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European union membership and CO_2 emissions: A structural decomposition analysis

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ABSTRACT

This paper's interest lies in the environmental pressures of the European Union (EU). EU membership requires a series of economic and political changes that should impact a country's production and consumption structures and its trade relationships. These changes, in turn, will affect CO_2 emissions sources and levels. This is especially true for the new Member States that joined during the 2004–2007 enlargement of the European Union, given the difference in their levels of development and production structure. As these countries increase participation in a globally integrated production chain their emission's structure and level should change. Using a Structural Decomposition Analysis we are able to quantify the main drivers of changes in emissions differentiating six components, namely: emissions intensity, industrial structure and sourcing, consumer preferences, final demand sourcing and consumption levels. Grouping the countries into five groups, New European Union countries, Old European Union countries, the United States of America, China, and the Rest of the World, we measure trading pattern changes and their impact on CO_2 emission levels. The main results show that, although New European Union countries countries' emissions generally declined, the changes were not large enough to offset their increased emissions from access to more and wider ranging export demand. Increased CO_2 emissions embodied in final goods exports were especially notable.

1. Introduction

International trade flows have been intensified by the fragmentation of production. As a consequence, there has been greater production and commercial integration among countries, the entry of certain economies into specialized markets in the world, and the expansion of production scale. All of these have been incentivized by the reduction of trade barriers, foreign investments and technological advances, especially in the fields of communication and information.

One instrument that fosters the increase of international trade, and which is the focus of this paper, is the formation of monetary unions or free trade areas. There are costs and benefits involved in participating in such agreements. Costs include the loss of monetary policy as a macroeconomic tool for stabilization, while benefits include the increases in trade, investment, and diversification of consumption bundles (Micco et al., 2003). A large part of the trade literature focusing on the impacts of the formation of the European Economic and Monetary Union (EU) shows measurable effect on the member countries' patterns of international trade, e.g., Bun and Klaassen (2002), Micco et al. (2003), Barr et al. (2003), De Nardis and Vicarelli (2003), Flam and Nordström (2006), Sousa and Lochard (2004), Faruqee (2004), and Baldwin et al. (2005).

The interest in this paper lies in the environmental pressure of EU-related economic restructuring. From a historical perspective, there have been different waves of entrance into the EU. For the specific aim of this paper, we are interested in the wave that occurred in the 2000s. Cyprus, Slovakia, Slovenia, Estonia,

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Hungary, Latvia, Lithuania, Malta, Poland, and the Czech Republic joined the EU in 2004, while Bulgaria and Romania joined the EU in 2007. As discussed by Barlow and Radulescu (2005), Grosjean et al. (2013), BenYishay and Grosjean (2014), Tarabar and Young (2017) and Tarabar (2017), EU membership requires a series of economic and political changes that should impact the country's production and consumption structure and its trade relationships. These institutional reforms affected the productivity of these economies (Driffield et al., 2013), which, in turn, should affect the CO_2 emissions level and source (Bae et al., 2017; Brizga et al., 2013; Malik and Lan, 2016). This is especially true for countries that entered during the 2004 and 2007 EU enlargement because there is a clear distinction in levels of development and, perhaps more interestingly, because these nations have emerged from decades under socialist planning as market economies within the fold of the European Union.

European agreements negotiated between the EU and the Central and East European countries from the 1990s included a set of conditions compatible with a market economy that had to be met by applicant countries before membership would be given (Lane, 2007). The aim of these agreements and other pre-accession mechanisms was to gradually liberalize trade among these countries and old EU Member States, and prepare the new Member State institutionally for entry in the EU.

The entrance of new countries into the EU increased trade among these countries and the EU's old members, along with the rest of the world. Our hypothesis is that the greater participation in a globally integrated production chain would change the structure of emissions (Brunel, 2017; Douglas and Nishioka, 2012; Levinson, 2009; 2015; Shapiro and Walker, 2018). Further, the gradual entry of new Member States into the EU should influence their economic integration with the EU members and the rest of the world, hence, affecting their trade structure. This scenario provides us with a unique opportunity to assess how greater economic and commercial integration impacts emissions embodied in international trade. Therefore, this paper contributes to a better understanding of the spatial pattern of CO_2 emissions in the context of the economic and political reforms towards a more market-based economy occurring in Central and Eastern European countries upon joining the EU.

The dissociation between consumption and production enables transferring the emissions burden of production from one country to another (Dietzenbacher et al., 2012; Lan et al., 2016; Malik and Lan, 2016; Oshita, 2012; Vale et al., 2018; Xu and Dietzenbacher, 2014; Zhang et al., 2018; Araújo et al., 2020). For the specific case of CO_2 emissions, the expectations for developed countries include a trend towards stabilization of domestic emissions but with an increase in global emissions embodied in their consumption. Both consumption and production are sources of increasing emissions, as emissions from the production side are expected to have increased more than those from the consumption side for developing countries. Arto and Dietzenbacher (2014) find that the net imports of emissions by developed countries increased while the net exports for developing countries have increased.

Increases in production-based emissions from changes to sourcing patterns in developing countries have been motivated by lower production cost, given lower wages, and the moderate environmental regulations of the developing countries (Grether and Mathys, 2013; Zhang et al., 2017). This implies that there is an emission cost of sourcing, which Hoekstra et al. (2016) define as an increase in global emissions due to sourcing from high-wage and low-emission-intensity countries to low-wage and high-emission-intensity countries. The reduction in emissions of the former is overcompensated by the increase in emissions of the latter, thereby raising global emissions.

To quantify the main drivers of changes in emissions, we employ a Structural Decomposition Analysis (SDA)[1] in line with those developed by Oosterhaven and Van Der Linden (1997), Arto and Dietzenbacher (2014) and Hoekstra et al. (2016), which enables us to disentangle the different drivers of such changes, namely: emissions intensity, industrial structure and sourcing, consumer preferences, final demand sourcing and consumption level. We use the World Input–Output Database (WIOD) and the countries grouped into five groups or regions: New European Union countries (NEU), Old European Union countries (OEU), the United States of America (USA), China (CHN), and the Rest of the World (ROW).[2]

The advantage of using an input–output model is the possibility of performing a systematic analysis of the economies through industrial linkages. Thus, we are able to map direct and indirect links in the structure of intermediate and final goods trade among these countries using inter-sectoral and inter-regional interdependence relationships. Table 1 presents the expected changes to CO_2 emissions to both OEU and NEU in light of the countries joining the EU. Because the expected changes include both increase and decrease of CO_2 emissions, the net effect is an empirical question.

The present study relates to a recent literature that seeks to understand environmental pressures from international trade, such as, Wang and Yang (2020a), Wang and Yang (2020b), and Wang et al. (2020). Unlike previous studies (Brizga et al., 2013; Pesic and Ürge-Vorsatz, 2001; Stern and Davis, 1998) that analyzed changes in CO_2 emissions from NEU countries but do not differentiate pure technology changes from changes in the economy's openness, i.e., they do not separate the technical component (emissions intensity) from the trade component. Because economic integration and trade pattern changes often accompany each other (Oosterhaven and Van Der Linden, 1997), the use of a full interregional input–output system for applying a Structural Decomposition Analysis enables us to separate the effect of technology and consumption shift from the effect of shifts in trade patterns. The decomposition of the change in CO_2 emissions in these components can help to explain how the economic transition of these countries can generate environmental pressures.

2. Method and data

2.1. Method

The SDA is a standard method based on input–output models that allow the division of changes in output, income, or other variables into different components, such as technological variation or final demand variation (Miller and Blair, 2009). We follow the work of Xu and Dietzenbacher (2014) and Hoekstra et al. (2016) and extend the SDA for a Interregion Input–Output (IRIO) model and to assess the effect of different groups of countries in CO_2 emissions in terms of sourcing.

Starting from a standard IRIO with M regions indexed by superscripts t and r, and N industries indexed as i, j, we can define its main components as: the ($MNx1$) vector of gross output ($\mathbf{x}$), the ($MNxMN$) matrix with the intermediate interindustry and inter-country transactions ($\mathbf{Z}$), and the ($MNxM$) matrix of final demand ($\mathbf{Y}$). The classic input–output relationship holds, such that

[1] For a comprehensive SDA review applied to energy and emissions see Su and Ang (2012), Wang et al. (2017), and Lahr and Dietzenbacher (2017).

[2] *NEU*: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Romania, Slovak Republic, and Slovenia; *OEU*: Austria, Belgium, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Sweden; *ROW*: Australia, Brazil, Canada, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, Russia, Taiwan, and Turkey. By creating these groups, we are able to quantify emissions costs of the entrance of the new Member States that joined during the 20042007 enlargement on the European Union.

Table 1
Expected local CO_2 emissions impacts.

	Emissions Impact	
	Old European Union Members	New European Union Members
Emissions intensity	Increased efficiency from access to a wider source of technologies is expected to decrease CO_2 emissions	Increased efficiency from access to a wider source of technologies is expected to decrease CO_2 emissions
Industrial structure	Increased access to a wider source of technologies is expected to decrease CO_2 emissions	Increased access to a wider source of technologies is expected to decrease CO_2 emissions
Intermediate demand sourcing	Increased intermediate product importing with larger content of embodied emissions is expected to decrease CO_2 emissions	Increased intermediate product exporting with larger content of embodied emissions is expected to increase CO_2 emissions
Consumer preferences	Increased preference for goods and services with lower CO_2 content is expected to decrease CO_2 emissions	Increased preference for goods and services with lower CO_2 content is expected to decrease CO_2 emissions
Final demand sourcing	Increased final product importing with larger content of embodied emissions is expected to decrease CO_2 emissions	Increased final product exporting with larger content of embodied emissions is expected to increase CO_2 emissions
Consumption level	Increased access to goods and services is expected to increase CO_2 emissions	Increased access to goods and services is expected to increase CO_2 emissions

$\mathbf{x} \equiv \mathbf{Z} + \mathbf{Y} \equiv \mathbf{Ax} + \mathbf{Y}$, in which $\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1}$ is the inter-regional technical coefficient matrix, and $\hat{\mathbf{x}}$ is the diagonal matrix vector $\mathbf{x}$. If we solve this for the output, then, $\mathbf{x} = \mathbf{LYi}$, where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ denoting the Leontief inverse multiplier matrix, and $\mathbf{i}$ is a $(Mx1)$ summation vector.

