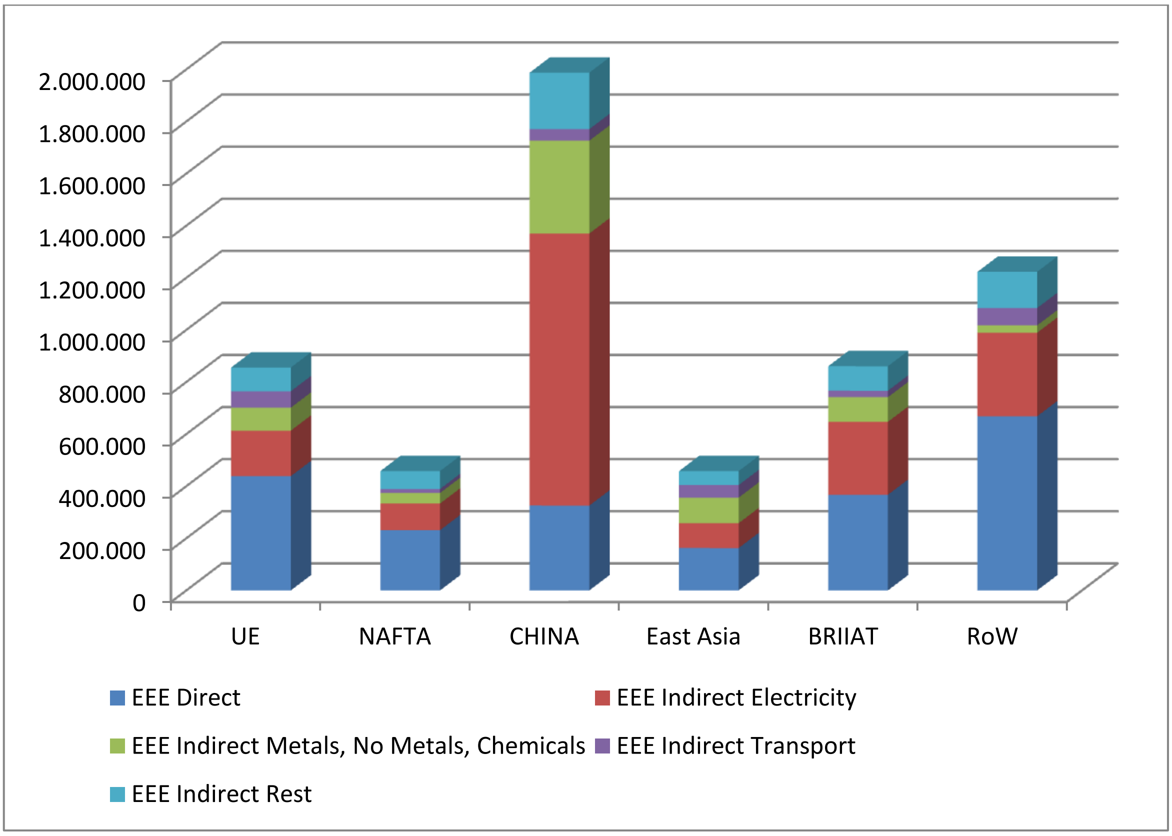
[5] The difference in the decomposition of the third element of the PHH (associated with global value chains) between a model bi-regional and multi-regional is that in the latter model segregation is complete, since, by providing information to all countries involved in trade of inputs and final goods exports to be found in the third element associated with global value chains of intermediate goods are provided. In the bi-regional model the third element is divided into two, and the associated trade in the rest of the world cannot be distinguished by lack of information between trade in final goods and intermediate.

Figure 1 Direct versus indirect emissions in world exports by 7 regions, $KtCO_2$, 2009



A detailed study of domestic linkage effects that the trade has, allow us to identify the sectors responsible and, hence, on which we must act if we want to reduce that impact (Figure 2). We are observed different pollution patterns from developed regions and Chinese economy. While in EU, NAFTA and East Asia, direct emissions are the most important, in China indirect emissions, associated with a highly polluting electricity sector, explain almost 50% of virtual carbon in exports. Is important to highlight the comparison of composition between this emissions and emissions from regions like BRIIAT and Row, where direct emissions embodied in exports are more important.

Figure 2 Direct *versus* indirect emissions in world exports by regions, $KtCO_2$, 2007



The novelty of the proposed methodology compared with other studies is to analyze if virtual carbon embodied in exports is associated with exports of intermediate goods or goods that have been completed in the region considered, either a phase or only the final assembly and, after being exported, are destined for final demand in other regions (Figure 3). While the EU and RoW export virtual carbon incorporated into final goods (around 65% of total), China export more intensively virtual carbon embodied in parts and components (by 47% of the total, 10% more than the other two regions). Such that, when these emissions are exported can be reassigned to sectors that buy and transform to produce goods and services and eventually sells domestically or sell in successive rounds to other countries. Figure 4 shows how the industries responsible in the international fragmentation of production are too responsible as importers of this virtual carbon: Electrical and Optical Equipment, Textiles and Textile Products and Machinery.

