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Analysis

The role of consumption patterns, demand and technological factors on the recent evolution of CO_2 emissions in a group of advanced economies☆

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ABSTRACT

Changes in production structures and modifications of patterns of consumption are key factors in the fight against environmental harm. Initiatives such as Agenda 21, promoted by the UN, highlight the need to evaluate the relationships among factors of production and consumption, innovation and demographics, and the environment, in the attainment of sustainable development. In this context, our work studies in depth those factors underlying the economic activity of households, in a representative group of European Union countries and the US. Within the framework of an input–output model, a Structural Decomposition Analysis is considered in order to identify the weight that growth in demand, changes in patterns of consumption, changes in the distribution of income, the substitution of inputs, and changes in energy intensity have all had on the evolution of CO_2 emissions. The work specifically seeks to identify common patterns and differential behaviors among productive sectors in the European social environment. The results show that growth in demand, and therefore in production, largely absorbs the limited effect of technological and efficiency improvements and the incipient changes observed in consumption patterns.

1. Introduction

The evolution of the European economy in recent decades has clearly been positive, relying on a significant rate of GDP growth, which has encouraged job creation and the increased per capita income of citizens of the member countries. Nevertheless, the growth of the European economy has coincided, in certain countries, with a considerable increase in greenhouse gases (European Environment Agency, 2010).

In this context, it is clear that policies designed to achieve sustainable economic development in the long term must analyze the effects on the environment generated by productive activities, i.e., the economic structure of countries, its evolution and growth. This need is reflected in important international initiatives, such as the Conference on Environment and Development held in Rio de Janeiro in 1992, the World Summit on Sustainable Development held in Johannesburg in 2002, the Kyoto Protocol, and Agenda 21. European countries are among the group of nations publicly committed to the fight against environmental damage.

There is a broad consensus that significant changes in production technologies, accompanied by changes in patterns of private consumption, are fundamental to the attainment of environmental improvements. In this context, chapter four of Agenda 21 is devoted to methods of consumption, and urges "the evaluation of the relationship between production and consumption, the environment, innovation…and demographics". This is the framework within which our work has developed, attempting to show the relationship between environmental emissions, production technologies, and patterns of household consumption, and studying in depth the distinct responsibility that the factors of technology and demand have on the evolution of CO_2 emissions.

The relationship between CO_2 emissions and the productive activities of a country has been widely studied, considering input–output methodology as a powerful instrument in the quantification of emissions and in the description of the connections between the productive agents involved. Weber and Perrels (2000), Herce et al. (2003), Sánchez-Chóliz and Duarte (2004), Gallego and Lenzen (2005), Rodrigues et al. (2006), Tukker et al. (2006), Wiedmann et al. (2006) and, more recently,

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Roca and Serrano (2007), Sánchez Chóliz et al. (2007) and Tarancón and Del Río (2007) are among the authors who have evaluated the impact of a specific productive structure on CO_2 emissions for the Spanish economy. See Turner et al. (2007) and Wiedmann et al. (2007) for a review of the literature.

Following this methodology, several studies have focused more specifically on the relationship between households and the generation of emissions, both directly through the use of energy goods, and indirectly through the consumption of other goods and services. Biesiot and Noorman (1999), Wier et al. (2001), Lenzen et al. (2004), Carlsson-Kanyama et al. (2005) and Moll et al. (2005) have analyzed the relationship between patterns of consumption and emissions, concluding that different household types lead to different consumption patterns and levels of emissions, mainly depending on income level. Hertwich (2011) presents a review of the study of this problem through the life cycle of the product, or household metabolism. Vringer and Blok (1995), Lenzen et al. (2006) and Kerkhof et al. (2009a, 2009b) highlight the existence of a certain scale effect related to total spending, linking the increase in pollutant emissions from households with income levels, as also seen in the work of Nijdam et al. (2005). Druckman and Jackson (2009) show that expanding lifestyle aspirations is a significant factor driving household CO_2 emissions. Muksgaard et al. (2000) combine both factors, showing how the scale effect of increased spending exceeds the relatively small positive effects resulting from changes in consumption patterns. Carlsson-Kanyama et al. (2005) emphasize the need to adapt technological and efficiency improvements in support of the reductions obtained from changes in the behavior of households. Interesting contributions studying the relationship between household behavior and embodied emissions also include Druckman et al. (2011) and Chitnis et al. (2012, 2013).

In this general context, our objective is to evaluate the impact that the current patterns of household consumption and production observed in advanced economies have on one of the main greenhouse gases, CO_2.[1] More specifically, our study, through a Structural Decomposition Analysis (SDA) based on IO tables and information about consumption structures, aims to examine the explanatory factors of the most recent evolution of emissions in a significant group of European Union countries and the USA.

Combining available information with respect to input–output tables (OECD, 2009), sectoral emissions of CO_2 (Eurostat — European Environmental Agency) and surveys of family budgets (compiled and reconciled by Eurostat), our work examines the role played by increases in expenditure, distribution of household expenditures on different goods (patterns of consumption), technological change, and intensity of emissions, on the total emissions of these economies, as well as on the explanation of differences found among countries. We consider the following countries in our sample: Austria, Germany, Denmark, Spain, France, United Kingdom, Italy, Netherlands, Portugal, Sweden and the United States.[2] For each, changes in emissions are analyzed from 1995 to 2005, the only period for which it is possible to find comparable information for this group of countries, productive sectors, and households. Although the period analyzed may not be sufficient to identify technological change and its contribution to the evolution of emissions, it can certainly be significant in understanding trends of consumption, as well as identifying production differences and habits of consumption on an international level. Our data have been homogenized in order to make sectoral and international comparisons. We consider that the study contributes to an understanding of the structures of consumption and their responsibility in the modulation of environmental damage, in line with the principles promulgated by Agenda 21.

The rest of the paper is structured as follows. Section 2 presents the methodology, based on the application of a Structural Decomposition Analysis to emissions associated with households in an input–output framework, as well as the description of the data-bases used and the criteria followed with respect to homogenization. Section 3 contains the analysis of our results, by country as well as by sectors of activity, and Section 4 closes the paper with a review of our main conclusions.

2. Material and Methods

2.1. Methodological Aspects

As mentioned above, in order to quantify the weight that technological and demand factors have on the evolution of household emissions, we apply a methodology frequently used in the input–output literature, Structural Decomposition Analysis (SDA).

SDA has been broadly applied to analyze the contribution of different factors to temporal changes in resource use and environmental emissions.[3] (Rose and Casler (1996) or Casler and Rose (1998) for its foundations, and Rørmose and Olsen (2005), Rørmose (2010) and Su and Ang (2012) for technical aspects and a review of its limitations).[4] Most of the environmental applications of SDA correspond to single-country studies, significantly the number of papers studying China's economic growth and its contribution to global emissions (see Peters et al., 2007; Guan et al., 2008; Feng et al., 2009, among others). There are also a good number of papers with single-country analysis for different EU countries (some examples are Munksgaard et al. (2000) for Denmark, de Haan (2001) and Edens et. al. (2011) for the Netherlands, Seibel (2003) for Germany, Yamakaya and Peters (2011) for Norway, Roca and Serrano (2007) for Spain, Baiocchi and Minx (2010) for the UK, or Cellura et. al. (2012) for Italy). Common features derived from these articles are the role of demand as a major source of upward pressure, while improvements in efficiency tend to reduce emissions (although with significant differences depending on the country and period studied).

From an international perspective, Luukkanen and Kaivo-oja (2002), De Nooij et al. (2003) and Alcántara and Duarte (2004) are among the few papers that apply SDA to study the evolution of energy consumption (in the first case, also CO_2) for a group of countries and regional differences in terms of demand, efficiency and productive structures. The interesting paper of De Nooij et al. (2003) adapts SDA methodology to explicitly capture between-country differences in the explicative components of energy consumption. Promising fields of research are the use of multi-regional input–output models (MRIO) to describe international economies and their dependencies in terms of resources (Minx et al., 2009) or the use of scenario analysis for discussing future trends (Guan et al., 2008) that, as we will see later, in fact overcome certain limitations of the use of single-region models (Wiedmann et al., 2007), or the ex-post character of SDA methodology.

The general idea on which SDA is based is the additive decomposition of the changes in a variable determined by a series of multiplicative factors acting as accelerators or retardants of their evolution. For

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[1] According to the European Environmental Agency, CO_2 represents approximately 80% of the total GHG emissions of the Union (EEA, 2002).

[2] The inclusion of the United States in the analysis is due to its relevance in the emissions of greenhouse gases, being one of the principal polluters on a world level. On the other hand, its similarities in production, income distribution and consumption patterns make it a reference comparable to the European economies included in the analysis.

[3] For instance, Su and Ang (2012) identify more than 40 articles from 1999 to 2010 including SDA applications to study energy and atmospheric emissions.