Define $\mathbf{e} \equiv [e_i]$ as the $(MNx1)$ vector of emission intensities, i.e., the amount of CO_2 emission per unit of output i. Hence, we can incorporate the emissions level into our framework as:

$$\mathbf{s} = \hat{\mathbf{e}}\mathbf{x} = \hat{\mathbf{e}}\mathbf{LYi} \tag{1}$$

where $\mathbf{s}$ is the vector of total emissions directly and indirectly generated in satisfying final demand.

As countries enter the EU, they face economic and political reforms that in turn will affect their production structure. For instance, the reduced or non-existing trade tariffs within the EU should incentivize new members to trade more intermediate goods with old members, and vice-versa. Also, households should have access to new and different bundles of goods and services. Both of these changes should have an impact on the emission levels from new and old members of the EU. By breaking down the change in emission levels in different components we are able to trace which are the main drivers of CO_2 emissions, namely, changes in energy intensity, in the countries' production structures, in the sourcing countries, and changes in final demand mix of goods and levels of consumption.

We want to analyze emissions considering possible changes in trade patterns that occurred after the entry of new members into the EU. Therefore, we differentiate technology changes, i.e., changes in the production structure, from changes in sourcing of intermediate goods. For example, there may be no change in how a good is being produced, but only from where a country is acquiring its input. The same is true in cases of final demand; there can be a change in the level and mix of goods, such that this mix can be broken down into types of goods and sourcing of goods (origin of consumption of the final goods). We follow Oosterhaven and Van Der Linden (1997) and Hoekstra et al. (2016) and differentiate the origin of emission in five groups: new EU members (NEU), old EU members (OEU), USA, China (CHN) and the Rest of the World (ROW).

To properly disentangle these components we define $\mathbf{Z}^{*t} \equiv [z^{*t}_{ij} = \sum_r z^{rt}_{ij}]$ as the total input requirements of industry j for input of industry i in country t. Using $\mathbf{Z}^{*t}$, we can create $\mathbf{Z}^{*} \equiv [\mathbf{Z}^{*t}] = \begin{bmatrix} \mathbf{Z}^{*1} & \dots & \mathbf{Z}^{*M} \\ \vdots & \ddots & \vdots \\ \mathbf{Z}^{*1} & \dots & \mathbf{Z}^{*M} \end{bmatrix}$, which is the intermediate input requirements regardless of the source country. In practice, the $(MNxMN)$ matrix $\mathbf{Z}^{*}$ is the horizontal stacking of $\mathbf{Z}^{*t}$ which is then vertically stacked M times. Similarly, we can define a $(MNxM)$ matrix $\mathbf{B}$ indicating the total need for products from (worldwide) industry i per unit of final demand in country r.

$\mathbf{Z}^{*t}$ is used to create the trade coefficient matrix $\mathbf{C} = [c^{rt}_{ij} = z^{rt}_{ij}/z^{*}_{ij}]$, with the $(MNxMN)$-dimension, which indicates the fraction of intermediate demand for total (worldwide) products i, for industry j in country t, that is actually satisfied by the supply from country r. Similarly, we can define a $(MNxM)$ matrix $\mathbf{F}$ that will capture the trade coefficients for the final demand, and is created following the same steps presented above. Matrices $\mathbf{C}$ and $\mathbf{F}$ allow the identification of each sourcing groups and are the key to our decomposition strategy. The intuition is that $\mathbf{C}$ and $\mathbf{F}$ give us the weighted importance in trade for each country. Let $\mathbf{A}^{*} = \mathbf{Z}^{*}(\hat{\mathbf{x}}^{*})^{-1}$ and $\mathbf{Y} = \mathbf{Gy}$, where $\mathbf{y} \equiv [\sum_r y^{rt}_{ij}]$ is a $(Mx1)$ vector. Thus, defining $\mathbf{A} = \mathbf{C} \circ \mathbf{A}^{*}$ and $\mathbf{G} = \mathbf{F} \circ \mathbf{B}$, in which the symbol $\circ$ is the Hadamard product, i.e., cell-by-cell multiplication, we can re-write Eq. (1) as:

$$\mathbf{s} = \hat{\mathbf{e}}\mathbf{LGy} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{C} \circ \mathbf{A}^{*})^{-1}(\mathbf{F} \circ \mathbf{B})\mathbf{y} \tag{2}$$

2.1.1. Decomposition analysis

The starting point for the decomposition of changes in CO_2 emissions between two periods of time $(\Delta\mathbf{s} = \mathbf{s}_1 - \mathbf{s}_0)$ is the polar decomposition analysis by Dietzenbacher and Los (1998):

$$\begin{aligned} \Delta\mathbf{s} = & (\Delta\hat{\mathbf{e}})\mathbf{L}_{1/2}\mathbf{G}_{1/2}\mathbf{y}_{1/2} && \text{emission intensity} \\ & + \hat{\mathbf{e}}_{1/2}(\Delta\mathbf{L})\mathbf{G}_{1/2}\mathbf{y}_{1/2} && \text{industry structure} \\ & + \hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}(\Delta\mathbf{G})\mathbf{y}_{1/2} && \text{consumption pattern} \\ & + \hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}\mathbf{G}_{1/2}(\Delta\mathbf{y}) && \text{consumption level} \end{aligned} \tag{3}$$

where the subscript 1/2 is the average of both period of times.

Two of the most interesting components of Eq. (3) for our analysis are the industry structure and consumption pattern terms. By using the matrices C and F described above, it is possible to further decompose these terms to properly identify changes in technical coefficients and changes in trade coefficients, i.e., to distinguish pure technology changes from changes in the openness of the economy.

Start with $\Delta\mathbf{L} = \mathbf{L}_1 - \mathbf{L}_0 = \mathbf{L}_1(\Delta\mathbf{A})\mathbf{L}_0$, specified in Oosterhaven and Van Der Linden (1997). As $\mathbf{A} = \mathbf{C} \circ \mathbf{A}^{*}$, then by simple substitution we have $\Delta\mathbf{L} = \mathbf{L}_1 - \mathbf{L}_0 = \mathbf{L}_1\Delta(\mathbf{C} \circ \mathbf{A}^{*})\mathbf{L}_0$. Pre and post multiplying it for $(\mathbf{I} - \mathbf{A}_1)$ and $(\mathbf{I} - \mathbf{A}_0)$, respectively:

$$\Delta\mathbf{L} = \mathbf{L}_1(\mathbf{C}_{1/2} \circ \Delta\mathbf{A}^{*})\mathbf{L}_0 + \mathbf{L}_1(\Delta\mathbf{C} \circ \mathbf{A}^{*}_{1/2})\mathbf{L}_0 \tag{4}$$

where the first term $\mathbf{L}_1(\mathbf{C}_{1/2} \circ \Delta\mathbf{A}^{*})\mathbf{L}_0$ is the effect of the actual changes in the technical coefficients, and the second term $\mathbf{L}_1(\Delta\mathbf{C} \circ \mathbf{A}^{*}_{1/2})\mathbf{L}_0$ indicates the effect of the changes in the trade coefficients.

Similarly, using $\mathbf{G} = \mathbf{F} \circ \mathbf{B}$, we can to rewrite $\Delta\mathbf{G}$ as $\Delta\mathbf{G} = \Delta\mathbf{F} \circ \mathbf{B}_{1/2} + \mathbf{F}_{1/2} \circ \Delta\mathbf{B}$. Thus, using this plus Eq. (4), it is possible to re-write Eq. (3) as:

$$\begin{aligned}\Delta\mathbf{s} = & (\Delta\hat{\mathbf{e}})\mathbf{L}_{1/2}\mathbf{G}_{1/2}\mathbf{y}_{1/2} && \text{emission intensity}\\ & +\hat{\mathbf{e}}_{1/2}[\mathbf{L}_1(\mathbf{C}_{1/2}\circ\Delta\mathbf{A}^*)\mathbf{L}_0]\mathbf{G}_{1/2}\mathbf{y}_{1/2} && \text{technology change}\\ & +\hat{\mathbf{e}}_{1/2}[\mathbf{L}_1(\Delta\mathbf{C}\circ\mathbf{A}^*_{1/2})\mathbf{L}_0)]\mathbf{G}_{1/2}\mathbf{y}_{1/2} && \text{intermediate demand sourcing}\\ & +\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}(\mathbf{F}_{1/2}\circ\Delta\mathbf{B})\mathbf{y}_{1/2} && \text{consumer preferences}\\ & +\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}(\Delta\mathbf{F}\circ\mathbf{B}_{1/2})\mathbf{y}_{1/2} && \text{final demand sourcing}\\ & +\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}\mathbf{G}_{1/2}(\Delta\mathbf{y}) && \text{consumption level}\end{aligned} \tag{5}$$

Lastly, since we explore the entrance of new countries in the EU as a shock to a country's trade pattern, we follow Hoekstra et al. (2016) and split the **C** and **F** matrices to reflect the geographic origin of the inputs. This allows us to assess the effect that trade changes or sourcing patterns have on global emissions. We can measure emissions embodied in trade from a domestic perspective, and a foreign perspective, i.e., emissions embodied in exports and emissions avoided by imports. Define $\mathbf{c}^r$ as a (*MNxMN*) matrix and $\mathbf{d}^r$ as a (*MxMN*) matrix, both with ones for each country group *r* and zeros in all other country groups. These matrices include a domestic component with cells of foreign shares (in the columns for sourcing country group *r*) equal to zero.

