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Decomposing the Annual Growth in Greenhouse Gas Emissions, 1995-2008

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Decomposing the annual growth in greenhouse gas emissions, 1995-2008

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Abstract

The evolution of anthropogenic greenhouse gas (GHG) emissions is a complex phenomenon involving countries with different technological and socio-economic structures, which are linked through international trade. In order to better understand this phenomenon, it is important to asses the relevance of each of the different factors driving the emission of GHG. In this paper we aim to disentangle the annual growth in world's GHG emissions into its determinants between 1995 and 2008. We use the EU-funded FP7 World Input-Output Database (WIOD) to decompose the annual variation in global and national emissions of 41 world regions into the changes of population, final demand per capita, commodity structure of the final demand, trade structure, and technology; and taking into account the transboundary effects.

We find that the change in the level of final demand per capita was the main driver for the growth in global GHG emissions (+14.01 $GtCO_2e$), followed by demographic growth (+4.16) and trade structure (+0.58 $GtCO_2e$). Changes in the technology and in the commodity composition of the final demand reduced the emissions (-8.4 and -1.47 $GtCO_2e$), but were insufficient to offset the growth in the other factors. We also estimate that more than 20% of the growth in the emissions of emerging economies was driven by developed countries. Moreover, the inter-country effects are a significant driver for the evolution of national GHG emissions. In almost all the developed countries, the net effects of foreign factors on the growth of emissions are larger than those of domestic factors. In emerging economies, the growth on GHG emissions is mainly driven by domestic factors. However, foreign factors also have a relevant impact on emissions (44% of the net change in China, 37.3% in Brazil, 26.3% in India).

Keywords: GHG Emissions; Structural Decomposition Analysis; Multiregional Input-Output Model.

1. Introduction

In order to monitor the progress towards the stabilization of greenhouse gases (GHG) concentrations in the atmosphere, United Nations Framework Convention on Climate Change reports periodically GHG inventories (UNFCCC, 2005, 2011). These emissions inventories compile information on the evolution of the major sources of GHG over time. However, they fail to explain the driving forces behind these trends which is essential for the definition of climate policies, since they are a key component on the construction of emission scenarios (Nakicenovic, 2000).

Structural Decomposition Analysis (SDA) allows decomposing the changes in the aggregate GHG emissions of a country into the factors underlying the evolution of the release of these substances to the atmosphere. Thanks to this method, it can be distinguished to what extent different factors, such as technological change, population growth, changes in consumption levels and habits, or the evolution of trade structure, influence the change of emissions over time. In recent years, an increasing number of studies have used SDA techniques to analyse the evolution of GHG emissions (see Su and Ang, 2012). However, these studies are focused on single regions and, therefore, ignore the linkages with the socioeconomic structures of other countries. As a consequence, the changes in the emissions of one country derived from socio-economic changes in other countries are not taken into account (e.g. the changes in the emissions of country A due to an increase of the exports to country B resulting from the growth of B's population).

These international effects are closely linked to some relevant policy questions as the transfer of emissions between countries via international trade (Peters et al. 2011), the environmental load displacement (Muradian et al., 2002), or the debate over how to share the responsibility of emissions among countries (Peters, 2008). For instance, in the last years, 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[1]. 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

[1] World Input Output Database. www.wiod.org

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 change in countries' and global emissions.

In this paper, for the first time, we decompose the change in global GHG emissions from a multi regional perspective. Taking the World Input-Output Database as a starting point, we decompose the emissions of 40 countries plus the rest of the world, for the period 1995-2008, into 5 factors (technology, trade structure, commodity structure of the final demand, final demand per capita, and population), distinguishing between domestic changes and foreign/trade related changes.

The paper is structured as follow: section 2 describes the database and the methodology used, section 3 summarizes the main findings and section 4 presents the conclusions.

2. Methodology and data

There is a considerable body of literature on how to decompose the effects of different factors in the evolution of a variable. There are basically 2 techniques for such decompositions: 'Index Decomposition Analysis' (IDA) and 'Structural Decomposition Analysis' (SDA). IDA is usually adopted when the scope of the study is to have a better understanding of the drivers of the changes of emissions a specific sector. SDA is based on input-output analysis and is used to analyse the changes of the whole economy[2] (Su and Ang, 2012). A literature review of IDA can be found at Ang (2004) and Ang and Zhang (2000), while Su and Ang (2012) offer a detailed review of the literature on the application of SDA.

In this study, we will use SDA to decompose the annual change of GHG emissions between 1995 and 2008, at the country and global level, using information from Multi-regional Input-Output (MRIO) tables. Models based on MRIO tables have been widely used to analyze the environmental consequences of trade (see Wiedmann, 2009 and Wiedmann, et al., 2011 for a comprehensive revision of the literature and the existing databases). However, due to the lack

[2] In the case of emissions, there is also a body of literature that uses the Kaya (Kaya, 1989) identity to decompose the change of aggregated GHG emission as the product of population, GDP per capita, energy use per unit of GDP, carbon emissions per unit of energy consumed.

of MRIO tables at constant prices, SDA methods have been restricted to the study of single countries. The question of prices is very relevant in SDA, since these methods are used to estimate how quantities vary over time. Most input-output tables, however, are published in monetary units using prices from the current year. Since the SDA compares economic variables from different time periods with different prices, the input-output tables must be converted into the same price system (constant prices) (Yamakawa and Peters, 2011).

In the rest of this section we section we will show the use of SDA techniques together to MRIO tables to decompose the change in GHG emissions. The methodology is described for the case of 3 regions (r,s=1,2,3) and n sector (i,j=1,…,n), 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[3]:

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

where $\mathbf{Z}^{rs}$ is the intermediate matrix of sectoral deliveries from country r to country s, and the element z_{ij}^{rs} of $\mathbf{Z}^{rs}$ denotes the sales of sector i of country r to sector j of country s; $\mathbf{f}^{rs}$ is the column vector of country s final demands (including private consumption, government consumption and investment) for goods produced by country r; and $\mathbf{x}^{r}$ is the column vector of gross output in country r. Further, let assume that the MRIO table is extended to include a vector of sectoral national emissions of GHG (emission released by the economic activities of each country), denoted by $\mathbf{g}$, and that the population of each region is denoted by the scalar p^r:

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

[3] Matrices are denoted in bold upper-case letters, vectors in bold lower-case and scalars in italics lower-case. The subscripts i, j denote industries while the superscripts r, s denote regions.

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

We can obtain the input coefficients as $\mathbf{A}^{rs} = \mathbf{Z}^{rs}\left(\hat{\mathbf{x}}^{s}\right)^{-1}$, 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 are defined as $\mathbf{e}^{r} = \left(\hat{\mathbf{x}}^{r}\right)^{-1}\mathbf{g}^{r}$.

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

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

The vector of final demand can be further split in several components. For that purpose, we define the following structures:

- the total final demand per capita is defined as $\mathbf{y} = \mathbf{h}(\hat{\mathbf{p}})^{-1}$, where the element h^{s} of vector $\mathbf{h}$ denotes the aggregate final demand of region *s* ($h^{s} = h^{1s} + h^{2s} + h^{3s}$).

- the commodity shares of the final are defined as $\mathbf{c}^{\mathbf{s}} = \mathbf{f}^{\mathbf{s}} \div h^{s}$[4] where $\mathbf{f}^{\mathbf{s}}$ is the vector of total final demand of region *s* by commodity $\left(\mathbf{f}^{\mathbf{s}} = \mathbf{f}^{\mathbf{1s}} + \mathbf{f}^{\mathbf{2s}} + \mathbf{f}^{\mathbf{3s}}\right)$. Therefore, we can write $\mathbf{f}^{\mathbf{s}} = \mathbf{c}^{\mathbf{s}} * h^{s}$. Note that the elements of $\mathbf{c}^{\mathbf{s}}$ indicate the share of each product in the total final demand of country *s*.

- the trade coefficients are defined as $\mathbf{c}^{\mathbf{rs}} = \mathbf{f}^{\mathbf{rs}} \div \mathbf{f}^{\mathbf{s}}$, and indicate the fraction of the total final demand of each commodity that is imported from country *r* ($\neq s$) or is produced domestically (if *r* = *s*).

Thus, the final demand of region *s* of products from *r* ($\mathbf{f}^{rs}$) can be expressed as the product of the share of imports from *r* in the final demand of each good consumed in *s*, the commodity mix of *s*, the final demand per capita of *s*, and the population of *s*: $\mathbf{F} = \mathbf{t} * \mathbf{c} * \mathbf{y}\hat{\mathbf{p}}$

Therefore, we can write (1) as follows,

$$\mathbf{g} = \hat{\mathbf{e}}\mathbf{x} = \hat{\mathbf{e}}\mathbf{Lt} * \mathbf{c} * \mathbf{y}\hat{\mathbf{p}}\mathbf{i} \qquad (2)$$

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[4] The symbols $\div$ and $*$ indicates Hadamard (elementwise) division and product respectively.

Expression (2) shows the emissions of GHG as the product of a series of factors. As we have pointed before, from a policy perspective it results interesting to quantify the effect of each of these factors in the change of the total emissions over time.

The SDA 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. There are several ways to decompose expression (2) (see Su and Ang (2012) for the different methods). We will follow the simplified method proposed by Dietzenbacher and Los (1998), based on the average of the 2 polar decomposition.