[4] Structural decomposition analysis is, together with index decomposition analysis, a technique widely used to study the factors underlying changes in environmental indicators such as energy, resources consumption, and atmospheric emissions. Both techniques aim to decompose changes in environmental variables in a group of representative variables. SDA uses input–output tables to attain sectorial information, while index decomposition deals with aggregated information. In this regard, since SDA considers the detailed structure of production and final demand provided by the input–output tables, it is more appropriate to study technological changes resulting from input substitution processes. Excellent studies on the similarities and differences between these techniques are Hoekstra and Van der Berg (2003) and Su and Ang (2012).

example, in an expression such as $y = x_1 \cdot x_2$, an explanation of the evolution of the variable dependent y is attempted (that is, Δy), from a series of addends that express what part of that variation is due to the changes in x_1, what part responds to those produced in x_2, and which to a mixture of both.

In our case, the starting point is the basic equilibrium equation of the Leontief model.

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \Leftrightarrow \mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{My} \tag{1}$$

where $\mathbf{x}$ is the vector of total production and $\mathbf{y}$ is the column vector of final demand, $\mathbf{A}$ is the matrix of technical coefficients, and $\mathbf{M}$ is the Leontief inverse. If the part of the final demand corresponding to household consumption ($\mathbf{y}^{\mathrm{h}}$) is only taken in this expression, the result is the production associated with this demand ($\mathbf{x}^{\mathrm{h}}$).

Let us denote by D_i the emissions of CO_2 (in physical units) directly caused[5] by the household consumption of the good i ($i = 1,\ldots N$). Similarly, let us denote by C_i the emissions directly generated in the production process of good i demanded by households. The total of CO_2 emissions associated with household consumption, E, will be:

$$E = \sum_{i=1}^{N} D_i + \sum_{i=1}^{N} C_i = D + C. \tag{2}$$

If we define $\mathbf{d} = \{d_i\} = \{D_i / y^h{}_i\}$ as the vector of coefficients of household direct emissions, $y^h{}_i$ being the demand for good i, and $\mathbf{c} = \{c_i\} = (C_i / x_i)$ as the vector of direct emissions per unit of production, i.e., the vector of sectoral emissions intensities, $\boldsymbol{\lambda}$ can be defined as the vector of *pollution values*[6] *in the production* whose elements show the total pollution directly and indirectly embodied in the production of each unit of good i purchased by the household:

$$\boldsymbol{\lambda}' = \{\lambda_i\} = \mathbf{c}'\mathbf{M}. \tag{3}$$

As can be seen, $\mathbf{c}$ and $\mathbf{M}$ have a technological character. Vector $\mathbf{c}$ represents the emission intensity (emissions per unit of product) while $\mathbf{M}$ captures the inter-sectoral relationships by way of the intermediate inputs consumption.[7]

If we denote by $\boldsymbol{\omega}$ the vector of *pollution values of the household*, that is, the total emissions of CO_2 produced in the economy by unit of final household demand, vector $\boldsymbol{\omega}$ can be obtained as the sum of the vector of *pollution values in the production* and the vector of *direct emission coefficients* from the household, that is:

$$\boldsymbol{\omega}' = \boldsymbol{\lambda}' + \mathbf{d}' = \mathbf{c}'\mathbf{M} + \mathbf{d}'. \tag{4}$$

Consequently, the emissions associated directly and indirectly with the demand of the household can be expressed as:

$$E = D + C = \mathbf{d}'\mathbf{y}^h + \mathbf{c}'\mathbf{x}^h = \mathbf{d}'\mathbf{y}^h + \mathbf{c}'\mathbf{M}\mathbf{y}^h = \mathbf{d}'\mathbf{y}^h + \boldsymbol{\lambda}'\mathbf{y}^h = \boldsymbol{\omega}'\mathbf{y}^h. \tag{5}$$

In order to study more deeply the factors underlying the final demand of the household in each country, this demand is broken down into four factors associated with: household consumption patterns ($\mathbf{H}$) (households classified by quintiles of income), the distribution of the demand throughout different groups of households ($\mathbf{z}$) (classified by quintiles of income), the *per capita* expenditure (Y) and the country population size (P):

$$\mathbf{y}^h = \mathbf{H} \cdot \mathbf{z} \cdot Y \cdot P. \tag{6}$$

Therefore, given that E can be expressed as:

$$E = D + C = \mathbf{i}'\hat{\mathbf{d}}\mathbf{y}^{\mathbf{h}} + \mathbf{i}'\hat{\mathbf{c}}\mathbf{x}^{\mathbf{h}} = \mathbf{i}'\hat{\mathbf{d}}\mathbf{y}^{\mathbf{h}} + \mathbf{i}'\hat{\mathbf{c}}\mathbf{M}\mathbf{y}^{\mathbf{h}} = \mathbf{i}'\mathbf{e}_d^h + \mathbf{i}'\mathbf{e}_e^h \tag{7}$$

with $\mathbf{i}' = (1,\ldots,1)$, the vector of emissions associated with the demand of households, can be expressed as the sum of the embodied ($\mathbf{e}_e^h$) and direct ($\mathbf{e}_d^h$) emissions. The application of SDA to vector $\mathbf{e}_e^h$ leads us to the following expression for the changes in household embodied emissions between two periods 0 and 1:

$$\begin{aligned}
\Delta\mathbf{e}_e^h &= \mathbf{e}_{e1}^h - \mathbf{e}_{e0}^h \\
&= \hat{\mathbf{c}}_1 \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathbf{M} \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathrm{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathbf{M} \cdot \mathrm{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \Delta\mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathrm{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathbf{M} \cdot \mathrm{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \Delta\mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \Delta\mathbf{z} \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_0 \cdot Y_1 \cdot P_1 - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathrm{M}_0 \cdot \mathrm{H}_1 \cdot \mathrm{Z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathrm{M} \cdot \mathrm{H}_1 \cdot \mathrm{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathrm{M}_0 \cdot \Delta\mathrm{H}_1 \cdot \mathrm{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathrm{M}_0 \cdot \mathrm{H}_0 \cdot \Delta\mathrm{z} \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot \Delta Y \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_1 \\
&\quad - \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\
&= \Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathbf{M} \cdot \mathrm{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \Delta\mathbf{H} \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathrm{H}_0 \cdot \Delta\mathbf{z} \cdot Y_1 \cdot P_1 \\
&\quad + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot \Delta Y \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot \Delta P.
\end{aligned} \tag{8}$$

Thus, we have decomposition with six terms, each representing the contribution of one explicative factor to the total variation of embodied emissions ($\mathbf{e}_e^h$). As can be observed, while the incremental term (Δ), runs from left to right when we move from one component to another, the variables that remain on its left in each one are valued in the period 0 (initial), the ones on the right being referred to period 1 (final).

This decomposition is exact, in the sense that there are no residuals. Nevertheless, it is not the only possibility with such a property, since other decompositions can be obtained by simply changing the order of the components of $\mathbf{e}_e^h$. This is the so-called problem of non-uniqueness of SDA solutions. Dietzenbacher and Los (1998) demonstrate that, if the expression used for the decomposition has n components, there exist $n!$ different exact decomposition forms. In this case, we will have $6! = 720$ forms to express $\Delta\mathbf{e}$ in an exact way from the components

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[5] Emissions associated with home heating, fuel for cars, etc.

[6] The term "value" is assigned due to the similarity of these indicators to traditional work values used in other types of analysis, corresponding to vertically-integrated economic assessment.

[7] We assume vector **c** of direct emissions intensity and the Leontief inverse **M** as separate and independent determinants in SDA. In general, dependence between the terms involved in an SDA could result in a bias of the contribution of the separated effects. The hypothesis of independence between **c** and **M** is commonly used in empirical analysis, although it is sometimes controversial, since certain factors affecting **M** also affect **c** (we can think, for instance, of an increase in the sectoral use of fuels). We believe that, under certain conditions, both factors can evolve and contribute to the total emissions, separately. Changes in the structure of the economy due to technological change (input savings, terciarization of production), maintaining the shape of the product manufactured with the same industrial inputs, will change the matrix **M**, but not necessarily the direct emission per unit of output **c**. On the other hand, changes in quality of the various energy carriers, given a constant level of technology and composition of output, different productivities of fuels, changes in carbon potentials, or inter-fuel substitutions may all imply a change in **c** but not necessarily in **M**. In any case, we have carried out the same calculations presented here but considering both determinants together, and the results for the aggregate factor **c′M** are practically identical to the sum of the effects of **c** and **M** estimated independently.

considered. In each of these 720 expressions, each addend would indicate the contribution of the term that is expressed as an increment, to the total variation of $\mathbf{e}_e^h$. As noted by Dietzenbacher and Los (1998) and Rørmose and Olsen (2005), the different expressions can provide quite different contributions to the total change for the same determinant, which in fact invalidates the arbitrary choice of either decomposition. In practice, different commitment solutions have been adopted to overcome this problem. In our work, the final contribution of each explanatory factor of $\Delta\mathbf{e}$ is obtained as an average of its contribution in each of the 720 decomposition forms, following Dietzenbacher and Los (1998), who present this option as an improvement to the polar-case solution.[8] The standard deviation of these contributions is also obtained. As support for this calculation, we take the algorithm proposed by these authors, and developed also in Rørmose and Olsen (2005).