Matrices $\mathbf{c}^r$ and $\mathbf{d}^r$ allow us to split the **C** and **F** matrices for each sourcing country group *r*: New European Union countries (NEU), Old European Union countries (OEU), United States of America (USA), China (CHN), and the Rest of the World (ROW). This is the relevant component of the SDA that allows us to distinguish the embodied emissions in trade between new and old EU countries.

This allows us to look at import shares separately for each sourcing country group *r* and to distinguish between types of producing or source countries. We split the **C** and **F** matrices into submatrices, one for each sourcing country *r*: $\mathbf{C} = \mathbf{c}^r\circ\mathbf{C} = [\sum_r(\mathbf{c}^r_{DOM} + \mathbf{c}^r_{NEU} + \mathbf{c}^r_{OEU} + \mathbf{c}^r_{USA} + \mathbf{c}^r_{CHN} + \mathbf{c}^r_{ROW}]\circ\mathbf{C}$ and $\mathbf{F} = \mathbf{d}^r\circ\mathbf{F} = [\sum_r(\mathbf{d}^r_{DOM} + \mathbf{d}^r_{NEU} + \mathbf{d}^r_{OEU} + \mathbf{d}^r_{USA} + \mathbf{d}^r_{CHN} + \mathbf{d}^r_{ROW}]\circ\mathbf{F}$. The non-zero columns in these matrices contain, for country group *r*, sourcing shares by source country.

We can re-write Eq. (5) to incorporate them, as such:

$$\begin{aligned}\Delta\mathbf{s} = & (\Delta\hat{\mathbf{e}})_{1/2}\mathbf{G}_{1/2}\mathbf{y}_{1/2}\\ & +\textstyle\sum_r\hat{\mathbf{e}}_{1/2}[\mathbf{L}_1((\mathbf{c}^r\circ\mathbf{C}_{1/2})\circ\Delta\mathbf{A}^*)\mathbf{L}_0]\mathbf{G}_{1/2}\mathbf{y}_{1/2}\\ & +\textstyle\sum_r\hat{\mathbf{e}}_{1/2}[\mathbf{L}_1((\mathbf{c}^r\circ\Delta\mathbf{C})\circ\mathbf{A}^*_{1/2})\mathbf{L}_0)]\mathbf{G}_{1/2}\mathbf{y}_{1/2}\\ & +\textstyle\sum_r[\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}((\mathbf{d}^r\circ\mathbf{F}_{1/2})\circ\Delta\mathbf{B})]\mathbf{y}_{1/2}\\ & +\textstyle\sum_r[\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}((\mathbf{d}^r\circ\Delta\mathbf{F})\circ\mathbf{B}_{1/2})]\mathbf{y}_{1/2}\\ & +\textstyle\sum_r[\hat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}((\mathbf{d}^r\circ\mathbf{F}_{1/2})\circ\mathbf{B}_{1/2})]\Delta\mathbf{y}\end{aligned} \tag{6}$$

2.2. Data

The data to quantify the drivers of changes in CO_2 emissions and identify the environmental pressures of EU come from the WIOD, 2013 Release. This database provides a time-series of the World Input–Output Tables (WIOTs) covering the period of 1995–2011. These tables have been constructed in a clear conceptual framework on the basis of officially published input–output tables in conjunction with national accounts from national statistical institutes around the world and international trade statistics such as OECD and UN National Accounts (Dietzenbacher et al., 2013; Timmer et al., 2015).

The WIOD covers 27 EU countries and 13 other major countries in the world and a model for the rest of the world. These 40 countries represent approximately 90% of world trade. The WIOTs provide details for 35 industries classified according to the International Standard Industrial Classification revision 3 (see Table A.3) in the Appendix).[3] The WIOD also provides the environmental satellite accounts for emissions expressed in Megatonne (Mt) of CO_2 at the industry level.

We create five groups of countries to quantify emissions costs of the entrance of the new countries into the EU. Given our focus, the first two groups are straightforward: New European Union countries (NEU) and Old European Union countries (OEU). The other three groups are the United States of America (USA), China (CHN), and the Rest of the World[4] (ROW) were based on the relative importance in terms of trade with NEU countries.

The SDA requires the use of input–output tables expressed in constant prices to analyze the structural changes across different periods. Therefore, we have used the input–output tables in previous year's prices available from WIOD and chained the outcomes in the year-to-year changes.[5] For example, for the change in 1996, we have used the input–output tables of 1995 (in current prices) and 1996 (in constant prices of 1995). Also, following Arto and Dietzenbacher (2014) and Xu and Dietzenbacher (2014), the results have been cumulated over the full sample period.[6] We consider only the period 1995-2007 to avoid the dramatic influence of the 2008 financial crisis on the flow of world trade and consequently the emission transfers through exports.

2.3. CO_2 emission trends

Fig. 1 shows the change in CO_2 emissions for each OEU and NEU country. Romania (−22.9 Mt) and Poland (−20.0 Mt) were the driver of total reductions in CO_2 emissions in the NEU group during the period from 1995 to 2007. Although Germany reduced its total emissions (−21.5 Mt), the increase in CO_2 emissions in the OEU group was mainly caused by Spain (84.5 Mt), Denmark (33.5 Mt), Italy (28.3 Mt), and Greece (22.3 Mt). The contribution of each country to changes in CO_2 emissions, considering the size of its economy, is also presented as the ratio of total emissions to the value added of each country. In the NEU group, Romania, Bulgaria, Slovak Republic and Poland were the most intensive countries in reducing CO_2 emissions. In the OEU group, Denmark, Greece, Spain and Finland contributed to the largest increases in emissions proportional to the size of their value added.

Tables 2 and 3 show the interregional CO_2 emissions multiplier by industry and country groups, which indicate the ability of these groups to propagate emissions through their industrial linkages in the global production structure.[7] The reduction of the emissions in the NEUs is reflected on evolution over time of the CO_2 emissions multiplier. The main sources of this reduction were the electricity industry and refined petroleum and nuclear fuel industry. This can be explained by the substitution of energy sources for cleaner

[3] This is the most detailed industrial aggregation available for this database. For a discussion on the data aggregation issues, such as the sector aggregation by Su et al. (2010), and Lenzen (2011) and spatial aggregation by Andrew et al. (2009), and Su and Ang (2010).

[4] Although Russia was the main country of the USSR, its trade balance with NEU group is smaller than the other groups. For instance, in 1995 Russia share of exports and imports from NEU were 10.1% and 17.1%, respectively; in 2007, its exports and imports share from NEU were 7.8% and 15.1%, respectively. Moreover, a preliminary network analysis based on trade balances provides little support for Russia to be a separate group. This analysis is available upon request. Therefore, we decided to aggregate the results of Russia in the ROW. The participation of Russia in the emissions changes in the ROW between 1995-2007 was: 26.2% of the technology component, 26.9% of the sourcing component, and 15.4% of the consumption component.

[5] Los et al. (2014) detail the procedures for the construction of WIOTs in previous year's prices.

[6] This approach is called the chaining approach in the literature, which can help reduce the impacts of temporal aggregation Su and Ang (2012).

[7] The multipliers measure the combined effects of the direct and indirect repercussions of a change in final demand consumption on the CO_2 emissions — that is, the additional unit of CO_2 emissions required for a dollar of new final demand.