Figure 3 Virtual carbon in final goods and GVC in exports for three regions, KtCO2, 2009

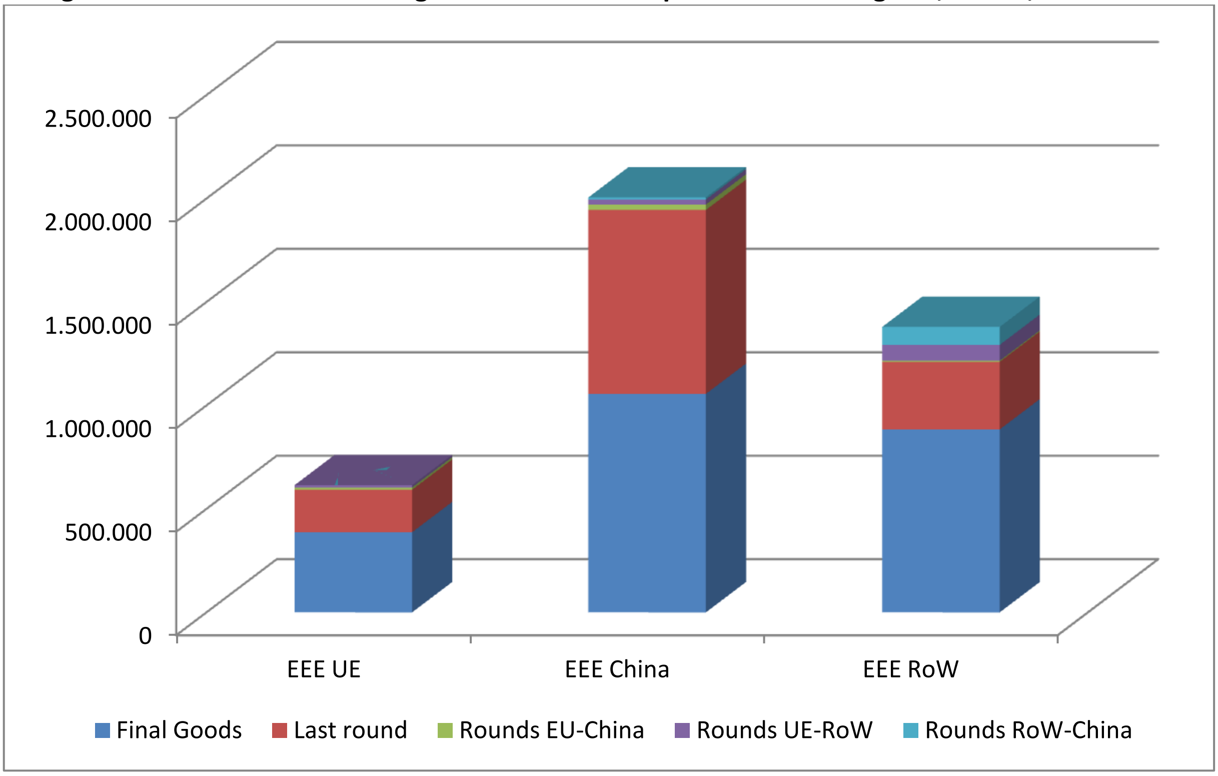
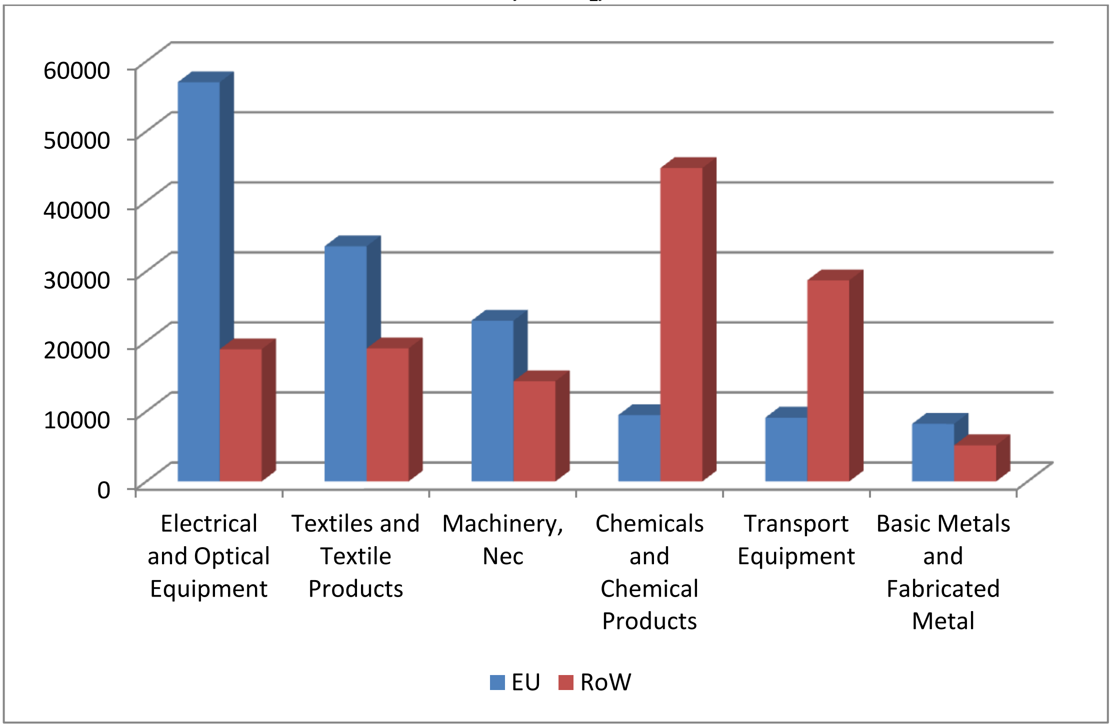