The changes in the emissions between two points in time (indicated by the subscripts 0 and 1) are given by $\Delta\mathbf{g} = \mathbf{g_1} - \mathbf{g_0}$, where subscripts indicate the years. The two polar decompositions are:

$$\begin{aligned}\mathbf{g_1} = & (\Delta\hat{\mathbf{e}})\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_0(\Delta\mathbf{L})\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_0\mathbf{L}_0(\Delta\mathbf{t}) * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} \\ & + \hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{s}_0 * (\Delta\mathbf{c}) * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * (\Delta\mathbf{y})\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0(\Delta\hat{\mathbf{p}})\mathbf{i}\end{aligned} \tag{3.1}$$

$$\begin{aligned}\mathbf{g_0} = & (\Delta\hat{\mathbf{e}})\mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i} + \hat{\mathbf{e}}_1(\Delta\mathbf{L})\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1(\Delta\mathbf{t}) * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i} \\ & + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * (\Delta\mathbf{c}) * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * (\Delta\mathbf{y})\hat{\mathbf{p}}_0\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1(\Delta\hat{\mathbf{p}})\mathbf{i}\end{aligned} \tag{3.2}$$

And the average of the polar decompositions[5]

$$\Delta\mathbf{g} = \frac{1}{2}(\Delta\hat{\mathbf{e}})(\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i}) \tag{4.1}$$

$$+\frac{1}{2}[\hat{\mathbf{e}}_0(\Delta\mathbf{L})\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_1(\Delta\mathbf{L})\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i}] \tag{4.2}$$

$$+\frac{1}{2}[\hat{\mathbf{e}}_0\mathbf{L}_0(\Delta\mathbf{t}) * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1(\Delta\mathbf{t}) * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i}] \tag{4.3}$$

$$+\frac{1}{2}[\hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{t}_0 * (\Delta\mathbf{c}) * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * (\Delta\mathbf{c}) * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i}] \tag{4.4}$$

$$+\frac{1}{2}[\hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * (\Delta\mathbf{y})\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * (\Delta\mathbf{y})\hat{\mathbf{p}}_0\mathbf{i}] \tag{4.5}$$

[5] 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.

$$+\frac{1}{2}(\hat{\mathbf{e}}_0\mathbf{L}_0\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\mathbf{i} + \hat{\mathbf{e}}_1\mathbf{L}_1\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\mathbf{i})(\Delta\hat{\mathbf{p}}) \quad (4.6)$$

Expressions 4.1 to 4.6 decompose the change in GHG emissions into 6 factors: changes in emission coefficients (4.1), changes in the economic structure (4.2), changes in the commodity mix of final demand (4.3), changes in the trade structure of final demand (4.4), changes in the final demand per capita (4.5), and changes in the population (4.6).

Expression (4.2) can further be decomposed to distinguish between changes in the production technology and changes in the trade structure of intermediate consumption. For rewriting the (1.2) we use $\Delta\mathbf{L} = \mathbf{L}_1(\Delta\mathbf{A})\mathbf{L}_0 = \mathbf{L}_0(\Delta\mathbf{A})\mathbf{L}_1$. Since $\mathbf{x} = \mathbf{Lt} * \mathbf{c} * \mathbf{y}\hat{\mathbf{p}}\mathbf{i}$, we have then that (4.2) can be written as

$$\frac{1}{2}[\hat{\mathbf{e}}_0(\Delta\mathbf{L})\mathbf{t}_1 * \mathbf{c}_1 * \mathbf{y}_1\hat{\mathbf{p}}_1\mathbf{i} + \hat{\mathbf{e}}_1(\Delta\mathbf{L})\mathbf{t}_0 * \mathbf{c}_0 * \mathbf{y}_0\hat{\mathbf{p}}_0\mathbf{i}] = \frac{1}{2}\hat{\mathbf{e}}_0\mathbf{L}_0(\Delta\mathbf{A})\mathbf{x}_1 + \hat{\mathbf{e}}_1\mathbf{L}_1(\Delta\mathbf{A})\mathbf{x}_0 \quad (5)$$

The following step is to split the change in the input coefficients equation (5) 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 $\mathbf{B}^{\mathbf{s}} = \mathbf{A}^{\mathbf{1s}} + \mathbf{A}^{\mathbf{2s}} + \mathbf{A}^{\mathbf{3s}}$, and the matrix of country technological matrices $\mathbf{B}$. The trade coefficients are defined for each country *s* as $\mathbf{T}^{\mathbf{rs}} = \mathbf{A}^{\mathbf{rs}} \div \mathbf{B}^{\mathbf{s}}$, and the matrix of country trade coefficients as $\mathbf{T}$. For each intermediate input, the corresponding $\mathbf{T}^{\mathbf{rs}}$ indicates the fraction that is imported from country *r* ($\neq s$) or is produced domestically (if $r = s$). Hence, we may write $\mathbf{A}^{\mathbf{rs}} = \mathbf{T}^{\mathbf{rs}} * \mathbf{B}^{\mathbf{s}}$, and for the whole system $\mathbf{A} = \mathbf{T} * \mathbf{B}$. This yield the following expression for the change in $\mathbf{A}$:

$$\Delta\mathbf{A} = \frac{1}{2}(\mathbf{T}_0 + \mathbf{T}_1) * \Delta\mathbf{B} + \frac{1}{2}\Delta\mathbf{T} * \mathbf{B} \quad (6)$$

From expressions (4.1) to (4.6), and (6), it follows that the change in the emissions of region 1 in sum notation reads

$$\Delta g^1 = \frac{1}{2}\sum_i \Delta e_i^1 (x_{i1}^1 + x_{i0}^1) \quad (7.1)$$

$$+\frac{1}{2}\left(\frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i0}^1 L_{ij0}^{1s}(T_{ji0}^{sr} + T_{ji1}^{sr})\Delta A_{ij}^r x_{j1}^r + \frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i1}^1 L_{ij1}^{1s}(T_{ji0}^{sr} + T_{ji1}^{sr})\Delta A_{ij}^r x_{j0}^r\right) \quad (7.2)$$

$$+\frac{1}{2}\left(\frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i0}^1 L_{ij0}^{1s}\Delta T_{ji}^{sr}(A_{ij0}^r + A_{ij1}^r)x_{j1}^r + \frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i1}^1 L_{ij1}^{1s}\Delta T_{ji}^{sr}(A_{ij0}^r + A_{ij1}^r)x_{j0}^r\right) \quad (7.3)$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s} e_{i0}^{1} L_{ij0}^{1s} \Delta t_{j}^{sr} c_{j1}^{r} y_{1}^{r} p_{1}^{r} + \sum_{i,j}\sum_{r,s} e_{i1}^{1} L_{ij1}^{1s} \Delta t_{j}^{sr} c_{j0}^{r} y_{0}^{r} p_{0}^{r}\right) \quad (7.4)$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s} e_{i0}^{1} L_{ij0}^{1s} t_{j1}^{sr} \Delta c^{r} y_{1}^{r} p_{1}^{r} + \sum_{i,j}\sum_{r,s} e_{i1}^{1} L_{ij1}^{1s} t_{j1}^{sr} \Delta c^{r} y_{0}^{r} p_{0}^{r}\right) \quad (7.5)$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s} e_{i0}^{1} L_{ij0}^{1s} t_{j0}^{sr} c_{j0}^{r} \Delta y^{r} p_{1}^{r} + \sum_{i,j}\sum_{r,s} e_{i1}^{1} L_{ij1}^{1s} t_{j1}^{sr} c_{j1}^{r} \Delta y^{r} p_{0}^{r}\right) \quad (7.6)$$

$$+\left(\frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i0}^{1} L_{ij0}^{1s} t_{j0}^{sr} c_{j0}^{r} y_{0}^{r} \Delta p^{r} + \frac{1}{2}\sum_{i,j}\sum_{r,s} e_{i1}^{1} L_{ij1}^{1s} t_{j1}^{sr} c_{j1}^{r} y_{1}^{r} \Delta p^{r}\right) \quad (7.7)$$

As showed in Table 1, expressions 7.1 to 7.7 can be used to decompose the change in the emissions of region 1 in 13 determinants (analogously, we can decompose the changes in the emissions of the other regions.). These 13 determinants can be combined in several ways. We propose aggregating them into the following 10 factors grouped into 2 categories: domestic and foreign factors. The domestic factors indicate the change in the emissions of one region due to changes in the region analysed, and the foreign factors account for the change in the emissions of one region due to changes in the socioeconomic structure abroad.

The domestic factors are: Tec_dom: the total change in domestic technology including both the changes in the domestic emission coefficients and the changes in the technology (factors 1 and 2, Table 1)[6]; TradeStr_dom: the change in the domestic trade structure of intermediate and final goods (factor 3 and 4, Table 1); GoodStr_Y_dom: the change in the commodity mix of the domestic final demand (factor 5, Table 1); Ypc_dom: the change in the domestic final demand per capita (factor 6, Table 1); Pop_dom: the change in the domestic population (factor 7, Table 1). Similarly, we would obtain the foreign factors from factors 8 to 13 of Table 1.

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

Table 1: Factors driving the change in GHG emissions of region 1.