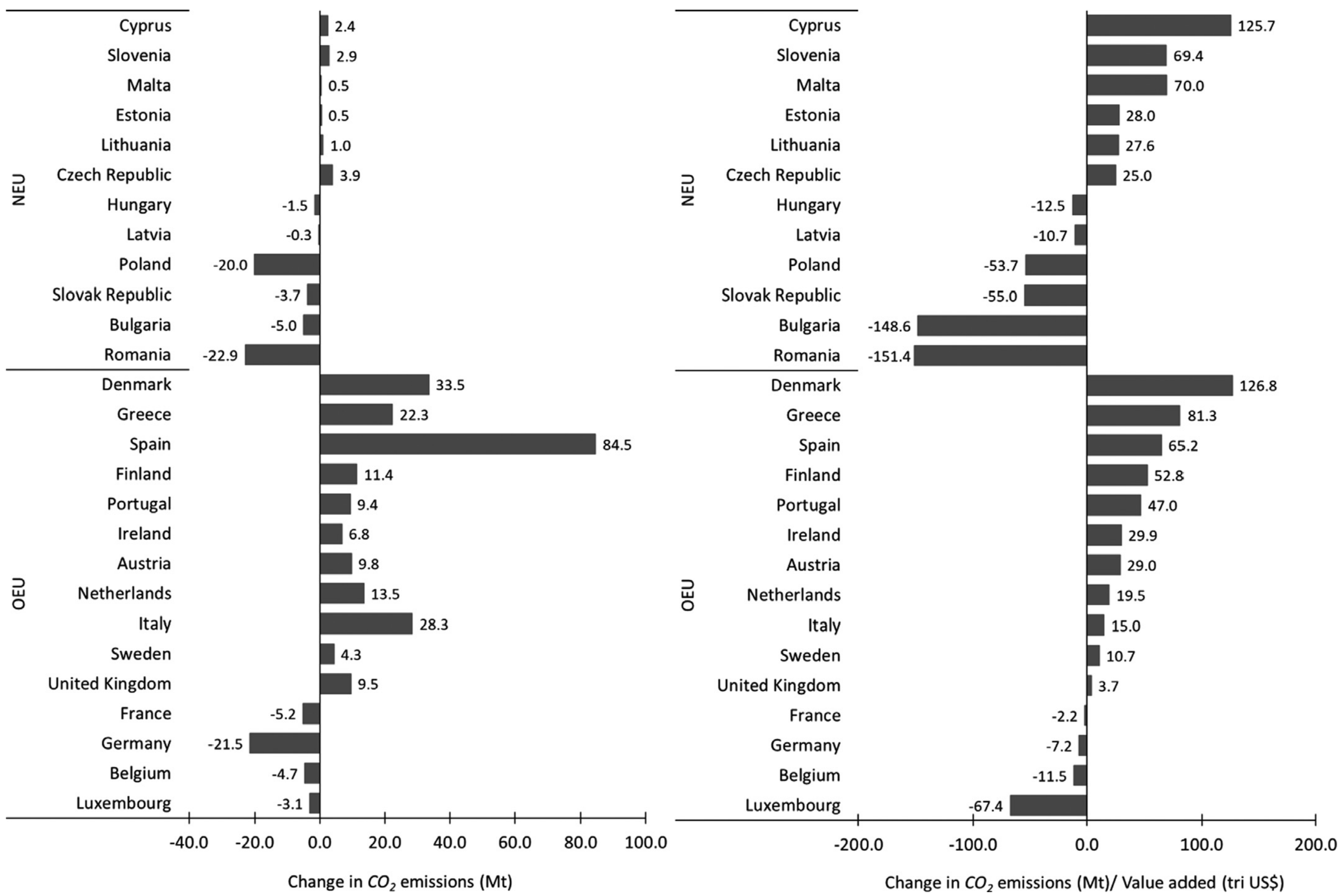


Fig. 1. Change in CO_2 Emissions (in Mt) by Country, 1995–2007. Source: World InputOutput Tables of the WIOD, 2013 Release.

Table 2
CO_2 Emissions Multiplier: New European Union Members.

Industrial sector energy consumption	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Nonmanufacturing	2.7	2.4	2.1	1.7	1.8	1.8	1.7	1.5	1.2	1.0	0.9	0.8
Energy-intensive	5.3	4.8	4.2	3.0	3.1	3.2	2.8	2.6	2.1	1.6	1.4	1.3
Nonenergy-intensive	2.8	2.3	2.2	1.8	1.8	1.9	1.7	1.6	1.2	0.9	0.8	0.8
Electricity	14.9	14.1	14.3	12.2	10.8	12.0	11.0	9.8	7.7	6.4	5.7	5.3
Service	1.9	1.6	1.5	1.1	1.1	1.2	1.1	1.0	0.8	0.6	0.6	0.5

Note: The industrial classification scheme in Table A.3 in the Appendix.

Table 3
CO_2 Emissions Multiplier: Old European Union Members.

Industrial sector energy consumption	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Nonmanufacturing	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.8	0.7	0.6	0.6	0.5
Energy-intensive	0.8	0.8	0.9	0.8	0.9	0.9	0.9	0.9	0.7	0.6	0.6	0.6
Nonenergy-intensive	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.2
Electricity	3.6	3.5	3.7	3.9	3.9	4.5	4.5	4.1	3.3	2.7	2.5	2.2
Service	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3

Note: The industrial classification scheme in Table A.3 in the Appendix.

fuels, the development of greener technologies, and improved energy efficiency. This effect suggests the importance of policies focused on encouraging emission reductions in specific sectors that have a larger capacity to propagate the global effects of emissions transfers. Despite the downward trend, the NEU emissions multiplier (0.9) was still significantly higher than the OEU emissions multiplier (0.4) in the year 2007 (Fig. A.1 in the Appendix A). This difference reflects the type of fuel used in industry and the energy efficiency in less developed countries (Malik and Lan, 2016; Zhang et al., 2017).

3. Results

Table 4 shows the results of decomposition of the CO_2 emissions between 1995 and 2007 for the five groups (NEU, OEU, USA, CHN and ROW).[8] The effects are aggregated into three categories: technology (emissions intensity and industrial structure), sourcing

[8] Table A.1 in the Appendix A shows the results of the decomposition of the emissions as a percentage change of the global emissions

Table 4
Decomposition of Changes in Territorial CO_2 Emissions (in Mt) of Each Group between 1995 and 2007.

	Source	NEU	OEU	USA	CHN	ROW	Total
Technology	Emissions Intensity	−291.8	−711.4	−288.2	−2,957.0	−2,893.9	−7,142.3
	Industrial Structure	−86.3	154.6	−631.2	1,179.3	857.7	1,474.1
Sourcing	Intermediate Demand	−4.4	−58.7	−221.3	652.4	186.4	554.4
	Final Demand	34.9	−78.5	−114.3	621.7	130.3	594.2
Consumption	Consumer Preferences	−39.4	−16.9	−331.8	93.5	261.9	−32.8
	Consumption Level	344.8	909.9	1,939.8	3,222.8	4,479.0	10,896.3
Total	Emissions	−42.2	198.9	353.1	2,812.7	3,021.4	6,343.9
	Sourcing	30.6	−137.2	−335.6	1,274.1	316.8	1,148.6

(intermediate and final demand) and consumption (consumer preferences and consumption level).

The overall increase in CO_2 emissions in the period was 6343.9 Mt. Breaking this increase among the five groups, most of them increased their emissions – OEU (3.1%), USA (5.6%), CHN (44.3%) and ROW (47.6%); only the NEU group had a reduction in total emissions (-0.7%). These results corroborate previous evidence that among the few countries that managed to reduce emissions in the 1990s and 2000s, most of these countries emerged from the East European and the former Soviet Union (Brizga et al., 2013).

The result of the decomposition shows that there was an emission intensity (**e**) driven reduction of −7,142.3 Mt of CO_2, mainly related to the more efficient use of fuels, changes in the energy mix, and changes in the emissions from non-energy related sources. However, the effects of technological changes on the industrial structure component (**A**) reduced emissions only in the NEU (-1.4%) and in the USA (-9.9%). The reduction of emissions driven by the technological component was surpassed by increases in the consumption level (171.8%, equivalent to 10,896.3 Mt of CO_2).

Sourcing pattern changes resulted in an 18.1% increase in total emissions. The transfer of emissions through a change in sourcing patterns was negative only in the OEU (−2.2%) and in the USA (−5.3%). Sourcing patterns in the countries with emission-intensive technologies, that is, those countries that have higher CO_2 emissions per unit of production, contributed to 25.6% increase in global emissions – NEU (0.5%), CHN (20.1%) and ROW (5.0%) (Table 4). The sourcing effect or trade structure effect increased emissions in 1148.6 Mt of CO_2 distributed between NEU (30.6 Mt), OEU (−137.2 Mt), USA (−335.6 Mt), CHN (1274.1 Mt) and ROW (316.8 Mt).

Fig. 2 shows the evolution of the CO_2 emissions decomposition between 1995 and 2007 for NEU and OEU groups. This represents the accumulated change in emissions for each year from 1996 to 2007. The decomposition of the emissions for the six components is detailed in Figs. A2.1–A2.7 in the Appendix A.

The OEU group's emissions increased 198.9 Mt of CO_2 over this period. Changes in the NEU group's emissions, also showed an increasing trend, except for the period between 1997 and 1999, accumulating a reduction of −42.2 Mt of CO_2 (Fig. A2.1 in the Appendix A). The reduction in total emissions in the NEU group was driven mainly by technology changes in the emissions intensity and the industrial structure components, in particular in the electricity industry (Table 5). This reduction was boosted by market reforms that the NEU group went through after the collapse of the socialist system, such as privatization, enterprise restructuring and competition policy (BenYishay and Grosjean, 2014; Tarabar, 2017). These reforms had strong effects in the electricity industry in Central and Eastern Europe during the 1990s; this, in turn, increased their energy efficiency and mitigated CO_2 emissions (Pesic and Ürge-Vorsatz, 2001; Stern and Davis, 1998). In addition to improved energy efficiency, the European Union climate policy contributed to reduced CO_2 emissions in these countries (Bae et al., 2017).

Technology changes generated variations of emissions in the NEU of −378.1 Mt of CO_2 and in −556.9 Mt of CO_2 in the OEU (Fig. A2.2 in the Appendix A). The technological changes in the NEU were composed by the reduction of −291.8 Mt of CO_2 from the emissions intensity component, concentrated in the following industries: electricity (−65.4 Mt) and energy-intensive (−149.8 Mt), such as, metals (−47.9 Mt), chemicals (−33.9 Mt) and non-metallic (−33.4 Mt). Further, the NEU group reduced the emissions in −86.3 Mt originating in the industrial structure component, with the reduction of −107.1 Mt of CO_2 in the electricity industry (Table 5). The reduction in emissions in the OEU group, through technology changes, occurred only in the emissions intensity component (−711.4 Mt); meanwhile, the industrial structure (154.6 Mt) and the consumption level (909.9 Mt) components contribuited to increase CO_2 emissions (Table 6).

In addition, Fig. 2 shows that in between 1995 and 2003 the NEU group experienced the largest reduction in CO_2 emissions (−69.1 Mt of CO_2). This period is prior to Cyprus, Slovakia, Slovenia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, and the Czech Republic joining the EU in 2004. In the period from 2004 to 2007, the NEU group CO_2 emissions increased by 26.9 Mt. The sourcing (26.9 Mt of CO_2) and consumption (130.4 Mt of CO_2) effects drove the increase in emissions in the period from 2004 to 2007, though in this period there is a net reduction of emissions because of the technology effect (−145.2 Mt of CO_2).