Figure 4 Industries from EU and RoW responsible for the virtual carbon in inputs exported by China, $KtCO_2$, 2009



3.2 Balance of avoided emissions by regions

International trade has avoided 1.1 GtCO_2 in 2009, which represents a reduction of 18.1% in relation to the total level of embodied emissions in the international trade of the seven regions considered here, or 4.4% of global emissions associated with the production of goods and services (Table 1). Nevertheless, due to the significant growth of international trade between 1995 and 2009, the avoided emissions account for smaller shares of the total export-associated emissions and total global emissions (-32.2% and -5.5%, respectively in 1995). In a world without international trade, where each region would have to produce everything it consumes, total emissions would have been 1.1 Gt tCO_2 higher than in reality. The abatement of emissions, in relative terms, amounts to 53.4% of the total pollution generated in the territory of the European Union in the year 2009 or 41.4% of the emissions associated with the international transport of goods and tourists. However, our aim is not only to identify the amount of total emissions avoided, but also the way in which this abatement is achieved as well as the different roles played by advanced economies, emerging economies and developing economies.

Table 1 Emissions embodied in exports and avoided imports and BAE, KtCO_2

	Regions (3)		Regions (7)	
	1995	2009	1995	2009
EEE	1,667,934	3,835,929	3,248,549	5,842,049
EAM	1,699,766	3,899,081	4,294,707	6,943,155
BAE	-31,833	-63,152	-1,046,159	-1,101,106
BAE/EEE	-1.9%	-1.6%	-32.2%	-18.8%
BAE/EEX	-0.17%	-0.25%	-5.5%	-4.4%

Note: EEE: virtual carbon in exports; EAM: emissions avoided by imports; EEX: virtual carbon in global production; BAE: Balance of avoided emissions.

Not all regions bear the same responsibility for the abatement of emissions; international trade increases the emissions of some of them while reducing the emissions in others (Table 2 and Table 3). The methodology proposed to isolate for each region the domestic emissions incurred through international trade permits us to identify the role which each of these regions plays in the total abatement of emissions. Six of the seven regions have managed to avoid emissions due to their ability to trade with the rest of the world (especially RoW with -1.199.029 kt CO_2 and NAFTA with -702.713 kt CO_2). The only exception is China, where the effect of trade was an increase of emissions by 1.12 trillion kt CO_2. The substantial export surplus of China, especially for final goods, means that its exports in terms of value and emissions are much larger than its (avoided) imports. However, the advanced economies belonging to the Euro area and East Asia (including those of "Other EU") have managed to avoid global emissions despite generating trade surpluses. This suggests that they specialise in producing or exporting activities which are less polluting and import activities which lead to high pollution. The regions of NAFTA, which includes the United States, and RoW, by contrast, are those which could easily avoid emissions due to the fact that they have trade deficits, which means that they import more than they export, with carbon embodied in both exports and imports. However, the observations reported in Table 2, if we focus on a single region, are influenced not only by its trade volume or trade balance but also by the pollution intensity of its industrial activities. In order to cancel this effect, we need to compute the net BAE between two regions, which allows us to isolate the impact which international trade has on the emissions generated by the total volume of trade.

