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Determining Factors in the Evolution of Emissions of Greenhouse Effect Gases in the European Union — Influence of Consumption Patterns

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Abstract

Changes in productive structures and modification of consumption patterns are key factors in the struggle against environmental damage. Initiatives such as Agenda 21, promoted by UN, show up the need to "evaluate the relation between production and consumption, environment, innovation, etc. and demographical factors" in order to achieve sustainable development. Within this context, our work deepens into the factors underlying the most recent evolution of CO_2 emissions, one of the main greenhouse gases, in a representative set of countries from the European Union. Within the framework of an input-output multi-sector model, the present work proposes structural decomposition analysis to identify the weight that factors such as demand growth, changes in consumption patterns, changes in income distribution, as well as the substitution of inputs or changes in energy intensity have on the evolution of CO_2 emissions. This work especially attempts to identify common and different behaviour patterns among productive sectors or groups of households in the European environment.

Keywords: Consumption patterns, SDA, input-output, demand, CO_2 emissions

1. Introduction

The evolution of the European economy in the last decades has been clearly positive, counting on an important GDP-growth rhythm, which has allowed creating employment and increasing per-capita income in the integrating countries. However, European economic growth has coexisted, in some countries, with a remarkable increase of atmospheric emissions of greenhouse gases (GHG).

In view of this situation, it seems clear that policies aimed at the achievement of long-term sustainable economic development should analyse the effects which productive activities have on the environment, taking into account both their structures and evolution and growth. This demand is reflected by international initiatives of great relevance such as the summits of Rio in 1992 and Johannesburg in 2002, as well as the Kyoto protocol or Agenda 21, which is a program launched by United Nations (UN) to promote sustainable development which comprises the commitment of European countries regarding struggle against environmental damage.

Table 1: Emission of greenhouse effect gases and objectives of the Kyoto Protocol for 2008-2012

Country	Evolution 1990-2000 (%)	Kyoto targets for 2008-12 and EU “burden sharing”	Index of distance to the target (index points)	Progress evaluation in 2000
Austria	2.7	-13.0	9.2	☹
Belgium	6.3	-7.5	10.0	☹
Denmark	-9.8	-21.0	0.7	☹
Finland	-4.1	0.0	-4.1	☺
France	-1.7	0.0	-1.7	☺
Germany	-19.1	-21.0	-8.6	☺
Greece	21.2	25.0	8.7	☹
Ireland	24.0	13.0	17.5	☹
Italy	3.9	-6.5	7.2	☹
Luxembourg	-45.1	-28.0	-31.1	☺
Netherlands	2.6	-6.0	5.6	☹
Portugal	30.1	27.0	16.6	☹
Spain	33.7	15.0	26.2	☹
Sweden	-1.9	4.0	-3.9	☺
United Kingdom	-12.6	-12.5	-6.3	☺
EU-15	-3.5	-8.0	0.5	☹

Source: European Environmental Agency, 2002. The evaluation carried out by EEA on the progress in 2002 awards “smileys” according to the distance to target indicator in 2000. DTI is a measure of the deviation of real emissions of greenhouse effect gases following the target line between 1990 and the objectives of Kyoto for 2008-2012, assuming that only household measurements are considered. The evaluation system is the following: ☺ Positive contribution to the tendency of the EU: Negative DTI values indicate that the member State is below the target line. ☹ Negative contribution to the tendency of the EU: positive DTI values indicate that the member State is above the target line

However, the behaviour of the countries within this context has been noticeably heterogeneous. Thus, although some European countries have developed relevant efforts to control emissions, some others —including Spain— have scarcely given any signal of a model of production and consumption which bring them closer to the fulfilment of the commitments signed in Kyoto. For instance, Table 1 shows the most recent evolution of GHG emissions in the EU, comparing them with the commitments signed in Kyoto. It can be observed that countries such as Spain, Portugal, Ireland or Belgium require urgent modifications in their production means as a way to reduce emissions.