Sourcing patterns change, generated a shift in emissions of −137.2 Mt for the OEU group and 30.6 Mt for the NEU group (Figure 2.3). The evolution in emissions in the NEU group through sourcing changes matches the period of gradual liberalization of the economy in new Member States to prepare them for entry into the European Union. The integration of the NEU into international trade has gradually evolved from the so-called European agreements signed in the 1990s. Hence, there is no distinct cut-off point in 2004 when NEU countries were admitted to the EU but rather a gradual change in emissions over the entire period. The cost of increasing CO_2 emissions in the NEU through the change in sourcing patterns is related to the greater insertion of the countries of this group in the global production chains. In these supply chains, production is fragmented in different territories with the tendency of emission-intensive activities to be shifted to low-income countries (Hoekstra et al., 2016; Vale et al., 2018).

Bae et al. (2017) identified that the increased inflow of foreign direct investment in the countries of the post-communist states also increased its CO_2 emissions, but this increase has not been fully offset by improved energy efficiency and EU climate policy. Malik and Lan (2016) also identified in an analysis for 186 countries from 1990 to 2010 that changes the supply chain to improve technological efficiency are not sufficient to reduce emissions. Although the NEU group enjoys greater welfare resulting from the increase of income after its insertion into the EU, this group also loses welfare due to the environmental pressure of the CO_2 emissions.

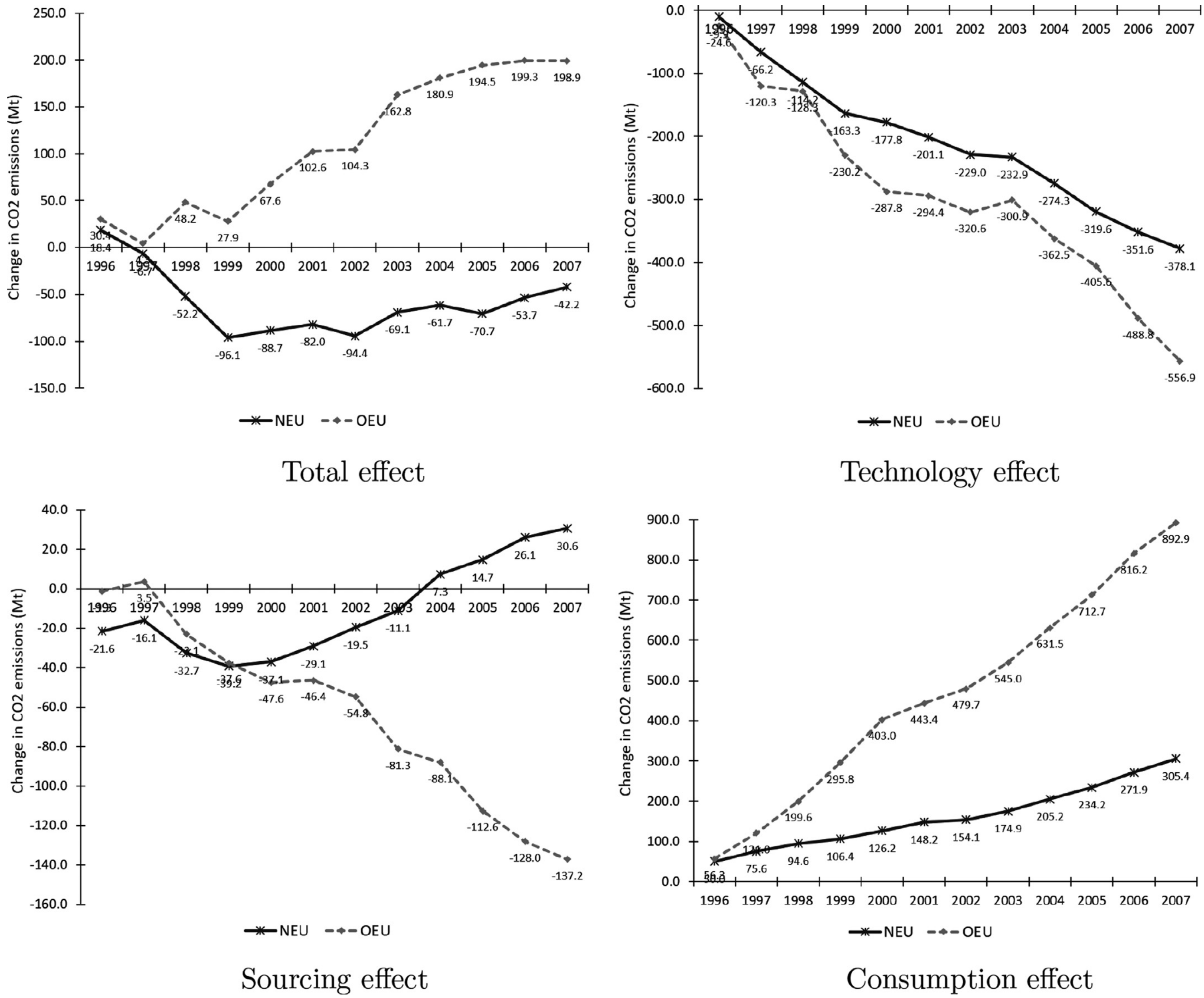


Fig. 2. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 Cumulated Effect, Note: The year-on-year effects are cumulated over the full sample period.

Table 5
Decomposition of CO_2 Emissions Growth (in Mt) by Industry between 1995 and 2007: New European Union Members.

Industrial sector energy consumption	Emissions Intensity	Industrial Structure	Industrial Sourcing	Consumers Preference	Final Demand Sourcing	Consumption Level	Total Emissions
Nonmanufacturing	−11.2	−9.5	−2.3	−6.1	0.5	16.4	−12.1
Energy-intensive	−149.8	24.6	−5.9	6.9	17.4	81.2	−25.6
Nonenergy-intensive	−33.0	2.4	1.4	3.9	1.9	9.1	−14.4
Electricity	−65.5	−107.1	−5.5	−39.9	12.0	189.6	−16.4
Service	−32.2	3.1	7.9	−4.2	3.2	48.4	26.3
Total	−291.8	−86.3	−4.4	−39.4	34.9	344.8	−42.2

Note: The industrial classification scheme in Table A.3 in the Appendix.

Table 6
Decomposition of CO_2 Emissions Growth (in Mt) by Industry between 1995 and 2007: Old European Union Members.

Industrial sector energy consumption	Emissions Intensity	Industrial Structure	Industrial Sourcing	Consumers Preference	Final Demand Sourcing	Consumption Level	Total Emissions
Nonmanufacturing	−14.2	−22.0	−21.7	15.4	−17.9	44.6	−15.9
Energy-intensive	−257.4	−3.1	−12.6	−11.8	−12.2	285.4	−11.7
Nonenergy-intensive	−32.0	4.5	−5.7	2.8	−11.3	29.9	−11.7
Electricity	−273.9	122.4	−9.4	−27.6	−19.1	315.0	107.5
Service	−133.9	52.8	−9.3	4.3	−18.0	234.9	130.8
Total	−711.4	154.6	−58.7	−16.9	−78.5	909.9	198.9

Note: The industrial classification scheme in Table A.3 in the Appendix.

Table 7
The Effect of Changing Sourcing Patterns in Territorial CO_2 Emissions by Country Group (in Mt) between 1995 and 2007.

		NEU	OEU	USA	CHN	ROW	Total
Domestic		−99.7	−238.7	−276.8	−43.4	−646.3	−1,304.9
Foreign	NEU	10.8	9.0	0.4	26.2	−1.4	45.0
	OEU	88.8	43.7	0.5	274.6	270.7	678.3
	USA	7.3	22.9	0.0	349.6	287.6	667.4
	CHN	0.6	−0.8	0.5	0.0	32.7	33.0
	ROW	22.8	26.7	−60.3	667.1	373.5	1,029.8
Total		30.6	−137.2	−335.6	1,274.1	316.8	1,148.6

The CO_2 emissions through the consumption component (Figure 2.4) have increased over time for the NEUs (305.4 Mt) and the OEUs (892.9 Mt). The consumer preferences component, which measures a shift in emissions due to changes in final consumption bundle, has reduced emissions by −39.4 Mt in the NEU and −16.9 Mt in the OEU group (Tables 5 and 6). While increased income in these countries have increased emissions through higher consumption levels, there was a reduction in emissions due to the change in the composition of final demand. The economic development of these countries created a shift from consumption of fuels and food to manufactured goods with lower emission intensity. Emissions reductions due to change in consumer preferences were generated mainly in agriculture, refined petroleum and nuclear fuel industry and electricity industry (for the NEU group: −5.4 Mt, −6.7 Mt and −39.9 Mt; for the OEU group: −6.1 Mt, −8.3 Mt and −27.6 Mt, respectively).

The overall change in OEU group emissions was higher than in the NEU group; this is an indirect consequence of the size of these countries' economies. While the NEU group concentrates 2.0% of the world's value added, the OEU group generates 26.8% of this additional value. To control for this effect, the change in emissions was divided by the total added value of each group. The results are shown in Figs. A2.1–A2.7 in the Appendix A. The NEU group presents the highest changes in emissions when taking into account the size of their value added. This can be explained by greater intensity in the generation of emissions in the NEU group. Although NEU countries have been able to reduce their emission levels, they still have a lower level of energy efficiency compared to the OEU countries – as shown by the CO_2 Emissions Multiplier in Tables 2 and 3.

3.1. The effect of changing sourcing patterns in territorial CO_2 emissions

In the previous subsection we discussed the overall results from the SDA analysis according to its three components: technology, sourcing, and consumption. In this subsection we disaggregate the sourcing results according to the different groups *r*. By doing so we are able to understand the CO_2 emissions embodied in trade between the groups. This is especially of interest as EU membership potentially changes trade patterns for several reasons as laid out in the introduction.[9]>

The SDA's results are also partitioned into emissions associated with domestic sourcing and foreign sourcing. Decomposition of CO_2 emissions growth through the change in sourcing patterns is detailed in Table 7.