Table 2 Trade balance and BAE by 7 regions, 2009

	Trade Balance	Trade Balance Final Goods	Trade Balance Inputs	BAE
EUROZONE	302,008	212,044	89,963	-144,194
Other EU	57,257	-6,080	63,337	-31,509
NAFTA	-317,563	-374,372	56,809	-702,713
CHINA	524,067	674,565	-150,499	1,228,262
EAST ASIA	169,389	55,797	113,592	-241,142
BRIIAT	57,549	-137,514	195,063	-10,780
RoW	-792,706	-424,441	-368,265	-1,199,029
Sum	0	0	0	-1,101,106

Note: TB in millions of US$, BAE in Kt CO_2.

Table 3 Emissions embodied in exports and avoided imports, 2009, KtCO_2

	EEX	EEE	EEM	EEE/EEX (%)	EAM/EAX (%)
EUROZONE	2,063,410	487,206	631,401	23.6%	30.6%
Other EU	1,098,519	368,265	399,774	33.5%	36.4%
NAFTA	4,978,060	458,081	1,160,794	9.2%	23.3%
CHINA	6,213,551	1,987,433	759,171	32.0%	12.2%
East Asia	1,776,974	457,714	698,856	25.8%	39.3%
BRIIAT	4,098,718	860,448	871,228	21.0%	21.3%
RoW	4,640,995	1,222,903	2,421,932	26.4%	52.2%
Total	24,870,227	5,842,049	6,943,155	23.5%	27.9%

Note: EEE: virtual carbon in exports; EAM: emissions avoided by imports; EEX: virtual carbon in global production; BAE: Balance of avoided emissions.

The proper way to evaluate the net impact of trade in terms of emissions is to aggregate for each pair of regions the net balance of avoided emissions between both regions (virtual carbon in exports minus virtual carbon avoided through the imports of both regions). This procedure allows us to isolate the importance of the trade volume between both regions. For instance, if the sum of the BAE of EU-China and the BAE of China-EU happens to be a positive number, as is actually the case, this means that the specialisation of both regions gives rise to an increase in emissions due to the international trade between both regions. In our case, when working with seven regions, there are 14 net BAE's. Seven of them permit a reduction of emissions whereas the remaining five give rise to an increase in emissions (Figure 5).

Trade between advanced economies (NAFTA, EU, Other EU and East Asia) with the region "RoW" explains 50% of the total avoided emissions of 1.1 Gt CO_2 (Figure 5, Table 4). At a closer look, this emission abatement mostly results from the trade between the EU and the RoW (-498.655 kt CO_2). There are two pairs of regions (EU-RoW and East Asia-RoW) in which international trade in both directions contributes to emission abatement, indicating that in these cases trade is driven by specialisation in line with the comparative advantages of the participating regions. Although in both cases RoW is the region which avoids the largest amount of emissions (an observation which may be explained by the fact that RoW has a negative trade balance), the other two regions also achieve a significant reduction in emissions. On the other hand, although the net trade of RoW with NAFTA and China appears to facilitate a reduction in total emissions, the data suggest that for both regions the trade with the RoW has led to a "flight" or "leakage" of emissions. For example, trade between RoW and China has reduced total emissions by 140,000 kt CO_2, but this does not mean that emissions have been avoided in both directions. The BAE of China-RoW has a value of 359,624 kt CO_2 (an increase in emissions), and the BAE of RoW-China has a value of -500,522 kt CO_2 (a reduction in emission). This indicates that the rest of the world achieves the greatest reduction in emissions of all the regions thanks to imports from China.

It can be confirmed that the trade between RoW and the other regions of the world is beneficial in environmental terms, because it permits the reduction of emissions. The RoW has a tendency to export goods with a low emission intensity and import goods with a high emission intensity. However, the fact that the RoW exports natural resource with a low value added and imports manufactured goods and capital goods, whose production is intensive in value added, perpetuates a pattern of trade which leads the RoW to specialising in resource extraction rather than manufacturing. Specifically, the emissions which other regions avoid by trading with the RoW can be largely explained by the imports of the sector "mining and quarrying" (-425,631 kt CO_2). This is largely due to the export of energy intensive, homogeneous and easily to offshore inputs (-395,716 KtCO2): Rubber and Plastics; Other Non-Metallic Mineral; Basic Metals and Fabricated Metal, Chemicals and Chemical Products (Reinaud, 2008). And due to international transport required to export too. In addition, many energy and food products are also intensive in emissions per dollar (213,377 KtCO_2).