Factor	Domestic (dom)	Foreign (fgn)
Emission coefficients	Factor 1: expression 7.1	
Technology	Factor 2: expression 7.2 when $\left(T_{ji0}^{sr}+T_{ji1}^{sr}\right)\Delta A_{ij}^{s}=\left(T_{ji0}^{s1}+T_{ji1}^{s1}\right)\Delta A_{ij}^{1}$	Factor 8: expression 7.2 $\left(T_{ji0}^{sr}+T_{ji1}^{sr}\right)\Delta A_{ij}^{s}\neq\left(T_{ji0}^{s1}+T_{ji1}^{s1}\right)\Delta A_{ij}^{1}$
Trade structure of intermediate goods	Factor 3: expression 7.3 $\Delta T_{ji}^{sr}\left(A_{ij0}^{r}+A_{ij1}^{r}\right)=\Delta T_{ji}^{s1}\left(A_{ij0}^{1}+A_{ij1}^{1}\right)$	Factor 9: 7.3 $\Delta T_{ji}^{sr}\left(A_{ij0}^{r}+A_{ij1}^{r}\right)\neq\Delta T_{ji}^{s1}\left(A_{ij0}^{1}+A_{ij1}^{1}\right)$
Trade structure of final goods	Factor 4: expression 7.4 $\Delta t_{j}^{sr}=\Delta t_{j}^{s1}$	Factor 10: 7.4 $\Delta t_{j}^{sr}=\Delta t_{j}^{s1}$
Commodity mix of the final demand	Factor 5: expression 7.5 $\Delta c_{j}^{r}=\Delta c_{j}^{1}$	Factor 11: 7.5 $\Delta c_{j}^{r}\neq\Delta c_{j}^{1}$
Final demand per capita	Factor 6: expression 7.6 $\Delta y^{r}=\Delta y^{1}$	Factor 12: 7.6 $\Delta y^{r}\neq\Delta y^{1}$
Population	Factor 7: expression 7.7 $\Delta p^{r}=\Delta p^{1}$	Factor 13 7.7 $\Delta p^{r}\neq\Delta p^{1}$

On the other hand, from expressions (4.1) to (4.6), and (6), we can also calculated to what extent the change in global emissions are driven by the changes in the socioeconomic structure of region 1. In sum notation it would read as:

$$\Delta\gamma^{1}=\frac{1}{2}\sum_{i}\Delta e_{i}^{1}\left(x_{i1}^{1}+x_{i0}^{1}\right) \tag{8.1}$$

$$+\frac{1}{2}\left(\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}\left(T_{ji0}^{sr}+T_{ji1}^{sr}\right)\Delta A_{ij}^{1}x_{j1}^{r}+\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i1}^{r}L_{ij1}^{rs}\left(T_{ji0}^{sr}+T_{ji1}^{sr}\right)\Delta A_{ij}^{1}x_{j0}^{r}\right) \tag{8.2}$$

$$+\frac{1}{2}\left(\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}\Delta T_{ji}^{s1}\left(A_{ij0}^{r}+A_{ij1}^{r}\right)x_{j1}^{r}+\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i1}^{r}L_{ij0}^{rs}\Delta T_{ji}^{s1}\left(A_{ij0}^{r}+A_{ij1}^{r}\right)x_{j0}^{r}\right) \tag{8.3}$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}\Delta t_{j}^{s1}c_{j1}^{1}y_{1}^{1}p_{1}^{1}+\sum_{i,j}\sum_{r,s}e_{i1}^{r}L_{ij1}^{rs}\Delta t_{j}^{s1}c_{j0}^{1}y_{0}^{1}p_{0}^{1}\right) \tag{8.4}$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}t_{j1}^{s1}\Delta c^{1}y_{1}^{1}p_{1}^{1}+\sum_{i,j}\sum_{r,s}e_{i1}^{r}L_{ij1}^{rs}t_{j1}^{s1}\Delta c^{1}y_{0}^{1}p_{0}^{1}\right) \tag{8.5}$$

$$+\frac{1}{2}\left(\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}t_{j0}^{s1}c_{j0}^{1}\Delta y^{1}p_{1}^{1}+\sum_{i,j}\sum_{r,s}e_{i1}^{r}L_{ij1}^{rs}t_{j1}^{s1}c_{j1}^{1}\Delta y^{1}p_{0}^{1}\right) \tag{8.6}$$

$$+\left(\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i0}^{r}L_{ij0}^{rs}t_{j0}^{sr}c_{j0}^{1}y_{0}^{1}\Delta p^{1}+\frac{1}{2}\sum_{i,j}\sum_{r,s}e_{i1}^{1}L_{ij1}^{1s}t_{j1}^{sr}c_{j1}^{1}y_{1}^{1}\Delta p^{1}\right) \tag{8.7}$$

Expressions 8.1 to 8.7 decompose the change in global emissions due to the changes in the socioeconomic structure of region 1 into the following 5 components: the change in the technology in country 1 (8.1 plus 8.2); the change in the trade structure of region 1 (8.3 plus 8.4); the change in the commodity mix of the final demand of region 1 (8.5); the change in the final demand per capita of region 1 (8.6); and the change in population in region 1 (8.7).

We have applied the previous methodology to the analysis of the change in global GHG emissions using the World Input-Output Database (WIOD). This database comprises a set of harmonized supply, use, and symmetric I-O tables, valued at current and previous year prices. It also includes data on international trade and satellite accounts related to environmental and socio-economic indicators. The WIOD comprises information from 1995 to 2009[7], for 35 industries, 59 products and 41 countries: 27 Member States of the European Union (EU), 13 non-EU countries (Australia, Brazil, Canada, China, India, Indonesia, Japan, South Korea, Mexico, Russia, Turkey, and the United States of America (USA)), and the Rest of the World (RoW) as an aggregated region. A detailed description o the database can be found at the website of the project (www.wiod.org).

3. Results

The following sections summarize the results of the decomposition of the change in global GHG emissions between 1995 and 2008. Section 3.1 shows the results for the change in global emissions and section 3.2 includes the figures by country.

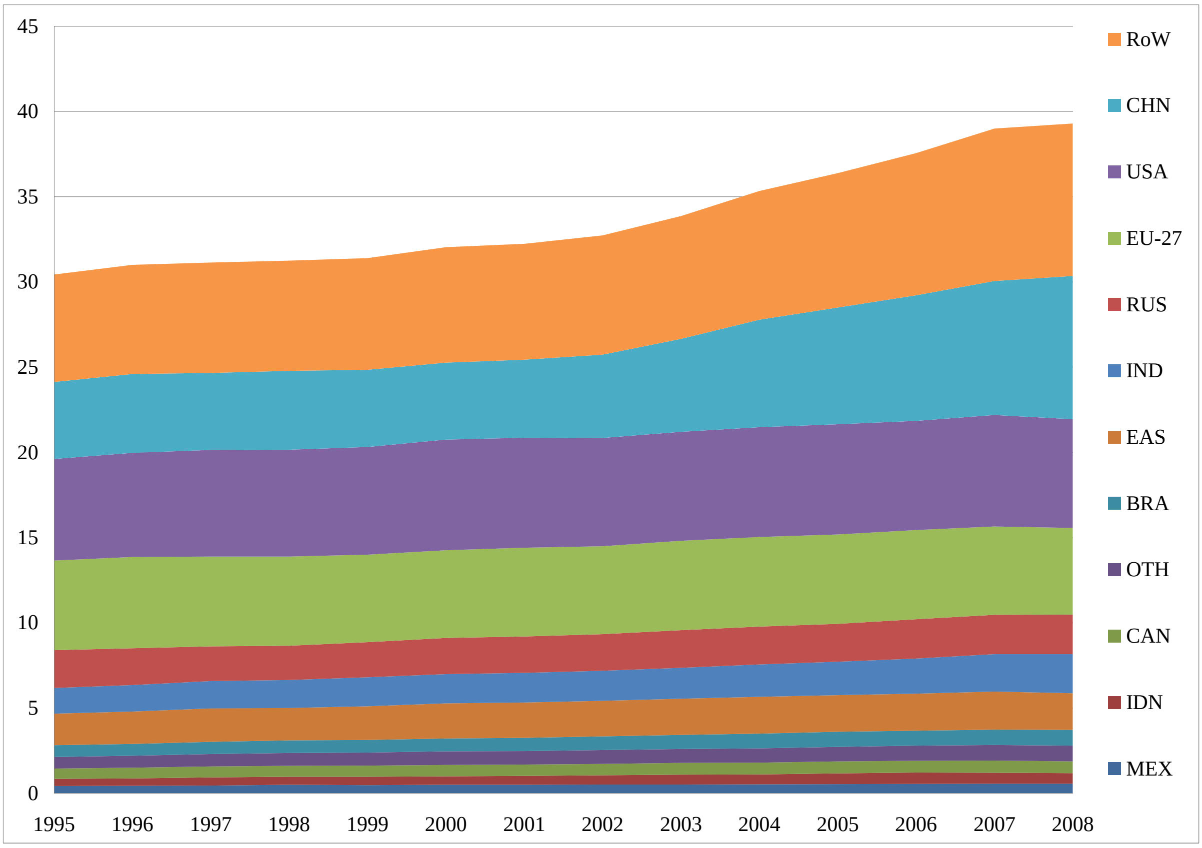
3.1. Main drivers of the change in global GHG emissions

Figure 1 and Table 2 (column 7), show the evolution of global GHG emissions between 1995 and 2008. In 2008, World's GHG emissions totalled 39.3 Giga tonnes of CO_2 equivalents ($GtCO_2e$). China was the country that emitted most GHG in the world (22.8%, 8.95 $GtCO_2e$), followed by USA (16.2%, 6.38 $GtCO_2e$), the EU-27 (12.9%, 5.08 $GtCO_2e$), Russia (5.9%, 2.33 $GtCO_2e$), India (5.8%, 2.29 $GtCO_2e$), and East Asian countries (5.5%, 2.15 $GtCO_2e$). These 6 regions accounted for more than 65% of global GHG emissions. The RoW as a whole released to the atmosphere 8.95 $GtCO_2e$ (22.8%).