The foreign sourcing effect measures the emissions embodied in international trade. Emissions avoided by imports (45.0 Mt) are lower than the emissions embodied in exports (130.3 Mt) in the NEU group between 1995 and 2007. This emissions transfer through foreign sourcing are boosted by trade between the NEU group members (10.8 Mt), OEU (88.8 Mt), USA (7.3 Mt), CHN (0.6 Mt) and ROW (22.8 Mt) groups. On the other hand, in the OEU the emissions avoided by imports (678.3 Mt) are larger than the emissions embodied in exports (101.5 Mt). Global CO_2 emissions to cover imports into the OEU group originated in the trade between OEU group members (43.7 Mt), NEU (88.8 Mt), USA (0.5 Mt), CHN (274.6 Mt) and ROW (270.7 Mt). Xu and Dietzenbacher (2014) and Grether and Mathys (2013) also identified that the emissions avoided by imports from developed countries are greater than the emissions embodied in their exports.

Sourcing pattern changes contributed to an increase of 30.6 Mt of CO_2 in NEU emissions (−4.4 Mt in the intermediate inputs trade and 34.9 Mt in the supply of final products and services), while the domestic sourcing effect reduced its emissions by −99.7 Mt of CO_2. The transfer of emissions from NEU to OEU, due to changes in the trade patterns, is 88.8 Mt of CO_2. These emissions embodied in export, through outsourcing of production, had origin in the supply of intermediate inputs (41.4 Mt) and final products (47.4 Mt). This result provides supporting evidence that the OEU group is transferring the emission-intensive production to the NEU group. Part of the production process that took place in the OEU countries (low emission-intensity countries) moved to NEU countries (high emission-intensity countries) after the EU enlargement.

Lower production costs, mainly due to the lower wages, in the NEU group may have been one of the incentives for the OEU group to outsource its production in those countries. This is an environmental pressure that accompanies welfare benefits generated by the greater economic integration between NEU and the rest of the world. The emissions transfer among countries that make up the NEU group (10.8 Mt) also suggests that economic integration among the countries of this group has remained small.

The sourcing effect in the OEU group reduced emissions by −137.2 Mt of CO_2 or −2.2% of global emissions. This reduction was driven mainly by the effect of domestic sourcing (−238.7 Mt) due to the change in the trade patterns within each country of the group; even though emissions increased by 43.7 Mt of CO_2 due to an integration among the countries within the group (concentrated in the final product trade 26.9 Mt, i.e., 61.5%). The transfer of emissions embodied in exports from OEU to NEU increased global emissions by only 9.0 Mt of CO_2.

3.2. Decomposition of change in CO_2 emissions by country

Fig. 3 presents the decomposition of the CO_2 emissions between 1995 and 2007 for each country. The effects are aggregated into three categories: technology, sourcing and consumption changes. Changing consumption patterns have contributed to increased emissions in all countries. Meanwhile, the effect of production structure changes, identified by technological shift, have driven emission reductions in most countries – except for Denmark. The reduction of emissions in the OEU group through

[9] Full results for each SDA effect are provided in Tables A2.1 and A2.2 in the Appendix A.

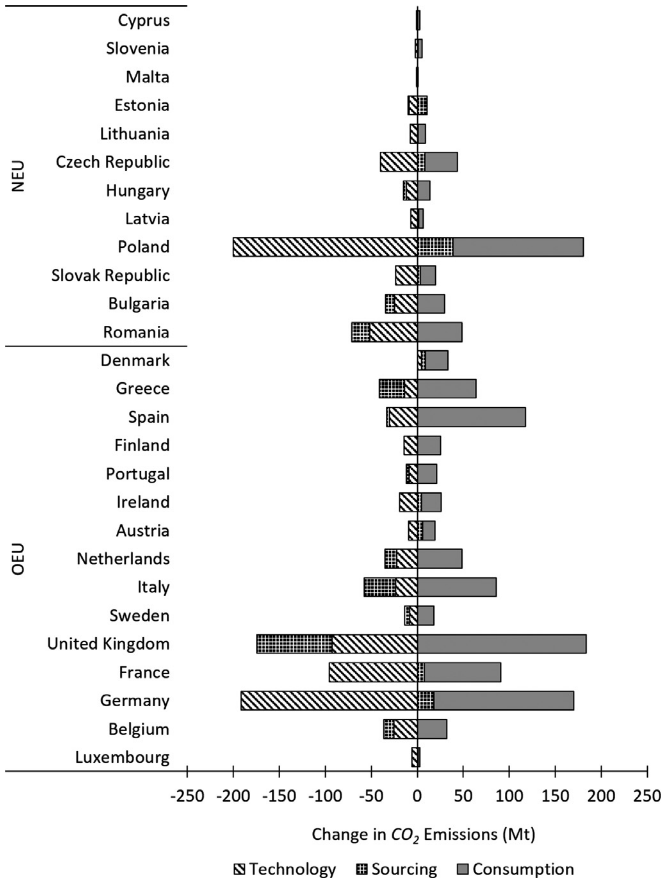


Fig. 3. Decomposition of Change in CO_2 Emissions (in Mt) by Country, 1995–2007.

changes in its sourcing patterns (−137.2 Mt), occurred mainly in the United Kingdom (−81.9 Mt), Italy (−34.2 Mt), Greece (−27.5 Mt), and Netherlands (−13.2 Mt), whilst Germany (18.1 Mt) increased emissions embodied in trade. As for the NEU group, Poland (39.0 Mt), Estonia (10.9 Mt), and Czech Republic (8.1 Mt) made the largest emissions transfers through outsourcing of production, while Romania (−19.8 Mt) and Bulgaria (−10.3 Mt) have reduced emissions embodied in trade.

In summary, the main results show that changes in consumption and production structure, driven by market reforms and new institutions in the NEU group, are important explanations for the changes in their CO_2 emissions. Although NEU countries diminished their emissions intensity, i.e., emission-output ratio, their total emissions increased. These increased emissions are due to increased trade with OEU countries, especially the transfer of emission in final goods exports. These results are important because the environmental pressures are not associated with domestic consumption only. The facilitated access to new technology should help mitigate but might not overcome these sourcing costs.

4. Implications and conclusions

This study set out to identify and understand the effect of structural changes and CO_2 emissions in the New European Union countries due to greater integration into the global economy. We used a Structural Decomposition Analysis on the World Input–Output Database from 1995 to 2007. This analysis contributes to the debate on the environmental impact of increased economic integration between NEU and OEU, the structural changes that have taken place in the production structure of the post-communist states, and the intensification of CO_2 emissions based on the consumption of goods and services produced outside the region of origin of consumption.

In addition to monetary aspects, free trade, market expansion and relocation of companies, the analysis on the process of economic integration must assess other externalities. Theses externalities, in our analysis, are being assessed through emissions. The input–output method used in this study is suitable for this analysis because it considers explicitly the country's interdependences (e.g., the technology from the intermediate use of inputs and consumption behavior from final demand side). The SDA analysis allows us to capture and assess systemic effects of many kinds—specifically, in this study, the changes that results from putting the industry-country in a more competitive environment and insertion into the global supply chain. The new Member States that joined during the 20042007 enlargement of the European Union have a new structure of economic relations. To know the implications of strengthening these relations from the perspective of emissions, provide knowledge for decision making in terms of policies for the group of countries.

Focusing on the NEU countries, the main results show that the changes in economic structure, driven by market reforms and new institutions, that have altered trade relationships, given their insertion in a globally integrated supply chain were important to explain the evolution in their CO_2 emissions. The technology changes due to the improved efficiency in the use of fuels and changes in production structure were responsible for reducing emissions in this group. The effect of EU's climate policy on emissions reduction was observed mainly in the electricity, metals, chemicals, nonmetallic, and refined petroleum and nuclear fuel industries. These industries are key to mitigating the effects of CO_2 emissions and can be policy targets for accelerating the adoption of measures to increase energy efficiency and substituting for cleaner energy sources.

The OEU countries maintained a high growth in total emissions driven by the consumption of final goods. However, this group managed to reduce emissions through trade by transferring part of the responsibility for the total emissions to other countries. In addition, the emissions growth embodied in exports of the OEU group was less than the growth in emissions embodied in its imports. This decrease in emissions exports was influenced by the change in the trade structure between NEU and OEU, which has increased the transfer of emissions between the two groups. The transfer of emissions from NEU to OEU was carried out mainly through trade of final goods. On the other hand, the trade of intermediate inputs drove the transfer of emissions from OEU to NEU.

The implication of these results is that emissions reductions associated with technology advances were not large enough to fully compensate for increases due to the change in sourcing patterns and the levels of consumption throughout the 2000s in the NEU group. The change of sourcing patterns in the NEU group is related to a context of increased outsourcing through the international fragmentation of production and greater integration with other countries of the EU.

These results are important because the environmental pressure in the European Union, especially in the NEU group, is a problem that goes beyond domestic accountability for emissions, given an increasing integration between NEU and OEU and international outsourcing. The process of economic integration can reduce regional disparities—both in terms of consumption (consumption preferences) and access to goods. The increase in regional interdependence enables a more homogeneous access to consumption bundle and production processes. Hence, given this integration process, efficiency improvements can occur in the long run, and lead to a reduction in emissions. Trade policies aimed at greater economic integration can help reduce emissions by allowing countries to have access to newer and greener technologies. However, these policies also can intensify CO_2 emissions from the consumption of goods and services produced outside the region of origin of consumption. These sourcing effects, associated with the growth in income created by increase in trade, create emissions increases that can overpower gains from technological changes and preference changes. Future research could also include assessing the emissions consequences of the United Kingdom leaving the European Union.