It also has to be pointed out that the trade between the EU and NAFTA allows an emission reduction due to the fact that the U.S. economy specialises in producing and exporting a range of goods and services which generate a minor pollution in its own territory than those which are imported. Despite the fact that the EU has a trade deficit of -71,196 $ millions (in final goods), it does not avoid emissions because it exports goods which are much more emission intensive than those which it imports. Nevertheless, however, the avoided emissions of the region NAFTA mean that its trade does reduce emissions, in such a way that it is able to compensate its trade surplus by exporting goods which are less polluting than its imports. Considering only domestic emissions in these economies would mean the loss of information delivered by global value chains and, along with it, the pollution going from China to the U.S. and finally to the EU which buys final products from the U.S.

Figure 5 Bilateral BAE for 7 regions with reduce of emissions, KtCO$_2$, 2009

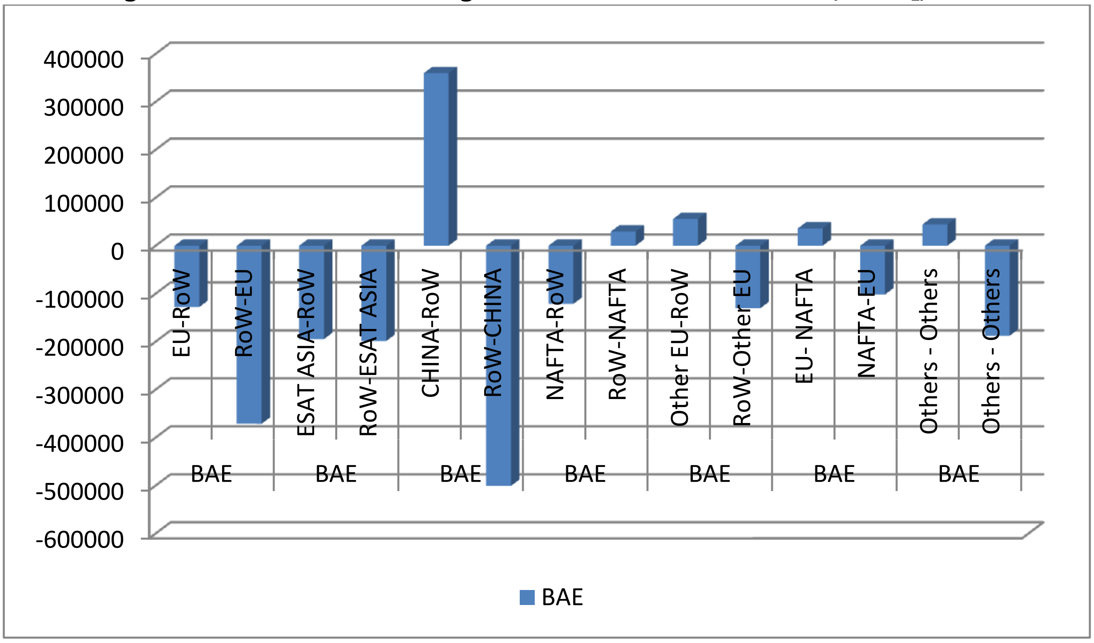


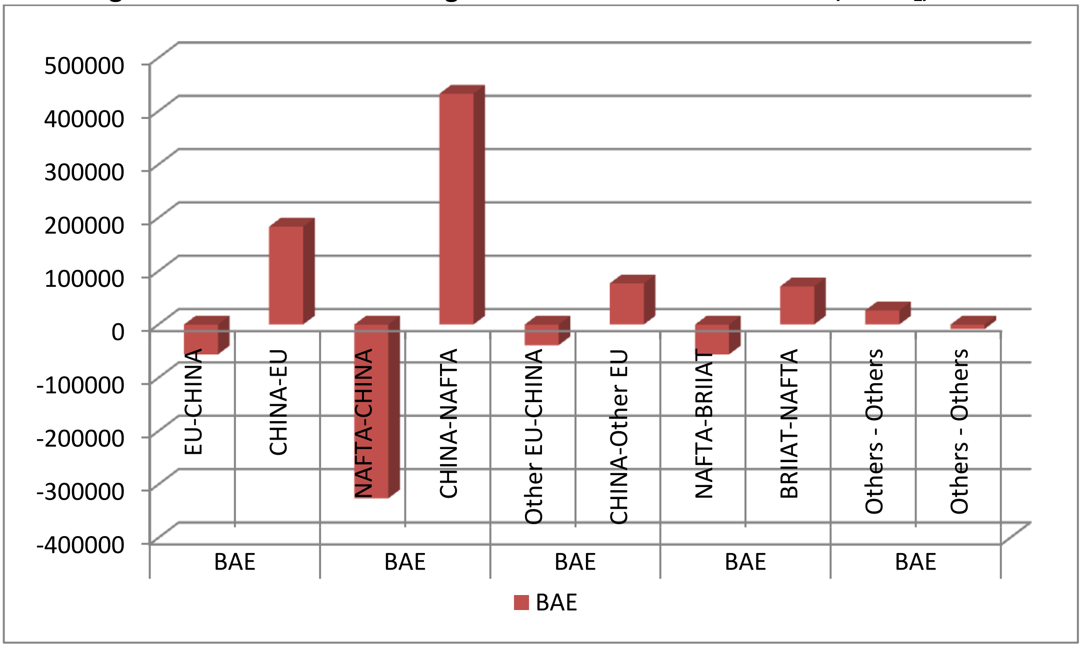
Table 4 Bilateral BAE by 7 region and partner of trade, KtCO$_2$, 2009