Regarding $\mathbf{e}_d^h$, changes in its value indicate technological improvements in the composition of products of reference (fuel with less capacity to pollute) and in the goods (automotive vehicles, heating, etc.) that the household uses as energy sources (less polluting motors, catalytic converters, etc.). In this case, a similar decomposition will be used, specifically that resulting from the expression:

$$\mathbf{e}_d^h = \hat{\mathbf{d}} \cdot \mathbf{H} \cdot \mathbf{z} \cdot Y \cdot P. \tag{9}$$

Once SDA is applied, adding embodied and direct emissions results, we can analyze the influence that the variations in technological and demand factors have on changes in household emissions, as well as the differences found, temporarily and between countries.

2.2. Data

The final selection of the 11 countries included in the study has been highly conditioned by the availability of information in different databases. A special effort has been made to include the United States.[9] Specifically, we have worked with the following information.

First, we use the collection of input–output tables from the OCDE, 2009 (OECD Input-Output Database, 2009). We have extracted the corresponding symmetric tables and their vectors of final demand and value added, updating them to constant prices from 1995 and homogenized in euros, using data of prices and rates of Exchange from the European Commission and from Eurostat.[10] The input–output tables were updated through techniques of adjustment type RAS and aggregated to the number of sectors considered. From these homogeneous tables, the values of output by industry and of final demand by households were obtained, as well as the matrix of technical coefficients (**A**) and the Leontief inverse (**M**).

Second, data on emissions of CO_2 by productive sectors were obtained from Eurostat's data-base in electronic support[11] (web) *Air Emissions Accounts by activity* (*NACE industries and households*), in which the emissions of polluting gases (by type) are provided for each branch of activity. For the United States, we have turned to the data published by the UN (electronic format, web) in the data-base *United Nations Framework Convention on Climate Change*, extrapolating from that an NACE classification for the European countries. We have also used data from the U.S. Environmental Protection Agency, 2007. The combined use of these data with the output values from the tables allows us to obtain the vectors **c** and **d**.

Third, patterns of consumption from the European countries were estimated from Eurostat data, corresponding to surveys of household budgets from each country (Household Budget Surveys, HBS). For the years 1995 and 2000, the existing data for 1994 and 1999 were used (harmonized by Eurostat). Specifically, information related to expenditure structure is broken down according to the classification COICOP, by the average expenditure in consumption by household in each quintile of income (in euros, and purchasing power parity). Additional transformations are necessary to complete the information in certain cases, and to make it compatible with the classification followed in the input–output tables (NACE). (More information on the process of estimating consumption patterns can be obtained in Mainar (2010)). For the United States, the data on distribution of expense was estimated from publications (electronic support, web) by the Bureau of Labour Statistics (BLS) in its *Consumer Expenditure Survey*. Combining this information with previous data leads us to a final level of aggregation of 18 sectors.

Finally, the population data that make up the values of P and those that calculate the final total household demand per capita (Y), are extracted from the census and population statistics of each country, compiled by Eurostat (for the United States, data from the Census Bureau).

3. Result

The application of SDA to an analysis of changes in CO_2 emissions associated with the final demand of households produces decomposition in all the explanatory factors indicated in the methodology. Nevertheless, for the purposes of clarity, the results are presented first with a certain level of aggregation, separating them into two blocks: the sum of all factors related to the structure of demand, and technological factors.

3.1. First Approach to the Effects of Demand and Technological Effects by Countries[12]

A first look at the results for the period 1995 to 2005 (see Picture 1 and Table 1), shows certain interesting and, to some extent, common features that we will develop later in more detail.

First, the advanced economies analyzed, with the sole exception of Sweden, have increased their emissions associated with households during the decade 1995–2005. Portugal, Spain, and to a lesser extent Austria, lead the growth in emissions, with a yearly emission growth of around 5% (3% for Austria), nearly doubling the emission growth rate of other polluting countries such as the US and Italy.

In this respect, Spain, Portugal and the US present increases primarily in the behavior observed during the first period (1995–2000), while Italy has a balanced contribution between periods, and Austria shows a significant increase in household emissions in the second period (2000–2005).

Second, for the whole period and for the whole sample (except for the limited data of Denmark), demand factors boost emissions upward. The contribution of technological factors is mixed, depending on the country and period analyzed. Thus, demand factors underlying household consumption are crucial in the explanation, for instance, of the significant growth in emissions observed in Spain, Portugal and Austria. All

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[8] Dietzenbacher and Los (1998) show that the polar-case solution is quite close to the average of the $n!$ forms. In our case, the polar-case solution will be given by

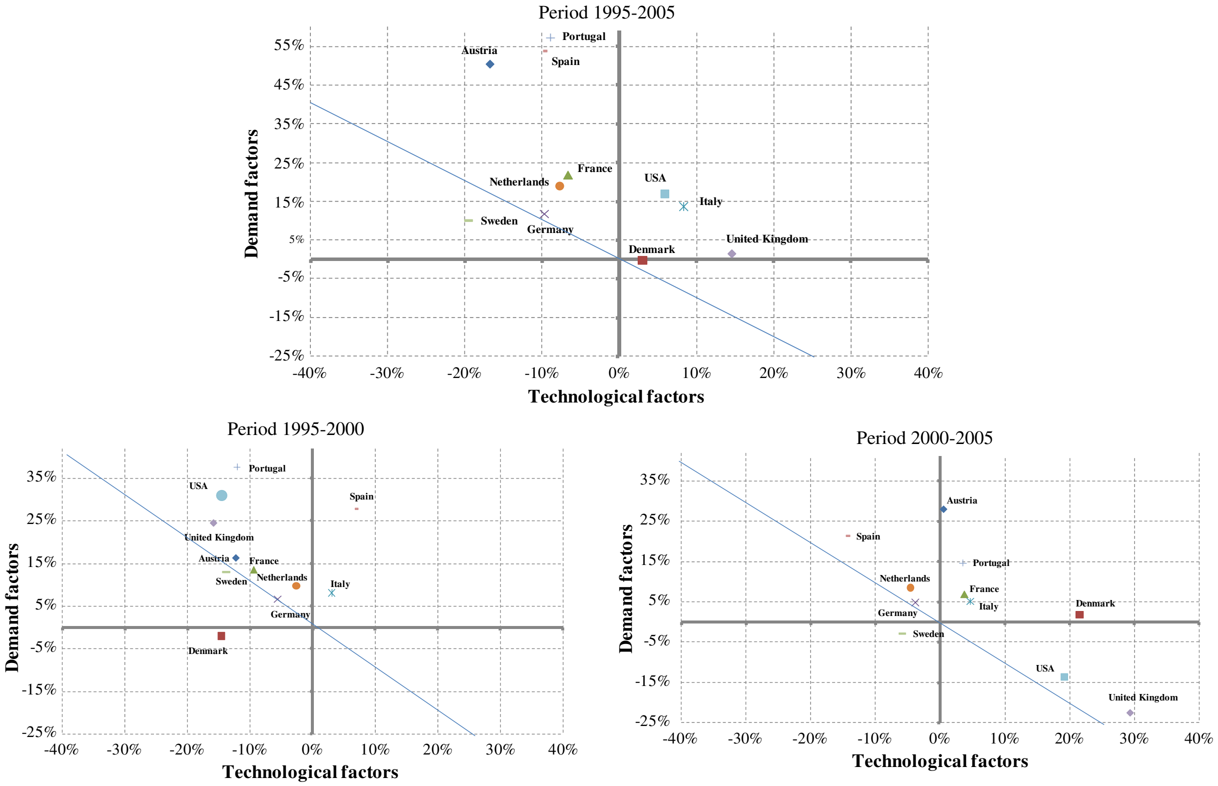
$$\begin{aligned}\Delta\mathbf{e}_e^h = 1/2(&\Delta\hat{\mathbf{c}} \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \Delta\mathbf{M} \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \Delta\mathbf{H} \cdot \mathbf{z}_1 \cdot Y_1 \\ &\cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \Delta\mathbf{z} \cdot Y_1 \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot \Delta Y \cdot P_1 + \hat{\mathbf{c}}_0 \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot \Delta P) \\ &+ 1/2(\Delta\hat{\mathbf{c}} \cdot \mathbf{M}_0 \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 + \hat{\mathbf{c}}_1 \cdot \Delta\mathbf{M} \cdot \mathbf{H}_0 \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 + \hat{\mathbf{c}}_1 \cdot \mathbf{M}_1 \cdot \Delta\mathbf{H} \cdot \mathbf{z}_0 \cdot Y_0 \cdot P_0 \\ &+ \hat{\mathbf{c}}_1 \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \Delta\mathbf{z} \cdot Y_0 \cdot P_0 + \hat{\mathbf{c}}_1 \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot \Delta Y \cdot P_0 + \hat{\mathbf{c}}_1 \cdot \mathbf{M}_1 \cdot \mathbf{H}_1 \cdot \mathbf{z}_1 \cdot Y_1 \cdot \Delta P).\end{aligned}$$

[9] When data for a certain country did not refer exactly to the years 1995, 2000 and 2005, the closest figures were used temporarily, extrapolating them with the support of other data.