[7] Since the figures for the year 2009 are preliminary estimates, the time scope has been constrained to the period 1995-2008.

Between 1995 and 2008, global GHG emissions increased by 29.1%, releasing additional 8.86 GtCO2e to the atmosphere (column 7 of Table 2). Data by country reveals that China was the country that most increased its national emissions (+3.88 GtCO_2e), succeeded by India (+0.79 GtCO_2e), USA (+0.42 GtCO_2e), East Asia (+0.3 GtCO_2e) and Brazil (+0.24 GtCO_2e). In the RoW the emissions of GHG grew by 2.64 GtCO_2e. The EU-27, on the contrary, showed a reduction of -0.17 GtCO2e (-3.3%), being Germany (-0.12 GtCO_2e), United Kingdom (-0.059 GtCO_2e) and France (-0.045 GtCO_2e) the countries with the highest reductions. In relative terms, China (+86.1%), India (+52.4%), and Indonesia (+50.9%) were the regions with the highest increases in their national GHG emissions.

Figure 1. Global GHG emissions by country, 1995-2008 (GtCO_2e)

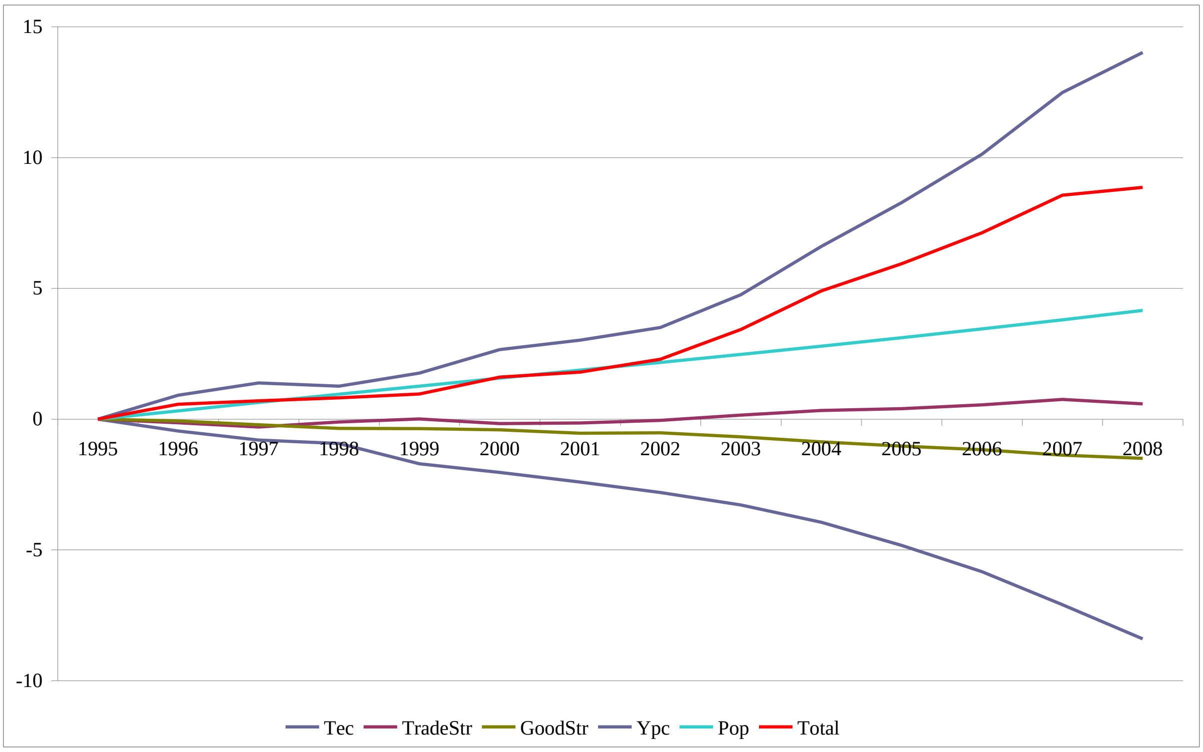


BRA: Brazil; CAN: Canada; CHN: China; EAS: East Asia (Japan, South Korea, Taiwan); EU-27: European Union 27 Member States; IDN: Indonesia; IND: India; MEX: Mexico; RUS: Russia; OTH: Other WIOD countries (Australia, Turkey); RoW: Rest of the World; USA: United States of America, WORLD: World.

According to data reported in Figure 2 and Table 2 (last row), the change in the level of final demand per capita was the main driver for the growth in global GHG emissions, contributing to an increase of 46% (+14.01 GtCO_2e) compared to 1995, whereas the growth in population contributed to increase global GHG emissions by 13.7% (+4.16 GtCO_2e) and changes in trade structure added 0.58 $GtCO_2e$. On the other hand, changes in the technology and in the commodity composition of the final demand reduced the emissions by 27.6% (-8.4 $GtCO_2e$) and 4.8% (-1.5 $GtCO_2e$) respectively. However, these reductions were insufficient to offset the growth in the other factors and consequently, as pointed bellow, global GHG emissions increased by 29.1% between 1995 and 2008.

The evolution of global GHG emissions could be divided into 2 periods: between 1995 and 2002 emissions grew at an average rate of 1% a year; in the second period (2002-2008), annual growth rate averaged 3%. This speed up in the growth rate of emissions was mainly driven by the expansion of the final demand per capita.

Figure 2. Main drivers of the change in global GHG emissions, 1995-2008 ($GtCO_2e$)



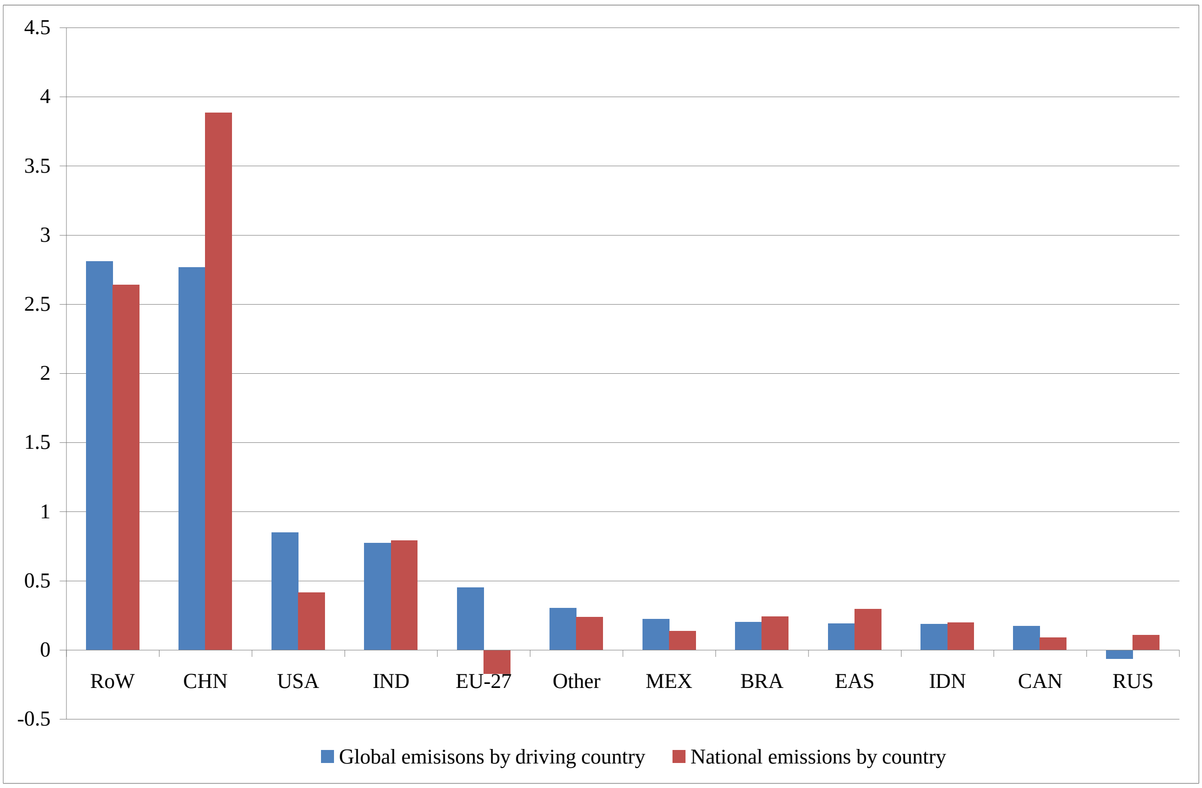
Tec: technology; TradeStr: trade structure; GoodStr_Y: commodity structure of final demand; Ypc: final demand per capita; Pop: Population.

These results can be disaggregated by the country that drove the growth in the global emissions. Figure 3 and Table 2 (columns 1 to 6) show the change in the global emissions due to the changes in the different factors, according to the country that ultimately caused the change in the emissions, and wherever the emissions were released. From this perspective, between 1995 and 2008, the RoW (+2.81 $GtCO_2e$), China (+2.77 $GtCO_2e$), USA (+0.85 $GtCO_2e$), India (+0.77 $GtCO_2e$), and the EU-27 (+0.45 $GtCO_2e$), were the regions that most contributed to the growth in global GHG emissions (column 6 of Table 2).