	BAE	BAE 2 Regions			BAE	BAE 2 Regions
EU- Other EU	23148			Other EU-NAFTA	14.515	
Other EU -EU	-47122	-23975		NAFTA-Other EU	-25.626	-11111
EU- NAFTA	35996			Other EU-CHINA	-38.622	
NAFTA-EU	-101514	-65518		CHINA-Other EU	77.085	38463
EU-CHINA	-55929			Other EU-EAST A	-5.754	
CHINA-EU	183555	127626		EAST ASIA-Other	3.912	-1843
EU-EAST ASIA	-6533			Other EU-BRIIAT	-10.300	
EAST ASIA- EU	12603	6070		BRIIAT-Other EU	17.629	7329
EU-BRIIAT	-13245			Other EU-RoW	55.774	
BRIIAT-EU	6934	-6311		RoW-Other EU	-130.170	-74396
EU-RoW	-127631					
RoW-EU	-371025	**-498655**				
NAFTA-CHINA	-325.868			CHINA-EAST ASI	43.257	
CHINA-NAFTA	432.748	106880		EAST ASIA-CHIN	-38.594	4664
NAFTA-EAST ASI	-72.474			CHINA-BRIIAT	131.992	
EAST ASIA-NAFT	36.462	-36012		BRIIAT-CHINA	-137.089	-5097
NAFTA-BRIIAT	-56.030			CHINA-RoW	359.624	
BRIIAT-NAFTA	71.349	15319		RoW-CHINA	-500.522	**-140898**
NAFTA-RoW	-121.201					
RoW-NAFTA	29.329	-91871				
ESAT ASIA-BRIIA	-61.003					
BRIIAT-ESAT ASI	3.299	-57704				
ESAT ASIA-RoW	-194.522					
RoW-ESAT ASIA	-198.436	-392958				
BRIIAT-RoW	27.097					
RoW-BRIIAT	-28.205	-1108				

China has been turned into a pollution haven for emissions of the advanced economies (NAFTA, EU, Other EU, East Asia), at least according to the balance of its BAE, which means that this trade generates an emission increase by 277,337 kt CO_2 in 2009 (Figure 6 and Table 4). However, trade between China and the other emerging economies and developing economies allows an emission reduction: -140,898 with Row and -5,007 with BRIIAT in 2009. In relation to the wealthy regions, their respective trade deficits with China allow them to avoid emissions, but nevertheless these reductions are not large enough to compensate the increase in emissions caused by an economy like China's, which is characterised by high emission coefficients owing to "dirty" technologies being employed. Although the principal trade partner of China is the U.S., within the region NAFTA these high volumes of trade between the two first regions are compensated to a certain degree by the fact that both regions exploit the available comparative advantages in emissions, which means that the increase in emissions amount to only 106,888 kt CO_2. Nevertheless, although the amount of trade between the EU and Other EU is smaller than that with NAFTA, the EU and Other EU are the two regions which utilise China most intensively as a pollution haven, meaning that the trade between both regions, according to the BAE, raises total emissions by 166,089 kt CO_2.

China's trade surplus in 2009 leads to avoided emissions balance of the rest of regions increases emissions in 1.228.262 kt CO_2 against only 221.210 kt CO_2 in 1995 increased (Table 5). However, when we consider the net BAE, the result is that the trade of China with the rest of regions only increase the net BAE in 131.638 kt CO_2 in 2009; when in 1995 the net BAE is only a little lower (110.887 kt CO_2). Chinese economic growth, based on international trade, has made it the world's first contaminant. However, the net effect of the trade in terms of emissions has had not increase significantly, as it has allowed its partners have reduced their emissions via emission trade (NAFTA, ROW).