[10] The databases used and described in this section were the most appropriate at the time of this research, and their validity and reliability are maintained. Additionally, new databases covering, among others, the countries considered in the study in a multiregional framework, are now available. Of special interest, given its wide European sample, is the World Input–output Database (WIOD), whose value is clear for future research. See Timmer (2012) and the WEB page: http://www.wiod.org/. A review of the current global multiregional input–output frameworks can be seen in Tukker and Dietzenbacher (2013).

[11] http://epp.eurostat.ec.europa.eu.

[12] These effects are obtained by adding the corresponding effects to the comprehensive implementation of SDA.



Picture 1. Position of the countries analyzed according to the influence of their technological and demand factors. Total CO_2 emissions. Period 1995–2000.

other things being constant, the demand factors in these countries imply an increase of more than 50% in household-associated emissions. Technological factors led to decreases in emissions during those ten years in France, the Netherlands, Germany, Spain, and, especially significant, Austria and Sweden.

And third, in general terms, demand factors predominated over technological factors, resulting in an overall increase of emissions.

These general trends can be qualified by sub-periods and countries.

Let us consider the first period, 1995–2000. We can see that demand factors, taken together, have contributed to increase CO_2 emissions (except in Denmark), surpassing in almost all cases the improvements produced through technology. The factors of demand explain a significant increase in Portugal, Spain and the US (more than 25% in all three).

Apart from Spain and Italy, all countries reduced their emissions through technological factors, either through improvements in efficiency or by the substitution of inputs, notably Austria, Denmark, Germany, Sweden, the UK and the US, where these factors helped significantly in controlling emission growth.

In the European countries, the reductions were due primarily to the sectors *Electricity, gas and water* and *Transport*, while in the United States, in addition to reductions from improvements in the *Transport* sector, a key factor was an increase in efficiency in the service sectors in general.

For the period 2000 to 2005, only Sweden, Germany and Netherlands maintain the decrease from the prior period due to technological factors.

In this period, Spain shows improvement in the technological components not experienced in the prior time period considered. Moreover, between 2000 and 2005, we observe three cases of household demand's contribution to reductions in CO_2 emissions: Sweden, the UK and the US.

In summary, we notice, through a first approximation, that, in general terms, technological factors tend to contribute to a reduction of CO_2 emissions, while demand drives emissions up. Likewise, factors of demand predominate over technological factors, justifying the increase in emissions observed in most of the economies. In what follows, we will address the specific economic factors underlying these changes.

Table 1
Decomposition of changes in CO_2 emissions associated with household demand. Technological and demand factors.

	1995–2005			1995–2000			2000–2005		
	Technological factors	Demand factors	Total	Technological factors	Demand factors	Total	Technological factors	Demand factors	Total
Austria	−16.8%	50.5%	33.7%	−12.3%	16.3%	4.0%	0.4%	28.1%	28.5%
Denmark	3.1%	−0.4%	2.8%	−14.5%	−2.1%	−16.7%	21.6%	1.7%	23.3%
France	−6.7%	21.9%	15.2%	−9.5%	13.6%	4.1%	3.7%	6.9%	10.6%
Germany	−9.7%	11.7%	1.9%	−5.6%	6.5%	0.9%	−3.8%	4.8%	1.0%
Italy	8.4%	13.6%	22.0%	3.1%	8.0%	11.1%	4.7%	5.1%	9.8%
Netherlands	−7.7%	18.9%	11.3%	−2.6%	9.7%	7.1%	−4.6%	8.5%	3.9%
Portugal	−9.3%	57.6%	48.3%	−12.1%	37.6%	25.6%	3.5%	14.6%	18.1%
Spain	−10.3%	54.1%	43.8%	6.3%	28.2%	34.5%	−14.5%	21.5%	6.9%
Sweden	−19.5%	10.0%	−9.4%	−13.8%	12.9%	−0.8%	−5.8%	−2.8%	−8.7%
United Kingdom	14.5%	1.5%	16.1%	−15.9%	24.6%	8.7%	29.5%	−22.7%	6.8%
USA	5.9%	17.0%	22.9%	−14.5%	30.9%	16.4%	19.2%	−13.6%	5.6%

Table 2
Full decomposition of changes (%) in CO_2 emissions associated with household demand.

		Austria	Denmark	France	Germany	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom	USA
Period 1995–2005	Emission intensity	−20.8	−4.0	−17.5	−21.0	5.7	−13.5	−31.2	−26.6	−20.2	21.3	13.9
	Intermediate inputs	4.0	7.2	10.8	11.3	2.7	5.9	21.9	16.4	0.7	−6.8	−8.0
	Total technological factors	−16.8	3.1	−6.7	−9.7	8.4	−7.7	−9.3	−10.3	−19.5	14.5	5.9
	Pattern of consumption	30.9	−15.0	−9.4	−7.3	−4.1	−11.9	6.1	7.5	−7.2	−16.4	−6.0
	Distribution of the demand	0.0	−0.2	0.0	−0.1	0.5	0.5	0.1	0.1	−0.1	0.0	−0.1
	Demand per capita	15.8	11.1	25.4	17.8	14.2	24.5	45.1	35.6	15.2	14.0	11.5
	Population	3.9	3.7	5.9	1.2	3.1	5.9	6.3	11.0	2.1	3.9	11.6
	Total demand factors	50.5	−0.4	21.9	11.7	13.6	18.9	57.6	54.1	10.0	1.5	17.0
	Total change in emissions	33.7	2.7	15.2	2.0	22.0	11.2	48.3	43.8	−9.5	16.0	22.9
Sub-period 1995–2000	Emission intensity	−15.3	−10.6	−12.1	−10.3	−3.6	−5.1	−17.5	−21.6	−16.4	−18.8	−9.1
	Intermediate inputs	3.0	−3.9	2.6	4.7	6.7	2.5	5.4	28.0	2.6	2.9	−5.5
	Total technological factors	−12.3	−14.5	−9.5	−5.6	3.1	−2.6	−12.1	6.3	−13.8	−15.9	−14.5
	Pattern of consumption	2.2	−10.5	−2.9	−8.7	−4.4	−6.7	1.6	0.2	−0.8	−3.2	−3.1
	Distribution of the demand	−0.3	−0.1	0.0	0.0	0.4	0.3	0.4	0.1	−0.1	−0.3	0.0
	Demand per capita	13.7	6.4	14.5	14.5	11.9	13.2	33.6	25.7	13.3	26.6	28.3
	Population	0.8	2.0	2.1	0.8	0.1	2.9	2.0	2.1	0.5	1.5	5.7
	Total demand factors	16.3	−2.1	13.6	6.5	8.0	9.7	37.6	28.2	12.9	24.6	30.9
	Total change in emissions	4.0	−16.6	4.1	0.9	11.1	7.1	25.5	34.5	−0.9	8.7	16.4
Sub-period 2000–2005	Emission intensity	−0.5	7.0	−4.5	−10.4	9.1	−7.8	−9.8	−4.1	−3.9	39.1	21.3
	Intermediate inputs	0.9	14.6	8.3	6.5	−4.4	3.2	13.3	−10.5	−2.0	−9.6	−2.1
	Total technological factors	0.4	21.6	3.7	−3.8	4.7	−4.6	3.5	−14.5	−5.8	29.5	19.2
	Pattern of consumption	24.9	−4.3	−6.7	1.3	0.7	−5.1	4.2	6.4	−6.9	−12.1	−2.5
	Distribution of the demand	0.3	−0.1	0.0	−0.1	0.0	0.2	−0.3	0.0	0.0	0.3	−0.1
	Demand per capita	0.0	4.4	10.0	3.1	1.6	10.5	7.2	7.6	2.5	−13.2	−16.3
	Population	2.9	1.7	3.6	0.4	2.8	2.8	3.5	7.5	1.6	2.3	5.3
	Total demand factors	28.1	1.7	6.9	4.8	5.1	8.5	14.6	21.5	−2.8	−22.7	−13.6
	Total change in emissions	28.5	23.3	10.6	1.0	9.8	3.9	18.1	7.0	−8.6	6.8	5.6

3.2. Decomposition of Technological Effects by Country

Under technological factors, we include two different types: those representing changes in sectoral emission intensity (emission per unit of output) and those related to production structure and the processes of input substitution, which are reflected in changes in the Leontief inverse.

Table 2 shows the results of SDA for the technological and demand changes. Data are given by country and period. Picture 2 represents the relative situation of countries in technological factors. Table 3 shows a measure of the variability of the results.[13]

As can be seen, the positive contribution of technological factors to the reduction in emissions observed in most of the EU countries, and especially during the first sub-period, is mainly based on a generalized reduction of the emission intensity component. Economic structure, and more specifically the shift towards more energy-intensity inputs, has acted to increase CO_2 emissions in all EU countries except the UK. As we will see, the increasing demand for goods by households has been accompanied by an increase in the demand for inputs by industry, resulting in more pollution.

The opposite case is observed for the UK and the US with respect to technological factors. Both countries experienced increases in the intensity component (mainly in the second sub-period), while structural changes have operated in the direction of CO_2 reduction.