Appendix A

Table A1
Decomposition of Changes in CO_2 Emissions (in % of Global Change) between 1995 and 2007.

	Source	NEU	OEU	USA	CHN	ROW	Total
Technology	Emissions Intensity	−4.6	−11.2	−4.5	−46.6	−45.6	−112.6
	Industrial Structure	−1.4	2.4	−9.9	18.6	13.5	23.2
Sourcing	Intermediate Demand	−0.1	−0.9	−3.5	10.3	2.9	8.7
	Final Demand	0.6	−1.2	−1.8	9.8	2.1	9.4
Consumption	Consumer Preferences	−0.6	−0.3	−5.2	1.5	4.1	−0.5
	Consumption Level	5.4	14.3	30.6	50.8	70.6	171.8
Total	Emissions	−0.7	3.1	5.6	44.3	47.6	100.0
	Sourcing	0.5	−2.2	−5.3	20.1	5.0	18.1

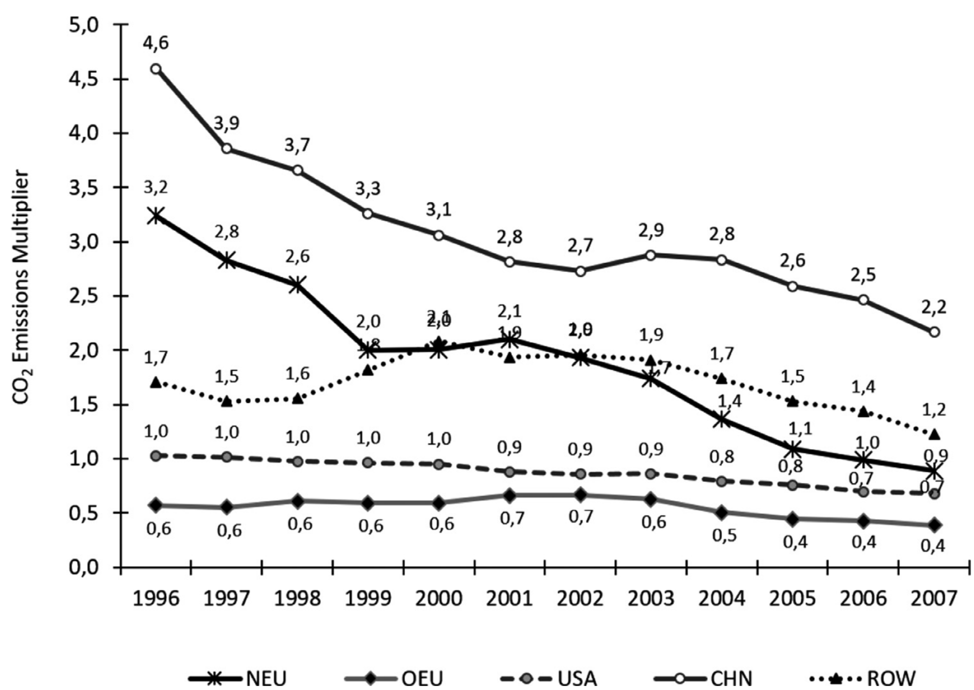
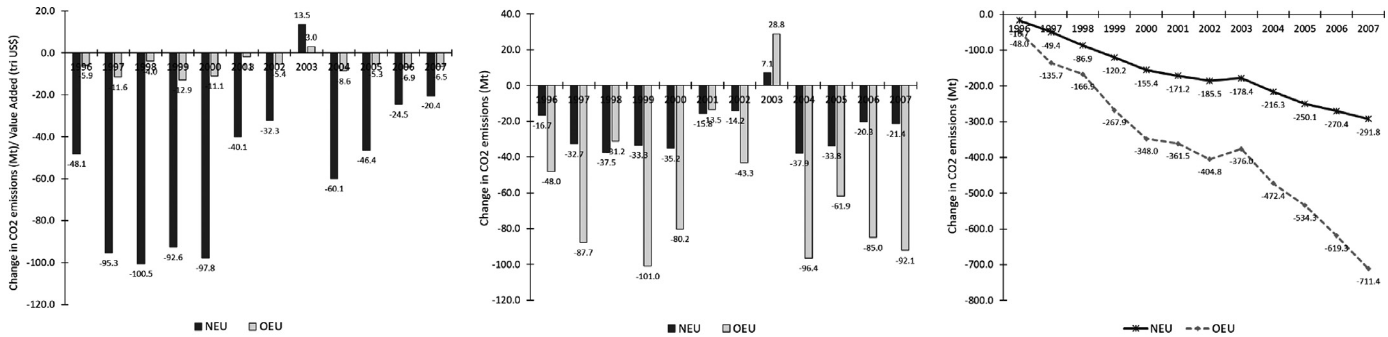
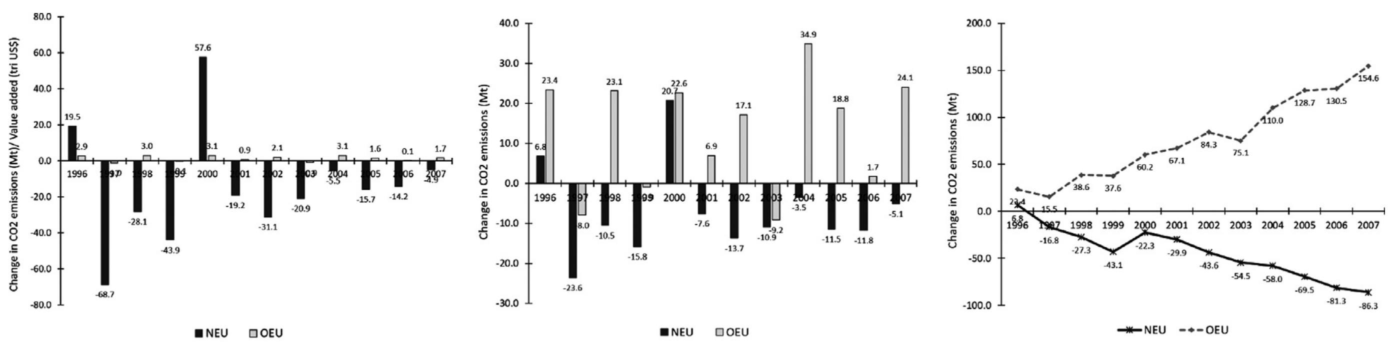


Fig. A1. CO_2 Emissions Multiplier by Country Group, 1996–2007. Source: World InputOutput Tables of the WIOD, 2013 Release.



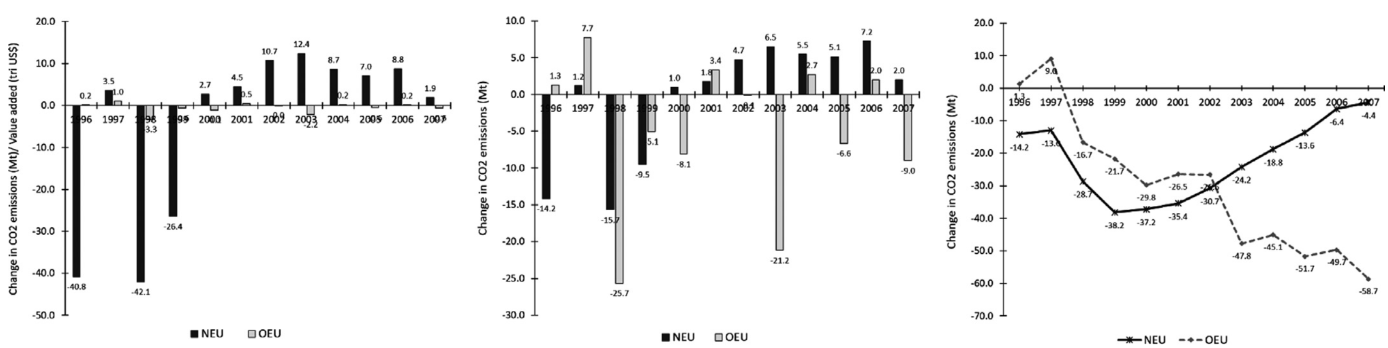
a Intensity: emission/value added b Intensity: level c Intensity: cumulated

Fig. A2.1. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Intensity.



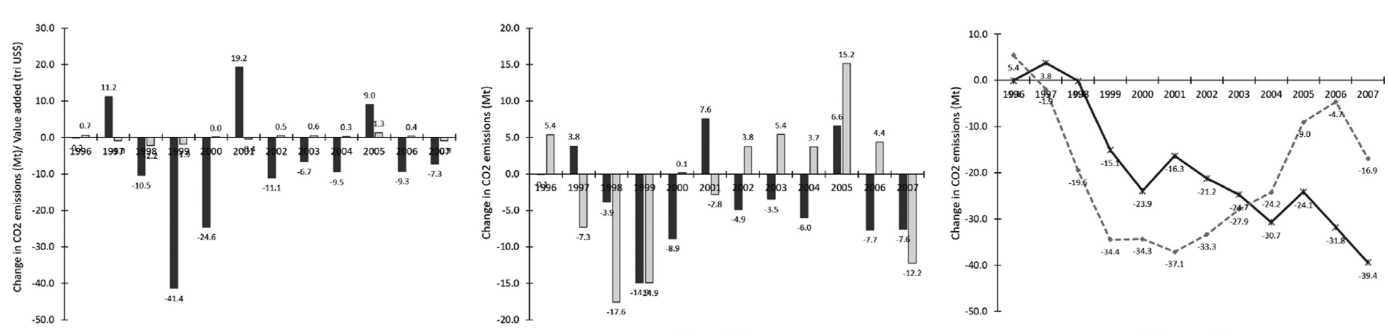
a Industrial structure: emission/value added b Industrial structure: level c Industrial structure: cumulated