When we mention the productive activities of a given country or territory, as it was acknowledged in the previously-mentioned summits, we cannot forget that these activities respond, in one or another way, to the demand of goods and services of the residents of that country. That is, it is the behaviour of consumers which ultimately conditions resource assignment within productive activities. Therefore, the analysis of consumption patterns, the ways of life of the population and household decisions become a key element to look for sustainable development policies. Duchin & Hubacek (2003) point out that a better understanding of current social structures, the forces which guide change in household decisions, as well as the proposal of scenarios regarding its evolution should be useful for the public action of governments and the process of decision making in civil society in our way towards sustainable development.

There is wide agreement to consider the achievement of significant changes in production technologies —which should come accompanied by changes in private-consumption patterns— as an essential means to reach environmental advances. Within this context, Agenda 21 devotes its fourth chapter to deal with consumption modalities, requesting to pay attention to natural resource demand and degradation generated by different consumption patterns. More precisely, in the section 4.10, b), it puts forward the need to “evaluate the relation between production and consumption, environment, innovation… and demographic factors”.

The relation between CO2 emissions and the productive activities of a country has been widely tackled in literature and the input-output methodology is considered as a powerful instrument for emission quantification and description of relations between the productive agents involved. Alcantara & Roca (1995), Weber & Perrels (2000), Munksgaard et al. (2000), Herce et al. (2003), Kagawa (2005) or more recently Sanchez Choliz & Duarte (2005), Sanchez Choliz et al. (2007), Roca & Serrano (2007) and Tarancon & Del Rio (2007) are some authors who evaluate the impact of a particular productive structure on CO2 emissions.

Within this framework, the objective of our work is to evaluate the impact which the current consumption and production pattern observed in the countries of the EU has on one of the main greenhouse effect gases: CO2. More precisely, our work —through structural decomposition analysis, SDA— deepens into the explanatory factors of the most recent evolution of emissions within a group of significant EU countries. Combining the most recent information available regarding input-output tables (OECD Industry directorate, 2007), sector-related CO2 emissions (Eurostat-European Environmental Agency) and surveys on familiar budgets (compiled and harmonized by Eurostat), the present work deepens into the role played by expenditure increase, household expenditure distribution in different goods (consumption pattern), technological change or intensity of emissions in the economies' total emissions, as well as the explanation of the differences found according to different countries. The interest of the work lies in the fact that, as far as we know, it is the first work which combines such a detailed description of information regarding productive sectors and consumption structures for explaining CO2 emissions within an important group of European countries. Information availability forces us to consider the following countries in the sample: Austria, Belgium, Denmark, France, Germany, Greece, Holland, Italy, Portugal Spain and United Kingdom (we do not dispose of enough data to include Finland, Ireland, Luxemburg or Sweden). We analyse the change in emissions in all of them for the period between 1995 and 2000, the only period in which it is possible to find comparable information for this set of countries, productive sectors and households. Nevertheless, although the period analysed is clearly insufficient to identify technological change and its contribution to the evolution of emissions, since its realization requires longer time periods, it may turn out to be relevant in order to understand consumption tendencies as well as to identify differences regarding production and consumption habits at international level. Information has been homogenized with the aim of being able to undertake sector, temporal and international comparisons. In this sense, we consider that the work deepens into the understanding of consumption structures and their responsibility in the modulation of environmental damage, following the principles promulgated by Agenda 21.

The rest of the paper is structured in the following way. Section 2 shows the methodology of the work, based on the application of structural decomposition analysis of emissions associated to households within an input-output framework. Section 3 shows the databases used as well as the criteria followed regarding information homogenization. Section 4 analyses the results and Section 5 closes the work with a summary of the main conclusions.

2. Methodology

The fundamental objective of the work is delimiting which factors condition the evolution of the volume of GHG emissions, following a methodology widely used in literature: Structural Decomposition Analysis (SDA). This decomposition method, defined by Rose & Chen (1991) as "the analysis of economic change through a set of (static and comparable) changes in key parameters of an input-output table", has been used in several occasions to study changes in energy consumption, CO2 emissions and generation of other pollutant elements, as it can be seen in Hoekstra & Van der Berg (2002), De Haan (2001), Wier (1998), Rormose & Olsen (2005), Alcantara & Duarte (2004) or Roca & Serrano (2007), among others (an excellent general approach to this kind of analysis can also be found in Rose & Casler, 1996).