Figure 6 Bilateral BAE for 7 regions with increase of emissions, KtCO_2, 2009



In the remaining trade relationships shown in Figure 6, according to the net BAE, the results is always the same: The region with a trade deficit manages to reduce emissions, but this reduction is not large enough to compensate the increase of emissions in the region running a trade surplus. In the case of trade between NAFTA and BRIIAT, the trade deficit of NAFTA amounting to -30,986 $ millions in 2009 permits an emission reduction, but this is not sufficient to compensate the increase in emissions which BRIIAT generates owing to its trade surplus (similar to the findings for the case of Spain-China trade by Lopez et al., 2013).

Table 5 Bilateral BAE by 7 region and partner of trade, KtCO_2, 2009

	1995	**2009**
BAE CHINA - 6 Regions	221.210	1.228.262
Net BAE CHINA - 6 Regions	110.887	131.638
Trade Balance China - NAFTA		289.279
BAE China - NAFTA	133.146	432.748
BAE NAFTA - China	-40.653	-325.868
Net BAE China - NAFTA	92.493	106.880
Trade Balance China - RoW		189.310
BAE China - RoW	54.060	359.624
BAE RoW - China	-52.619	-500.522
Net BAE CHINA - RoW	1.440	-140.898

3.3. BAE and the effects of region aggregation

The number of available regions determines the volume or importance of international trade, since in our case a distinction is made between the emissions which are generated within the borders of a region and those which are related to international trade. In this sense, Su and Ang (2011) evaluate the effect of spatial aggregation on the emissions related to international trade. To this end they construct a hybrid model which they then use to compute, on the basis of a MRIO, the emissions of China, disaggregating the country into a number of sub-national regions (1, 3 or 8 regions). Furthermore, they compute the emissions associated with the exports of China in 2007 based on y model of bilateral international trade. In their case the results of virtual carbon and exports with respect to the total emissions of China amount to roughly 19% of the total in a single region, roughly 17% with three regions and 16.4% with eight regions. Other recent studies have studied how the level of sectoral aggregation affects the estimation of environmental impacts. For example, Su et al. (2011) analyse the transfer of virtual carbon between countries, evaluating the incidence on the consumer responsibility in China and concluding that 40 industries are an adequate number for its quantification (varying between 10 and 120). Lenzen (2012) concludes that in order to make the input-output table compatible with environmental data it is preferable not to aggregate the environmental data due to the information loss resulting from aggregation, and therefore recommends disaggregating all data even if very little data is available. Our study is performed for three and seven regions, which allows not only to confirm or disprove the validity of the PHH but also to study the effects of aggregation on the estimation results, not owing to information gain or information loss but rather to the simple fact that there is – by definition – more international trade when the number of regions is larger[6].

The level of aggregation at which the computations are performed significantly affects the findings with respect to the avoidance or non-avoidance of emissions (Table 1). The computations based on three regions show that in 2009 the emission reduction amounted to a mere 63,152 kt CO_2, or 1.6% of the total, whereas with seven regions the amount of avoided emissions reaches a level of 1.1 Gt CO_2, or 18.8% of the emissions embodied in trade. However, at both levels of aggregation the same tendency can be observed: the relative importance of avoided emissions has decreased, as the growth of international trade is increasingly less beneficial for the environment. By regions, the trade of RoW with EU have managed to avoid emissions and the trade of China with the other two regions, RoW and EU, increase of global emissions (Table 6).

Nevertheless, when we compare our results to other studies, we should mentioned the work by Chen and Chen (2011), because it is the most recent one and the only one known to us which uses a MRIO model for the global economy which is also aggregated to three regions. These authors find a negative impact of international trade on the growth of global emissions, for the between the G7, BRIS and the rest of the world for the year 2004 a pollution haven hypothesis emerges, since total emissions rise by 0.13 Gt CO_2 of a total (2.3%) emissions exported which reach 5.64 Gt CO_2 in these 3 regions. However, it stands out that the estimates of avoided emissions in the study by Chen and Chen (2011) and our results for three regions are very similar in relative values (-1.6% versus 2.3%). The different aggregation of the two studies highlights the uncertainties which an aggregation of regions, countries, and industries to be studied poses with respect to the existence of non-existence of a PHH.

Table 6 Virtual carbon by 3 region and partner of trade, $KtCO_2$, 2009

	EU-China	China-UE	EU-RoW	RoW-EU	China-Row	RoW-China	Total
EEE	59.739	426.528	544.466	804.846	1.565.815	434.534	3.835.929
EAM	149.485	169.351	437.196	1.263.130	550.047	1.329.872	3.899.081
BAE	-89.746	257.178	107.270	-458.284	1.015.768	-895.338	-63.152
Net BAE	167.432		-351.014		120.430		
EEM	426528	59739	804846	544466	434534	1565815	3835928,7
BDEE	-366789	366789	-260380	260380	1131280	-1131280	0

Note: EEE: virtual carbon in exports; EAM: emissions avoided by imports; EEX: virtual carbon in global production; BAE: Balance of avoided emissions; EEM: virtual carbon in imports; BDEE: Balance domestic of embodied emissions.