Fig. A2.2. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Industrial Structure.



a Industrial sourcing: emission/value added b Industrial sourcing: level c Industrial sourcing: cumulated

Fig. A2.3. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Industrial Sourcing.



a Consumer's preference: emission/value added b Consumer's preference: level c Consumer's preference: cumulated

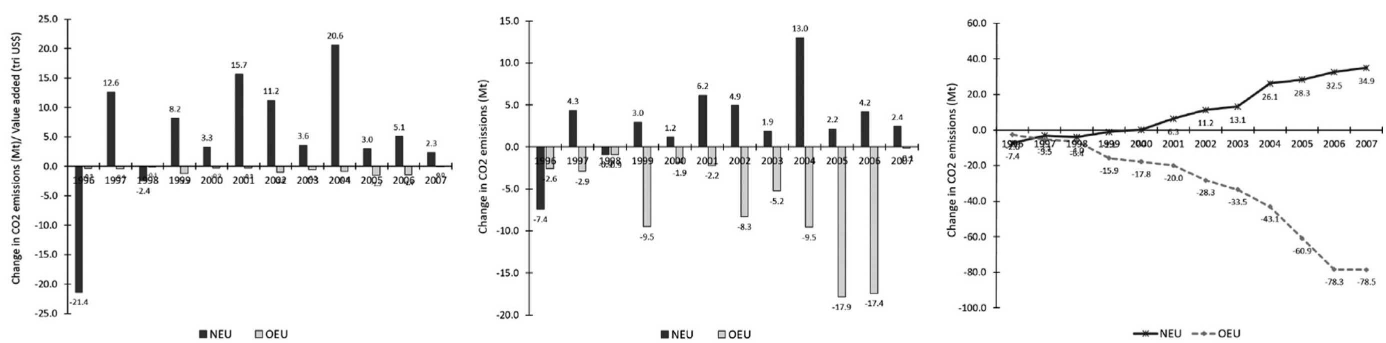
Fig. A2.4. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Consumer's Preference.

Table A2.1
Decomposition of Changes in Territorial CO_2 Emissions (in Mt) of New European Union Member between 1995 and 2007.

	Source	DOM	NEU	OEU	USA	CHN	ROW	Total
Technology	Emissions Intensity	−291.8	0.0	0.0	0.0	0.0	0.0	−291.8
	Industrial Structure	−76.0	−0.9	−10.0	−2.3	0.8	2.1	−86.3
Sourcing	Intermediate Demand	−68.7	5.4	41.4	3.9	0.6	13.0	−4.4
	Final Demand	−31.0	5.4	47.4	3.4	0.0	9.8	34.9
Consumption	Consumer Preferences	−44.7	2.4	−2.4	0.0	0.3	5.0	−39.4
	Consumption Level	256.5	13.7	30.2	7.0	3.9	33.4	344.8
Total	Emissions	−255.7	26.0	106.7	12.0	5.6	63.3	−42.2
	Sourcing	−99.7	10.8	88.8	7.3	0.6	22.8	30.6

Table A2.2
Decomposition of Changes in Territorial CO_2 Emissions (in Mt) of Old European Union Member between 1995 and 2007.

	Source	DOM	NEU	OEU	USA	CHN	ROW	Total
Technology	Emissions Intensity	−711.4	0.0	0.0	0.0	0.0	0.0	−711.4
	Industrial Structure	96.0	7.0	17.0	−7.7	7.7	34.6	154.6
Sourcing	Intermediate Demand	−111.2	5.4	16.8	11.7	0.6	18.0	−58.7
	Final Demand	−127.5	3.6	26.9	11.2	−1.4	8.7	−78.5
Consumption	Consumer Preferences	−40.3	4.6	7.8	−0.7	1.3	10.5	−16.9
	Consumption Level	539.0	21.4	137.5	49.0	23.5	139.6	909.9
Total	Emissions	−355.5	42.0	205.9	63.4	31.7	211.4	198.9
	Sourcing	−238.7	9.0	43.7	22.9	−0.8	26.7	−137.2

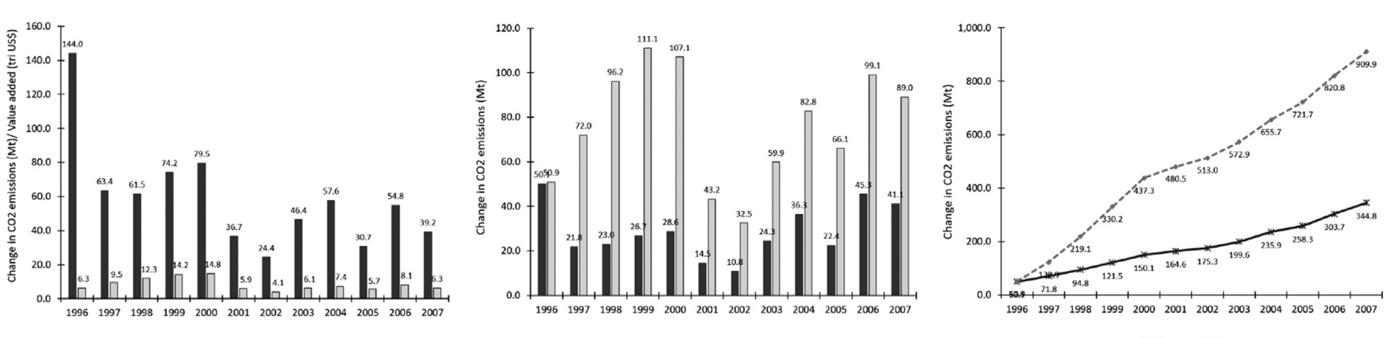


a Final demand sourcing: emission/value added

b Final demand sourcing: level

c Final demand sourcing: cumulated

Fig. A2.5. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Final Demand Sourcing.



a Consumption level: emission/value added

b Consumption level: level

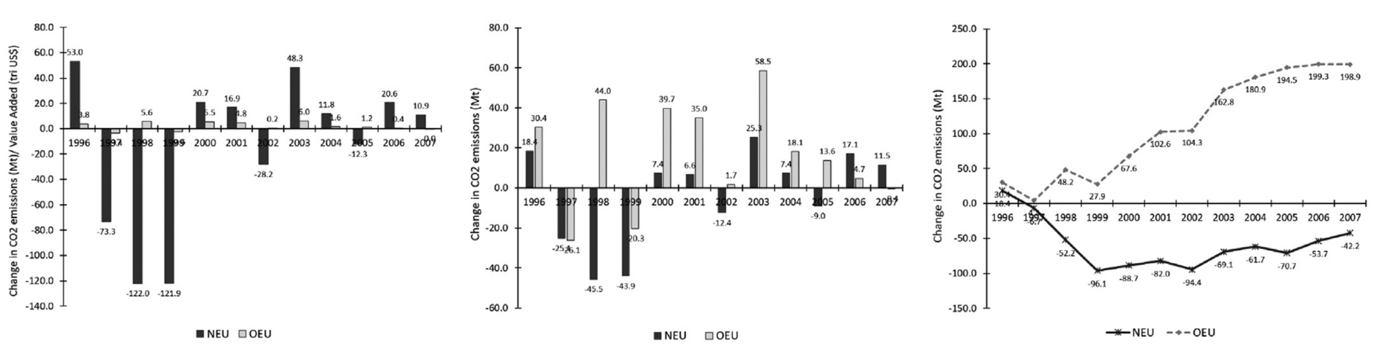
c Consumption level: cumulated

Fig. A2.6. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – SDA Components: Consumption Level.

Table A.3
Industrial Composition of the World Input-Output Tables.

Industrial sector energy consumption	Industry
Nonmanufacturing	Agriculture, Hunting, Forestry and Fishing
Nonmanufacturing	Mining and Quarrying
Energy-intensive	Food, Beverages and Tobacco
Nonenergy-intensive	Textiles and Textile Products
Nonenergy-intensive	Leather, Leather and Footwear
Nonenergy-intensive	Wood and Products of Wood and Cork
Energy-intensive	Pulp, Paper, Paper, Printing and Publishing
Energy-intensive	Coke, Refined Petroleum and Nuclear Fuel
Energy-intensive	Chemicals and Chemical Products
Energy-intensive	Rubber and Plastics
Energy-intensive	Other Non-Metallic Mineral
Energy-intensive	Basic Metals and Fabricated Metal
Nonenergy-intensive	Machinery, Nec
Nonenergy-intensive	Electrical and Optical Equipment
Nonenergy-intensive	Transport Equipment
Nonenergy-intensive	Manufacturing, Nec; Recycling
Electricity	Electricity, Gas and Water Supply
Service	Construction
Service	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
Service	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
Service	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
Service	Hotels and Restaurants
Service	Inland Transport
Service	Water Transport
Service	Air Transport
Service	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
Service	Post and Telecommunications
Service	Financial Intermediation
Service	Real Estate Activities
Service	Renting of M&Eq and Other Business Activities
Service	Public Admin and Defence; Compulsory Social Security
Service	Education
Service	Health and Social Work
Service	Other Community, Social and Personal Services
Service	Private Households with Employed Persons

Note: Industrial composition of the World InputOutput Tables of the WIOD, 2013 Release. Industrial sector ene.onsumption from the U.S. Energy Information Administration, International Energy Outlook.



a Total emission: emission/value added

b Total emission: level

c Total emission: cumulated

Fig. A2.7. Decomposition of Change in CO_2 Emissions (in Mt), 1995–2007 – Total Emission.

CRediT authorship contribution statement

Inácio Fernandes de Araújo: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - review & editing. **Randall W. Jackson:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - review & editing. **Amir B. Ferreira Neto:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - review & editing. **Fernando S. Perobelli:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - review & editing.

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