In all the regions, the growth in final demand per capita was the main driver for the increase in their contribution to global emissions. The growth in the final demand of China and the RoW generated contributed to increase global emissions by 4.88 and 2.49 $GtCO_2$ respectively. This was the main driver of the acceleration in the growth of GHG emissions since 2002 onwards. In the case of the USA and the EU-27, the changes in the final demand increased global emissions by 1.63 and 1.58 $GtCO_2e$ in correspondingly. Demographic growth also contributed to boost global emissions, especially the change in the population of the RoW (generating additional 1.58 $GtCO_2e$ worldwide), USA (+0.98 $GtCO_2e$), China (+0.4 $GtCO_2e$), and India (+0.35 $GtCO_2e$). As pointed bellow, technological changes limited the growth on global emissions; China (-2.53 $GtCO_2e$), the RoW (-1.9 $GtCO_2e$), the EU-27 (-1.37 $GtCO_2e$), USA (-0.95 $GtCO_2e$), and India and Russia (-0.48 $GtCO_2e$ each) were the countries that most contributed to the reduction of global emissions via technological change.

If we compare these figures with the ones corresponding to the national emissions (Figure 3 and column 7 of Table 2), we find that the change in global emissions driven by emerging economies, such as Brazil, Russia, India, Indonesia and China, was less than the change in their national emissions. Between 1995 and 2008, these group of countries increased their national emission by 5.22 $GtCO_2e$ (60% of the growth on global emissions) due to changes global socioeconomic structures (i.e. including both the changes in their domestic and in foreign structures). However, the growth in global emissions due to the socioeconomic changes in those countries limited to 3.86 $GtCO_2e$ (44% of the growth on global emissions). The contrary can be observed in developed economies (EU-27, USA, Canada, Japan, South Korea, and Australia); in these countries the increase in national emissions (+0.74 $GtCO_2e$, 8% of the change on global emissions) was lower than the growth in global emissions due to the changes in their socioeconomic structures (+1.81 $GtCO_2e$, 20% of the change on global emissions). The difference between both approaches show a growth in the net transferences of emissions between developed and emerging economies of 1.07 $GtCO_2e$, equivalent to 20% of the growth in the emissions of emerging countries.

Figure 3. Change in global GHG emissions by driving country and change in national emissions by country, 1995-2008 ($GtCO_2e$)



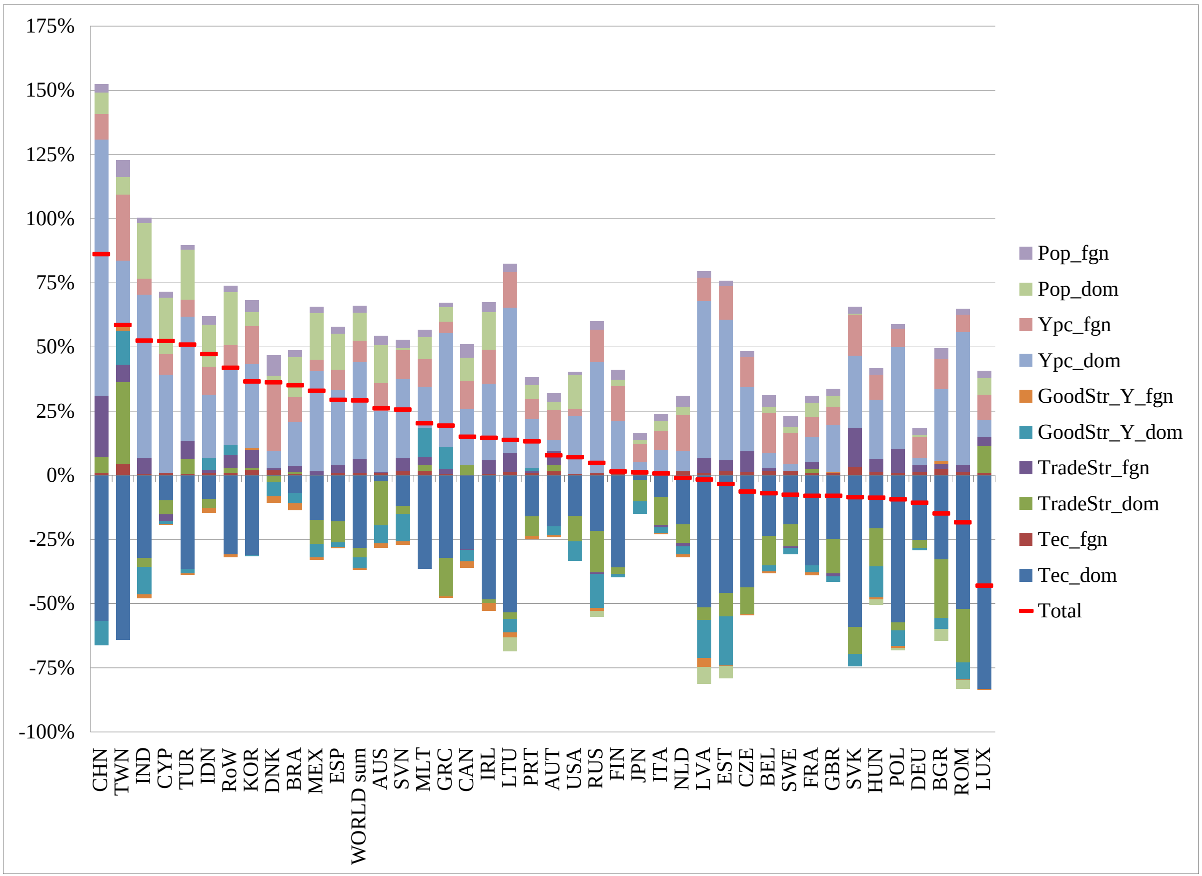
BRA: Brazil; CAN: Canada; CHN: China; EAS: East Asia (Japan, South Korea, Taiwan); EU-27: European Union 27 Member States; IDN: Indonesia; IND: India; MEX: Mexico; RUS: Russia; OTH: Other WIOD countries (Australia, Turkey); RoW: Rest of the World; USA: United States of America, WORLD: World.

3.2. Main drivers of the change in GHG emissions by country

Results by factor

At the country level (Figure 4 and Table 3), between 1995 and 2008 the evolution of GHG emissions was mainly driven by the growth in the level of domestic final demand per capita. Population (domestic and foreign) and foreign trade structure also contributed to increase the emissions in almost all the countries. On the contrary, the change in the domestic technology and in the good structure (domestic and foreign) reduced the emissions in most countries. However only in 15 European countries (and in the EU-27 as a whole) gains in terms of cleaner production, together with other factors, offset the growth in emissions.

Figure 4. Main drivers of the change in GHG emissions by country and World average, 1995-2008



AUS: Australia; AUT: Austria; BEL: Belgium; BRA: Brazil; BGR: Bulgaria; CAN: Canada; CHN: China; CYP: Cyprus; CZE: Czech Republic; DNK: Denmark; EST: Estonia; FIN: Finland; FRA: France; DEU: Germany; GRC: Greece; HUN: Hungary; IND: India; IDN: Indonesia; IRL: Ireland; ITA: Italy; JPN: Japan; KOR: South Korea; LVA: Latvia; LTU: Lithuania; LUX: Luxembourg; MLT: Malta; MEX: Mexico; NLD: Netherlands; POL: Poland; PRT: Portugal; ROM: Romania; RUS: Russia; SVK: Slovakia; SVN: Slovenia; ESP: Spain; SWE: Sweden; TWN: Taiwan; TUR: Turkey; GBR: United Kingdom; USA: United States of America; RoW: Rest of the World; WORLD: World.

In emerging economies and in the European countries that experimented the highest economic expansion, the weight of domestic final demand per capita in the change of emissions was greater than the World average (36.5%): China (45.3% of the gross change[8]), India (42.4%), Cyprus (42.2%), Latvia (39.7%), Slovenia (38.8%), Mexico (38.4%), Turkey (38%), Lithuania (37.8%), Greece (37.8%) and Russia (36.5%). This share was bellow 10% in most of the richest countries (in terms of GDP per capita) of the EU (i.e. Sweden, Belgium, Austria, Germany, Luxembourg and Sweden). In absolute figures, China (+4.51 GtCO_2e), the RoW (+1.89 GtCO_2e), USA (+1.34 GtCO_2e), Russia (+0.96 GtCO_2e) and India (+0.95 GtCO_2e) were the countries in which domestic final demand had most impact on emissions.

[8] The gross change in the emissions is defined as $\Delta\bar{g}_F^r = \left|\Delta g_F^r\right| / \sum_r \left|\Delta g_F^r\right|$, where F denotes the factor of the decomposition.

Changes in foreign final demand also affected significantly the evolution of GHG emissions in most countries. Denmark shows the highest change due to foreign final demand per capita (47.5% of the gross change). This is mainly due to the exports of water transport services, which are highly intensive in emissions. In some mature open economies, the effect of foreign final demand was higher than that of the domestic; this was the case of, Austria, Belgium, Denmark, Germany, Japan, Luxembourg, Netherlands, Sweden and Taiwan. Within this group of countries, in Austria, Belgium, Japan, Netherlands and Sweden the share of the gross change in emissions explained by foreign final demand was close to 20%. The RoW (+0.55 $GtCO_2e$), China (+0.44 $GtCO_2e$), Russia (+0.28 $GtCO_2e$), USA (+0.18) and India (+0.09 $GtCO_2e$) were the regions with the highest increase in emissions due to changes foreign final demand.