Important differences can be observed between sub-periods. The first sub-period can be characterized by a generalized reduction of energy intensity in all countries. Note that, all other things being constant, the improvement in CO_2 efficiency, i.e., the reduction of emissions per unit of output, would have allowed for an average reduction in emissions of around 12%. At the same time, most of the countries were growing, some of them strongly (Spain and Italy), which implied a greater demand of inputs for producing goods demanded by households, with an associated increase in emissions. All in all, with the exception of Spain and Italy, technological factors in this period drove a reduction of emissions in advanced economies.

This general trend is broken in the second sub-period. Although most of the countries maintain the contribution of energy intensity to the reduction of emissions, two countries, the UK and the USA, show an increase in this factor. With respect to the intermediate inputs, we cannot obtain a general rule. Some of the countries maintain a contribution of this factor to the increase in emissions (Austria, Denmark, France, Germany, Netherlands and Portugal), but in Spain, Italy and the UK, the changes in the economic structure, captured in the Leontief inverse, contributed in this period to alleviate the growth in emissions associated with household demand.

3.3. Decomposition of the Demand Effect by Countries

Table 2 also shows the contribution of the demand components to changes in CO_2 emissions. Picture 3 shows these demand components for the entire period.

As can be seen, for the whole period, the demand factors have barely increased emissions.

Generally speaking, the increase in per capita expenditure has been the main factor in emission growth, with population growth also contributing to this trend. Consumption patterns have contributed, in general, to the reduction of CO_2 emissions. This holds for all the countries except for the three leading the increase in household emissions, i.e. Spain, Portugal and Austria. In these countries, changes in consumption patterns, unlike in most other countries surveyed, have led to greater participation of sectors with high emission intensities (*Agriculture and food*, *Transport* and, especially *Energy products*) in household expenditure. The effect of changes in the distribution of demand between income groups is close to negligible.

Looking by sub-periods, in the first, 1995–2000, two of the four components of the demand effect are the most significant: the pattern of

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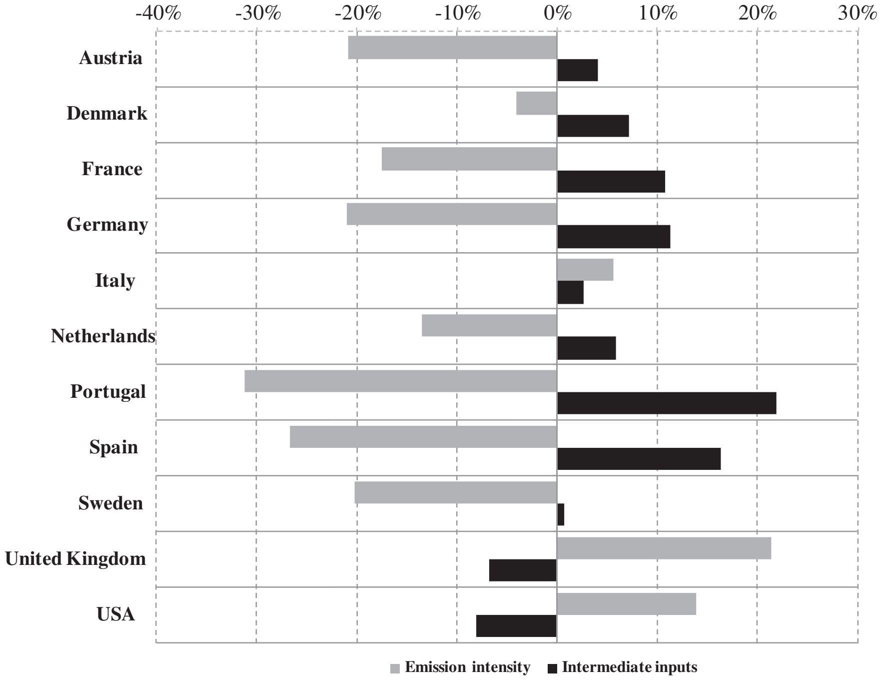
[13] Following Dietzenbacher and Los (1998), we accompany the SDA results with a measurement of variability. In this case, for each factor and country, and considering the range of the 720 different combinations, we divided the standard deviation (σ) by the mean (μ). These ratios indicate that the data variability is generally acceptable. In any case, we can say that the variability in the contribution of the components is high, in a general way, only in the factor related to the distribution of demand, which is precisely the less relevant component. Also, we observe that the ratio σ/μ is more variable in the first sub-period, 1995–2000, than in the period 2000–2005, which leads to interpret with more caution the results of the different components. No country appears to be particularly singled out by the value of its variations.



Picture 2. Changes in CO_2 emissions associated with household demand. Technological factors. Period 1995–2005.

consumption and *per capita* demand. The results in Table 2 also show that the increase in per capita demand is the main driver of growth in CO_2 emissions, while changes in patterns of consumption have contributed to reduce the volume of emissions in practically all the countries.

The first aspect, growth in demand per capita, was especially significant in the US during the period, when it generated an increase in CO_2 emissions of more than 28%. Spain also stood out (25.4%), as did the UK (26.6%) and Portugal (33.6%). In the remaining countries analyzed, the contribution of this component does not exceed 15%.

Patterns of consumption have allowed for reductions in emissions during this period in all countries considered, except Spain, Austria and Portugal. Nevertheless, the decreases were generally less significant than the increases generated by demand per capita in most countries.

Regarding the other two demand factors, distribution of the demand by quintiles ($\mathbf{z}$) and population (P), it can be seen that the contribution of the former has been of little impact, with values around 0.1% of the total change. Population increases in all countries resulted in increases in the volume of emissions.

In the second sub-period, 2000–2005, the strength of per capita demand as a driving factor of household emissions diminishes (observing a negative contribution in the UK and the US). Consumption patterns continue to be a source of emission growth in Austria, Portugal and Spain, while contributing to CO_2 reduction more than before in France, Sweden and the UK.

Population growth produces greater increases in CO_2 emissions than in the previous five-year period. This is especially significant in Spain, where the rise in population between 2000 and 2005 led to an increase of 7.5% in the volume of CO_2 emissions caused by household demand. The US (5.3%), France (3.6%) and Portugal (3.5%) also showed significant rises in pollution associated with population growth.

In summary, demand factors contributed to reductions in emissions through changes in patterns of consumption (except in Austria, Spain and Portugal). These effects were obscured by the considerable increases associated with per capita demand growth in most countries, especially in Portugal, Spain, France, the Netherlands and Germany. Population growth was especially significant in the US and in Spain, being associated with an increase of nearly 11% in household emissions. Nevertheless, the tendency for change that the data from 2000 to 2005 reflect must not be overlooked.

3.4. Effects by Sectors

Having seen the effects, and their decomposition by countries, an analysis by sectors is carried out, adding[14] the results of each sector for the European countries[15] described, in order to synthesize the information. These results can be seen in Table 4.

Data for the US are not included in this Table for space constraints, but are available as Supplementary Material, Table A1.[16]

As can be seen in Table 4, technology has contributed in a very different way in the two sub-periods. Between 1995 and 2000, in practically all sectors, technological factors account for a reduction of CO_2 emissions, in general through reductions of emissions from industrial activity, together with similar effects from energy and mining. The dominant sectors are *Energy products*, *Metals and machinery and equipment*, *Chemical products, pharmaceuticals and plastics* and *Hotels and restaurants*. Increases due to technology, although of minor importance, are only observed in the *Construction* and *Transport* sectors.

However, in the following five-year period, 2000 to 2005, reductions due to technological factors were only produced in *Communications*, and

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[14] Here, it is important to keep in mind that this aggregation does not represent a whole economy, rather it simply attempts to show average behavior.

[15] The reason for omitting sectors of the US from this aggregation is based on criteria of analysis and availability of data. Regarding the former, it seems reasonable to add the productive sectors, considering the member countries of the European Union separately. The existence of common policies, in industrial as well as in environmental matters, enables a more coherent integration. On the other hand, the peculiarities of the US production system, as well as its different ways of tackling the problem of emissions of greenhouse-effect gases, reinforce this choice. Regarding the availability of data, the different sources of data used to estimate emissions in both zones (Eurostat and UNFCCC, respectively) advise against mixing both types of assessments in each of the sectors.

[16] Data for the US, despite the differences in sectoral grouping, shows a similar trend to that observed for the European sectors between 1995 and 2000, characterized by reductions in emissions associated with technological factors, although compensated by increases associated with demand factors. Between 2000 and 2005, technological factors change the sign of their contribution, now observing improvements in the demand factors in some sectors, in accord with a generalized decline in consumption.

Table 3
σ/μ values of full decomposition of changes (%) in CO_2 emissions associated with household demand.