3.4 BAE by rows or activity sectors

Analysis by rows allows us to identify polluting industries when producing exports, many of which are not internationally traded directly. The most obvious example is the industry of electricity, gas and water, responsible for 50% of the virtual carbon in exports and, however, this sector represents a small share of that trade. The study of these industries is essential

[6] If we aggregate the global economy to one region the amount of “international trade” is zero.

because are largely responsible for the increase of emissions, something that we should consider when for implementing mitigation policies.

Net BAE calculated for 7 regions for industries/rows shows how a few industries account the most of emission reductions (Table 7). Specifically, the responsibility lies with Mining and Quarrying with 41.3% of the total, followed by Rubber and Plastics, with 21.5%, and Water Transport with 20.6%. However, this result don´t identify properly the regions and industries responsible, because the result includes multiple net BAEs cancellations by pairs of regions. By regions, we can highlight that RoW is the region responsible for the reduction of emissions via international trade, because this trade avoids 1.19 Gt CO_2 to the rest of planet and for most industries the trade is decisive. Trade of the other regions is compensated such a way that the specialization of the country almost has not impact. On the other side, the role of Electricity, Gas and Water has an underestimated weight due to these cancellations, although generates an increase of 157,760 kt CO_2.

Table 7 BAE Net by rows/industries to 7 regions, KtCO_2, 2009

	BAE Net 7 Regions	**BAE Net (%) 7 Regions**	**BAE NET RoW**
Mining and Quarrying	-454,708	41.3%	-425,631
Rubber and Plastics	-236,559	21.5%	-213,377
Water Transport	-226,711	20.6%	-237,442
Chemicals and Chemical Products	-84,676	7.7%	-71,411
Electrical and Optical Equipment	-58,324	5.3%	-47,859
Rest of sectors	-197,888	18.0%	-204,165
Electricity, Gas and Water Supply	157,760	-14.3%	-17,354
Total	**-1.101.106**	**100%**	**-1.199,885**

The problem with China in terms of emissions comes from the Electricity, Gas and Water industry, which is more polluting than the rest of its trading partners (Table 8). If we discount the weight that the electricity sector has, China would not be a pollution haven from other regions and BAE go from 1.22 Gt CO_2 to 0.48 Gt CO_2 and its net BAE would reduce emissions around - 205,036 Gt CO_2 instead of increasing in 131,638 Kt CO_2.

Table 8 China BAE and BAE Net by rows, $KtCO_2$, 2009

	BAE CHINA	NET BAE
Electricity, Gas and Water Supply	743,332	336,674
Basic Metals and Fabricated Metal	144,907	33,955
Other Non-Metallic Mineral	85,750	10,607
Chemicals and Chemical Products	61,424	-14,049
Water Transport	53,393	-54,576
Rubber and Plastics	9,376	-91,065
Rest of sectors	139,455	-89,908
Total	1,228,262	131,638
Total – Electricty sector	484,930	- 205,036

4. Conclusions

The fight against climate change must rest on national and international institutional frameworks and effective environmental policies, focused on industries that generate a greater negative effect on the environment and less on trade policy with environmental arguments. Trade barriers are not the answer because international trade avoids 1.1 Gt tCO_2 in 2009, or in other words, in the absence of international trade global CO_2 emissions would be increased in this quantity.

However, not all regions generate emissions savings, and the methodology proposed in this work allows to isolate domestic emissions of each region and, therefore, identify their contribution to the increase (or decrease) of global emissions. In this sense, it highlights the role of China, which has become a pollution haven for developed countries, which is compensated by the capability of the other regions considered to avoid emissions. The trade of different regions with rest of the world (RoW) causes more than half of global emissions savings, a trade based on the export of natural resources.

The natural resource endowments of each region (energy or no energy products), and the international price of these resources determines, on the one hand, international trade and, on the other side, the power generation technology used in each region. The RoW trade with the other regions considered (except China) avoids 0.5 Gt tCO_2 in 2009 because this region has been specialized in exporting to world's richest regions natural resources and heavy industrial goods with low value added, that if it were to produce in other regions will be more polluting. However, China has become a pollution haven that, in net terms leads to an increase of 0.27 Gt CO_2 in 2009 when traded with developed areas, due to the linkage effects generate in the domestic economy from industries that relocate all or part of their production in China. These linkage effects generated in the production process and which represent over 60% of virtual carbon in exports. The information provided by the analysis of domestic linkage effects is essential when we want propose mitigation policies, allowing focusing on a few industries that cause the most of the emissions.

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