Domestic population also contributed to increase the emissions in almost all the countries. Brazil (26.5%), Cyprus (24.4%), the RoW (20%), Indonesia (19%), Mexico (18%), and USA and Australia (17.6% each) were the regions in which the demographic growth had the largest effect in emissions in relative terms. In absolute numbers, domestic population had the largest effect in the most populated regions: RoW (+3.38 $GtCO_2e$), USA (+0.79 $GtCO_2e$), China (+0.38 $GtCO_2e$), India (+0.33 $GtCO_2e$) and Brazil (+0.11 $GtCO_2e$). In Russia, Romania, Bulgaria, Poland, Hungary, and the Baltic Republics the reduction of domestic population due to migration reduced slightly the emissions. Foreign population also increased the emissions in all the countries analyzed, but the impact of this factor was low compared to the others (+0.15 $GtCO_2e$ in China, or +0.07 $GtCO_2e$ in USA and in Russia).

The domestic technology is the second most important driving force of GHG emissions after the domestic final demand per capita. In all the countries analyzed domestic technology contributed to reduce the national emissions. Luxembourg (62.2% of the gross change), Germany (53%), France (51.6%), Poland (45.2%) and Finland (42.7%) were the countries with the largest reductions in emissions owing to domestic technology. The improvements in terms of energy efficiency and the changes in the energy mix towards cleaner energy sources (substitution of coal and oil by natural gas and renewables) were the major causes of this technological change. In Denmark (0.8%), Austria (2.9%) and Japan (5.5%) less than 10% of the gross change in emissions was caused by domestic technology. In absolute terms, China (-2.57 $GtCO_2e$), the RoW (-1.95 $GtCO_2e$), USA (-0.95 $GtCO_2e$), and India and Russia (-0.48 $GtCO_2e$ each) ranked the top five in terms of reduction of GHG by means of technological change. Foreign technology contributed to increase the emissions in all the countries, but the effect of this factor on the gross change was bellow 3% in all the cases.

In most countries, the changes in the domestic trade structure reduced the emissions. USA (-0.59 $GtCO_2e$), Russia (-0.36 $GtCO_2e$), the EU-27 (-0.38 $GtCO_2e$), Japan (-0.1 $GtCO_2e$), and India and Australia (-0.08 $GtCO_2e$) were the countries that most reduced their emissions by increasing the share of goods imported. On the contrary, in China (+0.22 $GtCO_2e$), the RoW (+0.1 $GtCO_2e$), Taiwan (+0.07 $GtCO_2e$) and Korea (+0.02 $GtCO_2e$) the emissions grew as a consequence of the increase of the share of domestic produced goods in the economy.

The change in foreign trade structures augmented the emissions in 33 out of 41 countries. The increase of the weight of Chinese exports in the economic structure of other economies caused a growth in Chinese emissions of 1.08 $GtCO_2e$. Changes in foreign trade structures also affected the emissions of other exporting areas such as the RoW (+0.32 $GtCO_2e$), the EU-27 (+0.13 $GtCO_2e$) or other East Asian economies (+0.05 $GtCO_2e$).

The commodity structure of domestic final demand also reduced the emissions in most countries. The increase in the share of less emission-intensive products in the domestic final demand reduced the emissions by 0.45 $GtCO_2e$ in USA, 0.42 $GtCO_2e$ in China, 0.29 $GtCO_2e$ in Russia, and 0.16 $GtCO_2e$ in India. This same trend can be observed in the effect of the commodity structure of foreign final demand, although the figures are lower.

Finally, it is also noticeable that domestic factors had a decreasing net effect on emissions on 21 out of 41 countries, while foreign factors contributed to increase the emissions in all the regions analyzed. Moreover, aggregating domestic and foreign factors (columns 6 and 12 in Table 3), we find that in almost all the developed countries, the net effect of foreign factors on the growth of emissions is larger than that of domestic factors. On the contrary, in the RoW, Brazil, Russia, India, Indonesia, China, Mexico, Turkey, Cyprus, Greece, Ireland and Spain the domestic changes are higher than foreign changes.

Results by country

This section explains the driving forces of the change in GHG emission of the World's largest economies (see also Figure 4, Figure 5 and Table 3).

In the USA, domestic final demand and population added 1.34 $GtCO_2e$ and 0.79 $GtCO_2e$ respectively, while foreign final demand and population 0.18 $GtCO_2e$ and 0.07 $GtCO_2e$. Domestic technology contributed to reduce the emissions by 0.95 $GtCO_2e$ and domestic trade and good structure by 0.59 and 0.45 $GtCO_2e$ in that order. Figure 5 shows that the change in

GHG emissions is highly correlated to the domestic factors, however, the foreign ones increased their relevance in the last years, representing one third of total change at the end of the period. From the year 2000 onwards, the domestic factors reduced the emissions by 0.3 $GtCO_2e$ while the foreign factors increased them by 0.2 $GtCO_2e$.

Between 1995 and 2007, GHG emissions grew in Japan by 6.7% (+0.08 $GtCO_2e$); however, in the year 2008, emissions drop by 5.3% (-0.07 $GtCO_2e$). As a result, in the whole period, Japanese emissions slightly increased by 1.1% (+0.01 $GtCO_2e$). In the case of Japan, foreign final demand per capita was the main driver for the growth in GHG (+0.09 $GtCO_2e$), while domestic final demand caused additional 0.04 $GtCO_2e$. In this country, foreign population also impacted on emissions more than the domestic (+0.04 $GtCO_2e$ versus +0.02 $GtCO_2e$). The changes in the domestic trade and good structures were the factors that most reduced the emissions (-0.1 and -0.06 $GtCO_2e$ respectively); domestic technology reduced the emissions by 0.02 $GtCO_2e$. Figure 5 shows the path followed by domestic, foreign and total changes in emissions. Until 2002, these 3 indicators follow a growing trend. However, since the year 2002 onwards, it can be noticed a decoupling between foreign (increasing) and domestic (decreasing) changes.

Germany is the country with the largest reduction in GHG emissions between 1995 and 2008 (-0.12 $GtCO_2e$). The improvements in domestic technology have favoured this trend, with a reduction of 0.28 $GtCO_2e$; changes in trade and good structures contributed to reduce the emissions by 0.04. As pointed bellow, Germany is part of the group of countries in which the effect of foreign final demand and population was greater than the domestic (+0.09 and +0.03 $GtCO_2e$ versus 0.03 and 0.01 $GtCO_2e$). Summing up the effect of all the domestic factors and all the foreign factors we can observe that domestic and foreign aggregates follow diverging paths. The foreign factors increased the emissions at a yearly rate of 1.1% (with a cumulative change of +0.17 $GtCO_2e$) while the domestic factors reduced the emissions at an annual rate of 2.3% (with a cumulative change of -0.9 $GtCO_2e$).

The pattern followed by the emissions in France is quite similar to that of Germany. The reduction in French emissions (-0.05 $GtCO_2e$) was driven by domestic technology (-0.2 $GtCO_2e$). Foreign and domestic final demand increased the emissions by 0.05 and 0.04 $GtCO_2e$ respectively, and population by 0.03 $GtCO_2e$ (foreign) and 0.01 $GtCO_2e$ (domestic). Here again the foreign and domestic effects followed opposite trends, but the growing foreign increases could not offset domestic reductions.