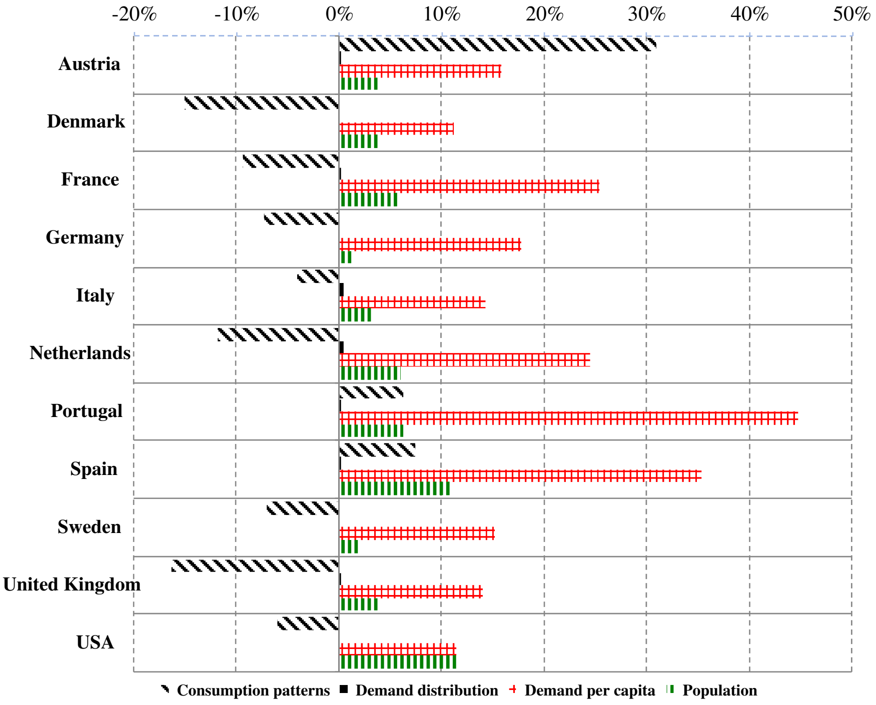
		Austria	Denmark	France	Germany	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom	USA
Period 1995–2005	Emission intensity	0.43	0.64	0.16	0.15	0.12	0.12	0.28	0.27	0.09	0.17	0.11
	Intermediate inputs	0.12	0.35	0.13	0.11	0.14	0.12	0.20	0.21	0.66	0.20	0.20
	Pattern of consumption	0.25	0.07	0.12	0.19	0.25	0.14	0.27	0.22	0.20	0.26	0.20
	Distribution of the demand	1.79	0.58	5.31	0.83	0.35	0.37	0.38	0.30	1.28	3.44	0.35
	Demand per capita	0.14	0.08	0.09	0.11	0.04	0.08	0.13	0.12	0.12	0.11	0.08
	Population	0.16	0.08	0.13	0.12	0.08	0.12	0.22	0.18	0.12	0.12	0.08
Sub-period 1995–2000	Emission intensity	0.09	0.04	0.16	0.09	0.11	0.07	0.19	0.29	0.08	0.14	0.16
	Intermediate inputs	0.14	0.05	0.09	0.07	0.05	0.07	0.17	0.17	0.11	0.22	0.17
	Pattern of consumption	0.24	0.04	0.47	0.09	0.07	0.07	0.60	0.39	0.58	0.17	0.19
	Distribution of the demand	1.80	0.24	0.31	0.07	0.36	0.15	0.19	0.25	0.58	0.24	1.42
	Demand per capita	0.07	0.10	0.06	0.07	0.03	0.04	0.07	0.13	0.08	0.09	0.06
	Population	0.08	0.09	0.08	0.08	0.06	0.06	0.15	0.17	0.09	0.13	0.12
Sub-period 2000–2005	Emission intensity	0.96	0.49	0.13	0.08	0.04	0.08	0.15	0.13	0.07	0.16	0.08
	Intermediate inputs	0.90	0.24	0.06	0.07	0.08	0.11	0.06	0.13	0.02	0.26	0.12
	Pattern of consumption	0.17	0.05	0.08	0.27	0.63	0.08	0.12	0.11	0.04	0.26	0.12
	Distribution of the demand	0.56	0.32	3.61	0.73	0.09	0.19	0.14	0.99	2.17	0.60	0.24
	Demand per capita	0.12	0.08	0.05	0.05	0.05	0.04	0.07	0.06	0.05	0.17	0.11
	Population	0.11	0.09	0.06	0.05	0.04	0.06	0.08	0.06	0.05	0.17	0.11

to a lesser extent, in *Chemical products, pharmaceuticals and plastics* and *Construction*, with increases in the emissions of CO_2 in the remaining sectors, confirming the notion that the period 2000 to 2005 represents a period of change.

Together, the European economies studied increased CO_2 emissions from household demand by 4.9% due to technological factors during that period, compared to a reduction of 6.4% experienced in the prior period. The combined effect of both periods is a drop of 1.6%, largely based on reductions experienced in the sectors *Energy products* (−15.1%), *Chemical products, pharmaceuticals and plastics* (−14.2%), *Metal products, machinery and equipment* (−9.2%) and *Hotels and restaurants* (−8.1%), reductions basically concentrated in the first sub-period.

Again, a different contribution is obtained for the intensity factor and the factor associated with changes in the Leontief inverse. Emission intensities contributed to a drop in emissions in virtually all sectors, while the increasing household demand for goods implied higher production, thereby contributing to the growth in emissions. More specifically, intermediate consumption between 1995 and 2000 contributed to emission increases throughout the economic sector. In the second sub-period, this is maintained for *Agriculture and food*, *Energy products*, *Metals and non-metals*, *Publishing, graphic arts and paper*, *Manufacture, wood and furniture* and *Electricity, gas and water*, sectors with high participation in the consumer market.

Demand factors can be associated with an increase in emissions in all sectors, not only for the combined periods, but also in the initial sub-period 1995 to 2000. Especially remarkable is the *Communications* sector, which had an increase of 124% in that decade. *Metal products, machinery and equipment*, *Chemical products, pharmaceuticals and plastics*, *Credit and insurance* and *Transport material*, also had significant increases, mostly during the first sub-period. Underlying this result is the increase in per capita demand as the principal driving force. This concurs with our previous findings in the analysis by countries. The only reductions caused by factors of demand were produced between 2000 and 2005 in *Electricity, gas and water* and in service sectors such as *Trade*, *Hotels and restaurants*, *Transport* and *Credit and insurance*.



Picture 3. Changes in CO_2 emissions associated with household demand. Demand factors. Period 1995–2005.

Table 4
Full decomposition of changes (%) in CO_2 emissions associated with household demand. Sectoral analysis. European countries.