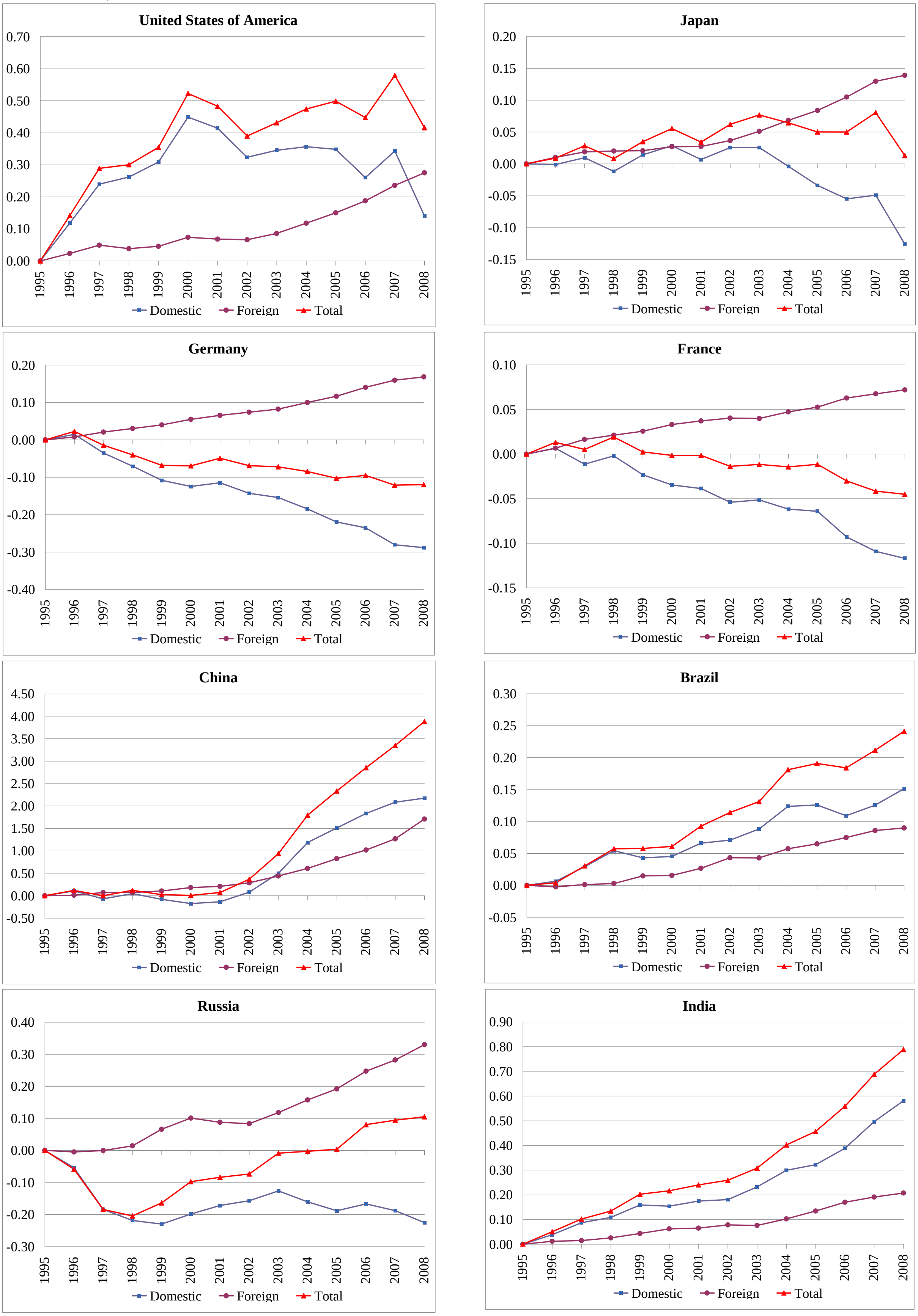
China is the country with the highest growth in emissions (+3.88 $GtCO_2e$). This increase in the emissions took place from 2002 onwards and was mainly driven up by the domestic final demand per capita (+4.5 $GtCO_2e$). The change in the weight of Chinese exports in other countries contributed to boost Chinese emissions by 1.08 $GtCO_2e$, and the growth in foreign final demand increased the emissions by 0.44 $GtCO_2e$. Domestic and foreign population augmented the emissions by 0.38 and 0.15 $GtCO_2e$ respectively. In contrast, domestic technology contributed to reduce the emissions by 2.57 $GtCO_2e$, and the changes in the composition of domestic final demand cut the emissions by 0.42. Aggregating domestic factors and foreign factors we can observe that both follow a similar growing trend (Figure 5). Moreover, the weight of domestic and foreign driven factors in the net change of emissions is quite similar (56% and 44% of the total change respectively).

In the period 1995-2008, GHG emissions increased in Brazil by 0.24 $GtCO_2e$ (+35%). Domestic final demand and population were the factors that most contributed to the growth in emissions (+0.12 and +0.11 $GtCO_2e$ respectively), followed by foreign final demand and population (+0.07 and +0.02 $GtCO_2e$ respectively). Other factors such as domestic technology, good structure of final demand (domestic and foreign) reduced the emissions by 0.09 $GtCO_2e$. The total net effect of domestic factors increased the emissions by 0.15 $GtCO_2e$ (62.7% of the net change), and the foreign factors by 0.09 $GtCO_2e$ (37.3%).

Between 1995-2008, GHG emissions increased in Russia by 0.11 $GtCO_2e$ (+4.7%). Domestic and foreign final demand were the main drivers for the growth in emissions (+0.96 and +0.28 $GtCO_2e$ respectively). Domestic technology, domestic trade structure and domestic good structure of final demand contributed to reduce the emissions by 0.48, 0.36 and 0.29 $GtCO_2e$ in that order. The total net effect of domestic factors reduced the emissions by 0.23 $GtCO_2e$, while the foreign factors increased the emissions by 0.33 $GtCO_2e$.

India is the second country with highest growth in GHG emissions (+0.79 $GtCO_2e$ between 1995 and 2008). Domestic final demand per capita and population were the factors that most contributed to increase the emissions (+0.95 and +0.33 $GtCO_2e$ respectively). Foreign dynamics also played an important role in the evolution of Indian emissions: foreign trade structure increased the emissions by 0.1 $GtCO_2e$, final demand by 0.09 $GtCO_2e$ and population by 0.03 $GtCO_2e$. On the other hand, domestic technology reduced the emissions by 0.48 $GtCO_2e$, domestic good structure by 0.16 $GtCO_2e$, and domestic trade structure by 0.06 $GtCO_2e$. As in the case of other emerging economies, although the domestic factors were responsible for the most part of the net growth in emissions (73.7%), foreign factors also influenced this growing trend (26.3%).

Figure 5. Domestic and foreign driven changes in GHG emissions of selected countries, 1995-2008 ($GtCO_2$-e)



4. Conclusions

The identification of the driving forces of the change in GHG emissions is essential for the definition of climate policies. We have calculated for the first time the effects of the different factors driving the evolution of GHG emissions worldwide in the period 1995-2008. According to our estimations, the change in the level of final demand per capita (especially in China, the RoW, USA, the EU-27 and India) was the main driver for the growth in global GHG emissions, contributing to an increase of 46% (+14.01 $GtCO_2e$), whereas the growth in population (mainly in the RoW, USA and China) and changes in trade structure contributed to increase global GHG emissions by 13.7% and 1.91% respectively (+4.16 and +0.58 $GtCO_2e$). Changes in the technology and in the commodity composition of the final demand reduced the emissions by 27.6% (-8.4 $GtCO_2e$) and 4.8% (-1.47 $GtCO_2e$) respectively. However, these reductions were insufficient to offset the growth in the other factors.

Between 1995 and 2008, global GHG emissions grew by 8.86 $GtCO_2e$ (+29.1%). Emerging economies (Brazil, Russia, India, Indonesia and China) increased their national emissions by 55.8% (+5.21 $GtCO_2e$), while the emissions of developed countries (EU-27, USA, Canada, Japan, South Korea, Taiwan and Australia) grew by +5.3% (+0.74 $GtCO_2e$). However, if we account for the change in global emissions according to the country that ultimately caused the change in the emissions, and independently where they were released, we find that growth on global emissions due to the change in the socioeconomic structures of emerging economies (26% less than the change in their national emissions). On the contrary, the contribution of developed economies to the change of global emissions exceeded national emissions by a factor of 2.4. These figures reveal a growth in the net transferences of emissions between developed and emerging economies equivalent to 20% of the growth in the emissions of emerging countries

At the country level, the evolution of GHG emissions was mainly driven by the growth in the level of domestic final demand per capita. Population (domestic and foreign) and foreign trade structure also contributed to increase the emissions in almost all the countries. On the contrary, the change in the domestic technology and in the good structure (domestic and foreign) reduced the emissions in most countries. However only in 15 European countries gains in terms of cleaner production, together with other factors offset the growth in emissions.

The inter-country effects are a significant driver for the evolution of national GHG emissions. In almost all the developed countries, the net effects of foreign factors on the growth of emissions are larger than those of domestic factors. In developing economies, the growth on GHG emissions is mainly due to domestic factors, however, foreign factors also have a relevant impact on emissions (44% of the net change in China, 37.3% in Brazil, 26.3% in India). These results connect with the outstanding debate about the role of international trade on the growth of GHG emissions and the allocation of the responsibility of emissions among countries.

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Table 2: Main drivers of the change in global GHG emissions by country, 1995-2008 ($MtCO_2e$)

	Tec (1)	TradeStr (2)	GoodStr_Y (3)	Ypc (4)	Pop (5)	Total change (6 = 1 to 5)	Change in national emissions (7)	Difference (8 = 6 – 7)
BRA	**-42**	**15**	**-29**	**136**	**121**	**201**	**241**	**-41**
CAN	**-169**	**68**	**-7**	**198**	**80**	**170**	**90**	**80**
CHN	**-2,526**	**412**	**-405**	**4,881**	**404**	**2,766**	**3,883**	**-1,116**
IDN	**-39**	**-7**	**26**	**127**	**80**	**187**	**198**	**-11**
IND	**-478**	**-11**	**-145**	**1,053**	**354**	**773**	**788**	**-15**
MEX	**-70**	**5**	**-16**	**205**	**98**	**223**	**137**	**86**
RUS	**-475**	**-320**	**-272**	**1,058**	**-55**	**-64**	**105**	**-169**
USA	**-950**	**-212**	**-599**	**1,634**	**977**	**850**	**416**	**434**
RoW	**-1,900**	**341**	**294**	**2,494**	**1,580**	**2,809**	**2,641**	**168**
JPN	-27	-11	-136	41	27	-106	13	-119
KOR	-138	73	-29	218	36	160	163	-4
TWN	-109	119	19	85	22	136	120	16
EAS	**-274**	**180**	**-146**	**344**	**85**	**189**	**296**	**-106**
AUS	-4	-46	-29	140	85	146	114	32
TUR	-97	28	-4	167	64	157	123	34
Other	**-101**	**-18**	**-34**	**307**	**149**	**303**	**237**	**66**
AUT	-8	19	-2	16	6	31	6	25
BEL	-31	-10	-6	33	9	-5	-11	6
BGR	-20	-19	-2	32	-5	-15	-12	-3
CYP	0	1	-1	5	3	8	3	4
CZE	-59	-8	2	55	1	-9	-9	0
DEU	-260	115	-38	93	12	-78	-120	42
DNK	3	7	-5	16	4	25	32	-7
ESP	-35	22	-5	148	73	202	89	113
EST	-10	6	-10	17	-1	1	-1	2
FIN	-23	1	0	28	4	10	1	9
FRA	-181	71	17	126	56	88	-45	133
GBR	-179	-12	-55	248	50	54	-59	113
GRC	-38	-10	14	70	9	45	20	25
HUN	-17	-10	-12	34	-3	-7	-7	0
IRL	-25	11	3	30	15	35	8	26
ITA	-28	-20	-24	93	37	57	4	54
LTU	-13	3	-1	26	-2	13	3	10
LUX	-7	2	0	3	2	-1	-4	3
LVA	-6	0	-2	15	-1	5	0	5
MLT	0	0	0	1	0	1	0	1
NLD	-36	-10	-15	60	17	17	-3	19
POL	-244	11	-14	224	-4	-27	-42	15
PRT	-10	-6	3	23	6	16	9	7
ROM	-95	-36	-10	121	-7	-28	-33	5
SVK	-39	-2	-2	32	0	-11	-5	-7
SVN	-2	3	-2	11	0	10	5	5
SWE	-11	3	0	17	5	14	-6	20
EU-27	**-1,374**	**130**	**-166**	**1,577**	**284**	**451**	**-174**	**626**
World	**-8,399**	**582**	**-1,498**	**14,014**	**4,158**	**8,858**	**8,858**	**0**