		S.01	S.02	S.03	S.04	S.05	S.06	S.07	S.08	S.09	S.10	S.11	S.12	S.13	S.14	S.15	S.16	S.17	S.18	Total
Period 1995–2005	Emission intensity	−12.5	−24.1	−9.1	−9.1	−9.0	−19.9	−18.3	−18.6	−10.9	−2.2	−6.2	−8.0	−9.9	3.2	−28.5	−14.5	−10.5	−14.2	−7.7
	Intermediate inputs	8.8	9.0	5.6	5.8	8.9	5.7	9.1	13.2	12.0	4.7	12.7	10.7	1.8	0.3	22.6	22.0	4.0	16.1	6.1
	Total technological factors	−3.7	−15.1	−3.5	−3.3	−0.1	−14.2	−9.2	−5.4	1.1	2.5	6.5	2.7	−8.1	3.5	−5.9	7.5	−6.5	1.9	−1.6
	Pattern of consumption	−4.8	2.7	13.4	−6.7	8.9	29.8	47.3	24.0	6.5	−17.8	6.6	−19.0	−8.8	−16.4	90.1	31.5	−5.3	−2.6	−7.1
	Distribution of the demand	1.1	0.0	−0.2	−0.1	−0.3	0.3	0.2	−0.5	−0.1	0.4	0.3	0.2	−1.2	−0.4	1.1	−0.5	0.2	−0.3	0.1
	Demand per capita	21.0	20.0	21.3	19.2	21.0	22.2	23.2	22.0	21.5	17.9	21.5	17.5	20.6	19.6	27.5	22.0	19.8	21.3	19.6
	Population	4.4	3.6	4.2	3.8	4.1	4.5	4.7	4.3	4.5	3.5	5.1	3.6	4.7	4.0	5.7	4.3	4.1	4.3	3.9
	Total demand factors	21.6	26.4	38.7	16.2	33.6	56.8	75.4	49.8	32.4	4.0	33.5	2.4	15.2	6.8	124.4	57.3	18.9	22.6	16.5
	Total change in emissions	18.0	11.3	35.2	12.9	33.5	42.6	66.2	44.3	33.5	6.5	40.1	5.1	7.2	10.3	118.5	64.8	12.4	24.5	14.9
Sub-period 1995–2000	Emission intensity	−12.9	−22.7	−8.7	−12.1	−16.0	−20.5	−22.7	−20.9	−14.8	−11.4	−13.5	−16.4	−14.6	−0.5	−30.3	−25.2	−14.6	−16.4	−12.3
	Intermediate inputs	6.5	6.8	3.7	7.8	6.0	9.2	8.5	12.4	7.8	4.4	18.9	14.6	3.3	1.1	28.7	23.2	3.9	9.9	5.9
	Total technological factors	−6.4	−15.8	−5.0	−4.3	−10.0	−11.2	−14.1	−8.4	−7.0	−7.0	5.3	−1.8	−11.2	0.6	−1.7	−2.0	−10.8	−6.5	−6.4
	Pattern of consumption	−6.5	4.0	2.0	−4.6	1.0	8.7	24.9	17.4	5.6	−11.3	9.1	−9.1	−1.3	−11.5	45.9	32.2	−4.7	−1.9	−4.8
	Distribution of the demand	0.8	0.1	−0.1	−0.1	−0.2	0.4	0.3	−0.3	−0.1	0.0	0.2	0.3	−1.0	−0.3	0.8	−0.4	0.1	−0.2	0.0
	Demand per capita	17.5	15.8	17.9	17.3	17.5	18.7	20.1	19.6	18.9	17.6	19.6	17.7	18.3	17.3	22.8	23.9	17.0	18.7	17.6
	Population	1.4	1.2	1.2	1.1	1.2	1.3	1.4	1.3	1.4	1.2	1.3	1.1	1.3	1.3	1.5	1.6	1.2	1.4	1.3
	Total demand factors	13.2	21.1	21.1	13.8	19.5	29.1	46.7	38.0	25.9	7.6	30.1	10.0	17.3	6.8	71.0	57.3	13.7	18.0	14.1
	Total change in emissions	6.8	5.3	16.1	9.5	9.5	17.9	32.5	29.5	18.9	0.6	35.4	8.2	6.0	7.4	69.3	55.3	3.0	11.5	7.7
Sub-period 2000–2005	Emission intensity	1.4	0.3	1.8	4.4	9.7	4.4	8.1	3.9	6.0	9.1	3.8	6.4	4.4	3.8	3.9	9.0	4.9	3.2	5.0
	Intermediate inputs	1.3	1.7	0.4	−3.1	1.9	−5.3	−3.1	−1.5	2.8	0.1	−3.9	−1.7	−1.1	−0.8	−7.4	−2.1	−0.2	5.1	−0.2
	Total Technological factors	2.7	2.1	2.3	1.2	11.6	−0.9	5.1	2.4	8.8	9.2	−0.2	4.8	3.4	3.0	−3.5	6.9	4.7	8.3	4.9
	Pattern of consumption	2.3	−2.3	10.9	−1.8	7.0	18.8	18.3	5.7	0.5	−5.8	−2.8	−10.9	−7.3	−4.7	27.9	−1.4	−0.5	−0.6	−2.1
	Distribution of the demand	0.1	0.0	0.0	0.0	0.0	−0.1	−0.2	−0.1	−0.1	0.3	0.1	0.0	−0.1	−0.1	0.1	−0.1	0.1	−0.1	0.1
	Demand per capita	2.4	3.5	0.7	1.0	0.8	0.5	−0.6	0.8	0.3	−0.2	2.7	0.7	1.9	1.8	1.6	−1.4	2.1	1.4	1.3
	Population	2.9	2.4	2.6	2.7	2.5	2.8	2.8	2.7	2.8	2.3	3.6	2.5	3.2	2.6	3.0	2.2	2.8	2.6	2.6
	Total demand factors	7.8	3.6	14.2	1.9	10.3	21.9	20.3	9.0	3.5	−3.3	3.6	−7.7	−2.3	−0.3	32.6	−0.8	4.5	3.4	1.8
	Total change in emissions	10.5	5.7	16.5	3.1	21.9	21.0	25.4	11.4	12.3	5.9	3.4	−2.9	1.1	2.7	29.1	6.1	9.2	11.7	6.7

S.01: Agriculture and food; S.02: Energy products; S.03: Metals and non-metals; S.04: Textiles and footwear; S.05: Publishing, graphic arts and paper; S.06: Chemical products, pharmaceuticals and plastics; S.07: Metal products, machinery and equipment; S.08: Transport material; S.09: Manufacture, wood and furniture; S.10: Electricity, gas and water; S.11: Construction; S.12: Trade; S.13: Hotels and restaurants; S.14: Transport; S.15: Communications; S.16: Credit and insurance; S.17: Real estate and other business activities; S.18: Public Administration, Education, Healthcare and other personal and social services for the community.

Emissions grew, on average, a scant 1.8% between 2000 and 2005, compared to 14.1% in the prior sub-period.

3.5. Effects of Direct Household Emissions by Countries

We now examine the factors that underlie direct household emissions and their evolution in time. As has already been pointed out, the decomposition of changes in direct emissions is similar to the decomposition carried out for total emissions (9). Table 5 summarizes the results obtained from the decomposition of variations in all technological and demand factors. Picture 4 graphically shows the position of the countries regarding the two groups of components (technological and demand).

With the exception of Italy, the countries under study can be classified in three blocks, according to their position in Picture 4. Denmark and the UK are the only countries in the quadrant with growth in emissions from technological factors and decreases from factors related to demand (basically due to patterns of consumption), while Portugal, Austria and Spain are located in the opposite block, with very high emission growth generated by factors of demand and reductions associated with improvements in the technology of related products (energy, except for electricity, and fuel). In this same quadrant, but with relatively inferior values, are the remaining countries (except for Italy). As a whole, only three countries reduce their total emissions — Germany, Denmark and Sweden. It should also be noted that in eight of the eleven countries analyzed, technological factors help to reduce emissions, although only in Sweden and Germany do such factors totally compensate for increases generated by demand factors.

Only Germany showed a decrease in direct household CO_2 emissions between 1995 and 2000, caused by the simultaneous influence of technological and demand factors (see Table 5). Factors of demand, in general, contributed to the increase in emissions, significantly in Portugal, Spain, the US and the UK. Technological factors generated improvements in all countries except Italy and Denmark, leading to significant reductions in direct CO_2 emissions in Portugal, Austria and Sweden. The total global balance in 1995–2000 was negative for five of the countries, and positive for the other six.

Between 2000 and 2005, technology played a positive role, leading to reductions in direct household emissions in most of the countries. The evolution of final demand again involved growth in direct emissions, except in Italy, Sweden, the UK and the US.

Detailed analyses of the variations in final household demand show similar qualitative behavior in the two sub-periods. The evolution of consumption patterns has allowed reductions in direct emissions in all cases, except for Austria, Spain and Portugal where an increase in the share of some polluting goods is observed, i.e., *Energy*, *Transport* and *Agriculture and food*. The growth in emissions due to the influence of demand per capita was especially significant in the first sub-period (1995 to 2000), reaching 24.1% in Spain, 26.4% in the UK, 27.0% in the US, and climbing to 33.6% in the case of Portugal. Again, the influence of the distribution of household demand according to income (by quintiles) is not significant. Population has an important effect on the growth of direct emissions in Spain, with a 10.5% increase between 1995 and 2005 (the major part in the second sub-period, 7.5% between 2000 and 2005) and in the US (10.5%). Increases in population entail, for example, a greater need for energy goods, independent of the existence, or not, of economic growth and its consistent increase in total expenditure. Growth in population has also resulted in a greater demand for private vehicles, leading to increased fuel consumption, which has a significant effect on the case of direct emissions in Spain and the US.

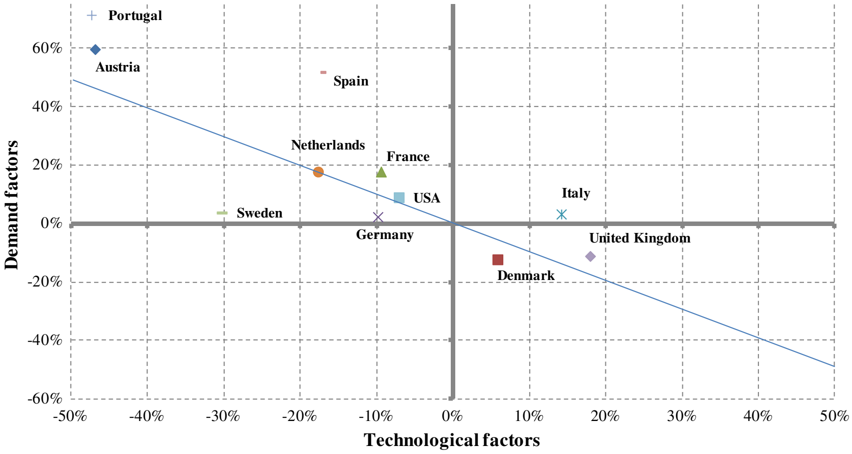
3.6. Uncertainty

A final consideration should be the necessary caution in the interpretation of the results obtained from our analysis.

Results from economic models in general, and from input–output models in particular, are associated with a wide range of uncertainties previously discussed in the literature. These concern both to methodological and empirical aspects. As noted by Lenzen et. al. (2003) and Wiedman (2009), uncertainties in input–output arise from a variety of sources: data reliability (i.e., basic source data), assumption of proportionality between monetary and physical flows, or aggregation of data about different products supplied by a single industry. As noted in Peters et. al. (2007), data uncertainty, although potentially important, is sometimes difficult to quantify. This source of uncertainty is obviously present in our work, since we are dealing with, and combining, economic and environmental information provided by different official sources (OECD, Eurostat, EPA, Census Bureau,…) with different criteria of data production. Regarding the SDA methodology, two specific sources of uncertainty must be considered. The first refers to the non-uniqueness problem, which has been discussed in the Methodological Aspects section. The second refers to the industry aggregation level. For instance, Weber (2009) in a US study showed that structural changes tend to be greater when the aggregation level decreases, while the opposite trend is observed for efficiency factors. Rørmose (2010), in a study of the sensitivity of SDA-environmental

Table 5
Decomposition of changes (%) in direct CO_2 emissions associated with household demand.