Regions: AUS: Australia; AUT: Austria; BEL: Belgium; BRA: Brazil; BGR: Bulgaria; CAN: Canada; CHN: China; CYP: Cyprus; CZE: Czech Republic; DNK: Denmark; EST: Estonia; FIN: Finland; FRA: France; DEU: Germany; GRC: Greece; HUN: Hungary; IND: India; IDN: Indonesia; IRL: Ireland; ITA: Italy; JPN: Japan; KOR: South Korea; LVA: Latvia; LTU: Lithuania; LUX: Luxembourg; MLT: Malta; MEX: Mexico; NLD: Netherlands; POL: Poland; PRT: Portugal; ROM: Romania; RUS: Russia; SVK: Slovakia; SVN: Slovenia; ESP: Spain; SWE: Sweden; TWN: Taiwan; TUR: Turkey; GBR: United Kingdom; USA: United States of America; RoW: Rest of the World; WORLD. EAS: East Asia (Japan, South Korea, Taiwan); EU-27: European Union 27 Member States; OTH: Other WIOD countries (Australia, Turkey).

Factors: Tec: technology; TradeStr: trade structure; GoodStr_Y: commodity structure of final demand; Ypc: final demand per capita; Pop: Population.

Table 3: Main drivers of the change in national GHG emissions by country, 1995-2008 ($MtCO_2e$)

	Tec_dom (1)	TradeStr_dom (2)	GoodStr_Y_dom (3)	Ypc_dom (4)	Pop_dom (5)	Total_dom (6 = 1 to 5)	Tec_fgn (7)	TradeStr_fgn (8)	GoodStr_Y_fgn (9)	Ypc_fgn (10)	Pop_fgn (11)	Total_fgn (12 = 7 to 11)	Total (13 = 6 + 12)
BRA	**-47**	**5**	**-29**	**116**	**107**	**151**	**4**	**18**	**-18**	**67**	**19**	**90**	**241**
CAN	**-175**	**24**	**-27**	**131**	**55**	**8**	**0**	**-1**	**-15**	**67**	**31**	**83**	**90**
CHN	**-2,566**	**278**	**-424**	**4,509**	**379**	**2,174**	**39**	**1,076**	**7**	**440**	**147**	**1,708**	**3,883**
IDN	**-38**	**-16**	**21**	**103**	**69**	**138**	**4**	**4**	**-7**	**46**	**13**	**59**	**198**
IND	**-484**	**-55**	**-162**	**955**	**327**	**581**	**6**	**97**	**-21**	**94**	**30**	**207**	**788**
MEX	**-73**	**-39**	**-22**	**162**	**76**	**105**	**1**	**6**	**-4**	**19**	**10**	**32**	**137**
RUS	**-482**	**-362**	**-289**	**959**	**-51**	**-225**	**19**	**-15**	**-27**	**282**	**71**	**330**	**105**
USA	**-946**	**-591**	**-450**	**1,342**	**786**	**141**	**25**	**-6**	**1**	**183**	**72**	**275**	**416**
RoW	**-1,950**	**118**	**246**	**1,894**	**1,311**	**1,619**	**64**	**321**	**-69**	**555**	**152**	**1,022**	**2,641**
JPN	-22	-103	-58	39	17	-126	10	2	9	86	31	139	13
KOR	-139	4	-2	146	24	33	9	32	4	66	20	130	163
TWN	-131	65	27	52	14	26	9	14	4	53	13	93	120
EAS sum	**-292**	**-34**	**-33**	**237**	**55**	**-66**	**28**	**49**	**17**	**205**	**64**	**362**	**296**
AUS	-11	-75	-31	105	64	52	3	2	-8	48	16	62	114
TUR	-89	15	-4	118	47	87	1	16	-1	16	4	36	123
Other sum	**-100**	**-61**	**-35**	**223**	**111**	**140**	**5**	**18**	**-9**	**64**	**21**	**98**	**237**
AUT	-15	2	-3	3	2	-10	1	4	-1	9	2	16	6
BEL	-36	-18	-3	9	4	-45	3	1	-1	24	7	34	-11
BGR	-26	-19	-3	23	-4	-29	2	2	1	10	3	17	-12
CYP	-1	0	0	3	1	3	0	0	0	1	0	1	3
CZE	-62	-15	0	35	0	-41	2	11	-1	16	3	32	-9
DEU	-280	-35	-9	28	8	-288	12	32	3	93	29	168	-120
DNK	0	-2	-5	6	2	1	2	1	-2	24	7	31	32
ESP	-55	-24	-6	88	43	46	2	10	-1	24	8	43	89
EST	-10	-2	-4	11	-1	-5	0	1	0	3	0	4	-1
FIN	-26	-2	-1	14	2	-13	1	0	0	10	3	14	1
FRA	-197	9	-15	54	31	-117	4	16	-6	43	15	72	-45
GBR	-183	-99	-15	134	30	-132	7	-9	2	53	20	73	-59
GRC	-34	-16	9	46	6	12	1	2	0	5	2	8	20
HUN	-17	-12	-10	18	-2	-22	1	4	-1	8	2	15	-7
IRL	-28	-1	0	17	8	-3	0	3	-2	8	2	12	8
ITA	-45	-58	-11	49	21	-44	4	-6	-3	40	13	48	4
LTU	-13	-1	-1	13	-1	-2	0	2	0	3	1	6	3
LUX	-7	1	0	1	1	-5	0	0	0	1	0	1	-4
LVA	-7	-1	-2	8	-1	-2	0	1	0	1	0	2	0
MLT	-1	0	0	0	0	0	0	0	0	0	0	0	0
NLD	-46	-17	-8	19	8	-44	4	-3	-3	33	10	41	-3
POL	-254	-14	-26	175	-4	-122	4	41	-4	32	7	81	-42
PRT	-12	-5	1	14	4	1	1	1	-1	6	2	8	9
ROM	-94	-37	-12	93	-6	-56	2	5	0	12	4	23	-33
SVK	-31	-6	-3	15	0	-24	2	8	0	8	1	20	-5
SVN	-2	-1	-2	6	0	1	0	1	0	2	1	4	5
SWE	-15	-7	-2	2	2	-20	1	0	0	10	3	14	-6
EU-27 sum	**-1,497**	**-378**	**-129**	**886**	**156**	**-962**	**56**	**127**	**-21**	**478**	**148**	**788**	**-174**
World sum	**-8,649**	**-1,111**	**-1,332**	**11,516**	**3,380**	**3,803**	**250**	**1,693**	**-166**	**2,498**	**778**	**5,054**	**8,858**

Regions: AUS: Australia; AUT: Austria; BEL: Belgium; BRA: Brazil; BGR: Bulgaria; CAN: Canada; CHN: China; CYP: Cyprus; CZE: Czech Republic; DNK: Denmark; EST: Estonia; FIN: Finland; FRA: France; DEU: Germany; GRC: Greece; HUN: Hungary; IND: India; IDN: Indonesia; IRL: Ireland; ITA: Italy; JPN: Japan; KOR: South Korea; LVA: Latvia; LTU: Lithuania; LUX: Luxembourg; MLT: Malta; MEX: Mexico; NLD: Netherlands; POL: Poland; PRT: Portugal; ROM: Romania; RUS: Russia; SVK: Slovakia; SVN: Slovenia; ESP: Spain; SWE: Sweden; TWN: Taiwan; TUR: Turkey; GBR: United Kingdom; USA: United States of America; RoW: Rest of the World; WORLD. EAS: East Asia (Japan, South Korea, Taiwan); EU-27: European Union 27 Member States; OTH: Other WIOD countries (Australia, Turkey).

Factors: Tec_dom: domestic technology; TradeStr_dom: domestic trade structure; GoodStr_Y_dom: domestic commodity structure of final demand; Ypc_dom: domestic final demand per capita; Pop_dom: domestic population; Total_dom: total domestic; Tec_fgn: foreign technology; TradeStr_fgn: foreign trade structure; GoodStr_Y_fgn: foreign commodity structure of final demand; Ypc_fgn: foreign final demand per capita; Pop_fgn: foreign Population; Total_fgn: total foreign.