		Austria	Denmark	France	Germany	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom	USA
Period 1995–2005	Technological factors	−46.9	5.8	−9.4	−9.9	14.2	−17.7	−47.4	−17.4	−30.3	17.9	−7.1
	Pattern of consumption	41.0	−26.3	−12.7	−15.9	−13.3	−12.0	24.0	7.1	−11.9	−28.5	−11.8
	Distribution of the demand	0.0	−0.3	0.0	−0.1	−0.4	0.7	0.2	0.0	−0.1	0.1	−0.1
	Demand per capita	14.9	10.8	24.7	17.2	13.9	23.3	41.4	34.1	13.8	13.5	10.4
	Population	3.7	3.6	5.7	1.2	3.1	5.6	5.7	10.5	1.9	3.8	10.5
	Total demand factors	59.6	−12.3	17.7	2.3	3.2	17.7	71.3	51.8	3.7	−11.1	9.0
	Total change in emissions	12.7	−6.4	8.3	−7.6	17.4	0.0	24.0	34.4	−26.6	6.8	1.8
Sub-period 1995–2000	Technological factors	−21.3	15.5	−11.9	−2.4	7.5	−8.1	−34.7	−8.3	−23.8	−12.1	−22.1
	Pattern of consumption	2.5	−26.0	−1.2	−16.8	−7.2	−8.3	21.4	3.4	0.3	−8.0	−5.2
	Distribution of the demand	−0.4	−0.1	0.0	−0.1	−0.4	0.5	0.8	0.1	−0.2	−0.4	0.0
	Demand per capita	13.1	7.0	14.5	14.2	11.9	12.8	33.6	24.1	12.7	26.4	27.0
	Population	0.7	2.2	2.1	0.8	0.1	2.8	2.0	2.0	0.5	1.5	5.5
	Total demand factors	16.0	−16.9	15.4	−1.9	4.4	7.8	57.8	29.6	13.2	19.5	27.3
	Total change in emissions	−5.4	−1.4	3.5	−4.3	11.9	−0.3	23.1	21.2	−10.6	7.4	5.2
Sub-period 2000–2005	Technological factors	−19.5	−9.0	2.6	−7.2	5.1	−8.7	−10.6	−7.5	−7.3	28.9	14.1
	Pattern of consumption	35.2	−1.2	−11.2	0.4	−4.6	−4.3	1.9	3.1	−14.4	−19.4	−6.6
	Distribution of the demand	0.7	−0.3	0.0	−0.1	0.0	0.4	−0.5	−0.1	0.0	0.5	−0.2
	Demand per capita	0.0	3.9	9.7	3.1	1.6	10.3	6.6	7.8	2.3	−12.7	−15.6
	Population	2.9	1.5	3.5	0.4	2.7	2.8	3.3	7.6	1.5	2.2	5.1
	Total demand factors	38.6	3.9	2.0	3.8	−0.3	9.1	11.3	18.4	−10.5	−29.4	−17.3
	Total change in emissions	19.1	−5.1	4.6	−3.4	4.9	0.4	0.7	10.9	−17.8	−0.6	−3.2



Picture 4. Position of the countries analyzed according to the influence of their technological and demand factors. Direct CO_2 emissions. Period 1995–2005.

results, shows the effect of aggregation on the weight of the different components. He recommends working at the most disaggregated sectoral level possible, and points out that, assuming the existence of bias in the results, this can be reduced if the most relevant sectors are not considered together. The number of sectors in our work is conditioned by the need to make compatible the aggregation level in OECD input–output tables, the environmental information, and the homogeneous expenditure groups provided by the classification COICOP in Household Budget Surveys (the same applies for the corresponding US statistics). Our starting point was the sectors breakdown of the input–output tables provided by the OECD (48 industrial sectors). The need to match data from the different sources and the lack of information in some sectors led us to perform our final calculations with an aggregation level of 18 sectors. As far as possible, most relevant sectors for the analysis (*Energy products*, *Chemical products*, *Agri-food* or *Hotels and restaurants*) have been kept separate.

Finally, and even of greater interest, is another assumption underlying our analysis. As we have shown, our work is with single-region models, implying that the production technology of imported goods and services in each country is identical to the domestic economy. In this regard, current developments in MRIO models allow relaxing this assumption, covering in this way an important shortcoming (see Minx et al., 2009; Wiedmann, 2009). Finally, we cannot forget that SDA develops an ex-post analysis, i.e., it analyzes past trends or changes that, however, cannot always be extrapolated to predict future behavior. An interesting line of research that could help to overcome this limitation is the combination of this approach with the design of different scenarios about the future (see for example Guan et al., 2008; Duarte et al., 2011).

4. Conclusions

In this work, we aim to quantify the relationships between technological and demand factors and the CO_2 emissions generated by satisfying the needs of households. We began with the hypothesis of a relationship among the characterization of households, patterns of consumption, and the intensity and effective generation of emissions, incorporating into the analysis not only other explanatory factors of demand, such as demand distribution or population size, but also technological improvements (in emissions intensity and in intermediate inputs) that could take place in the production of goods and services — improvements that, in many cases, involve a reduction in the generation of emissions.

The obtained results confirm the expected norms: that growth in demand, and hence in production, largely absorbs the limited effect of technological improvements and the incipient changes in consumption patterns.

From the analysis carried out here, improvements in productive processes, mainly reflected in reductions in emission intensities (rather than changes in the mix of intermediate inputs) have been especially significant in *Energy products*, *Chemical products*, *Pharmaceuticals and plastics*, *Metal products, machinery and equipment*, *Hotels and restaurants*, *Real estate and other business activities*. In any case, it is necessary to point out the difference between the two sub-periods analyzed, with a much greater degree of improvement in the five-year period 1995 to 2000.

Technological change is also reflected in direct household pollution, showing in general a reduction in the emissions associated with the consumption of fuel for private cars and for home heating.

However, demand factors have generally contributed to an increase in emissions. With the exception of certain countries, increases in household demand are an accelerant of CO_2 emissions, concealing in most countries the effects of technological improvements.

Nevertheless, our results show that the combined effect of demand is not homogeneous in all its components. The evolution of household demand has been explained by way of two main factors. Changes in consumption patterns affect the weight that goods and services have within the household expenditure budget (i.e., demand structure), and economic growth reflects increases in that demand.

The incipient changes in consumption patterns, and the consistent changes in the composition of household expenses, have contributed to a reduction of CO_2 emissions in the countries analyzed (with the exception of Austria, Spain and Portugal). Nevertheless, this effect has been overcome by the absolute increase in household demand.

The influence of changes in income distribution has also been analyzed. Our results show that the relevance of this distributional aspect is minimal. Changes in income distribution, and in the associated demand, have little impact on the growth or decrease of CO_2 emissions. In this regard, the possible transfers of households from one income quintile to another do not represent a significant change in the intensity of emissions, at least for the economies analyzed, with a relatively similar household structure. As a consequence, a further analysis of the potentialities and also limitations and uncertainties of this type of factors to capture within-country income differences is a natural extension of the present work.

Our results also suggest that changes in demand per capita and in population size have been important in explaining the increase in CO_2 emissions. Both magnitudes have pushed emissions up, countering the improvements that have occurred through changes in patterns of consumption. While the effects of increases in demand per capita are quite generalized, population growth has magnified this effect in certain countries. Countries such as Spain and the US, both with a large influx of immigrants between 1995 and 2005, have seen significant increases in demand.

Our results are consistent with those obtained by other studies in the international field, such as those of Munksgaard et al. (2000), Wier et al. (2001) and Kerkhof et al. (2009a, 2009b), in which relationships are established among households, their behavior or typology, and the evolution of emissions related to their demand and consumption. More specifically, their results show that total household expenditure or consumption is a determinant factor in the evolution of emissions. Moreover, as also shown in our paper, patterns of consumption together with the decrease of emission intensities in production have a positive effect on the reduction of emissions. However, both effects are outweighed by increases in total expenditure.

We can conclude that the growth in CO_2 emissions on the part of households is primarily associated with a global increase in demand, while technological factors have tended to ameliorate this growth. Moreover, changes in patterns of consumption, towards less polluting goods and services can be observed. However, the increase in final demand due to economic growth itself, and from the pressures of population growth, offset these positive effects.

These contrasting effects should be borne in mind when planning economic or environmental policies in compliance with the Kyoto Protocol. Aspects that have been shown to contribute to the reduction of emissions — continuing improvements in the technological efficiency of production, and maximizing the changes in patterns of household consumption, which is especially significant when speaking of the emissions associated with final household demand — must be emphasized in order to make the criteria established by the Kyoto Protocol compatible with economic growth. The combination of both aspects must be a primary objective of policies leading to the reduction of CO_2 emissions.

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