The general idea on which SDA is based is additive decomposition of changes in a particular variable determined by a series of multiplicative factors (that is, in an expression of the kind $y = x_1 \cdot x_2$. Precisely, it would be about explaining the evolution of a variable (Δy) from a series of addends which express which part of such variation is due to changes in x1, which part responds to changes produced in x2 and which part responds to the combination of both).

In SDA it is essential to define the expression which develops the variable which is to be explained; in our case, GHG emissions caused by consumer behaviour. The components of this expression should reflect those factors which, a priori, determine the evolution of such variable, so that its subsequent decomposition allows quantifying the contribution of each factor. In this case, the starting point is the equilibrium equation of the input-output model:

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

If vector My is pre-multiplied by the diagonalized vector $\hat{c}$, which reflects the unitary coefficients of CO_2 emissions, it is obtained the value of the emissions generated by the productive system due to expenditure in exogenous accounts ***y***.

$$e = \hat{c}(I - A)^{-1} y$$

The definition of y will depend on the objectives of the analysis. Since our objective is determining the influence of consumption patterns and income distribution (and, therefore, also expenditure) on GHG emissions, we will take final household demand as y in this case, so that we obtain the emissions generated by productive activities related to consumption.

In order to analyse the influence of consumption patterns and income distribution, final household demand (***dfh***) may be expressed as the product of three factors: consumption structure (***ec***) of each kind of household considered, distribution of such demand among households (***ddfh***) and the final household demand itself:

$$dfh = ec \times ddfh \times dfh$$

In this sense, it should be taken into account that, besides, the product of matrix ***ddfh*** and vector ***dfh*** gives rise to a vector whose components indicate the total consumption of each kind of household. Therefore, the emissions derived from the development of the productive activity to satisfy household demand for each country and time period may be expressed in the following way:

$$e_{j,t} = \hat{c}_{j,t} \times (I - A)^{-1}_{j,t} \times ec_{j,t} \times ddfh_{j,t} \times dfh_{j,t}$$

Sub-index j stands for the reference country and period t for the time period considered, where:

— ***e*** is the vector (n × 1) of total CO_2 emissions for each of the *n* productive sectors considered;

— $\hat{c}$ is the diagonalized vector (n × n) of gas emission intensities by total production in each sector;

— ***(I-A)***$^{-1}$ is Leontief inverse matrix (n × n), where *A* is the matrix of coefficients of the symmetric table;

— ***ec*** is a matrix (n × g) in which each column shows the unitary distribution of household expenditure in the stratum g among the goods corresponding to each productive branch;

— ***ddfh*** is a matrix (g × n) which shows, in each column, the distribution of final household demand in each productive branch (including the part corresponding to Non-Profit Institutions Serving Households —NPISH) for each sector; and

— ***dhf*** is a vector (n × 1) which includes final household demand (including that of NPISH) for each sector.

SDA allows different variations according to the assumption realized on the base period with which factor increases are weighted. For instance, in the case of $y = x_1 \cdot x_2$, it could be specified that $\Delta y = x_1(t_1)\Delta x_2 + x_2(t_2)\Delta x_1$, so that t_1 and t_2 may refer to both the initial period (in the style of a Laspeyres index) and the final period (like Paasche indices), or even take a mean of both results (Marshall-Edgeworth index). In case of two factors, the use of combinations of Laspeyres and Paasche or Marshall-Edgeworth eliminates every residue in the approximation of Δy. However, when one has more than two factors which contribute to change (as in the case shown in the following chapter), this cannot be generalized, so that two options are possible: whether we develop the additional assumption that the residue (by underestimation or overestimation) is practically null or we combine all the possible forms in which Δy can be expressed (n! 120 in this case) and the average values are obtained for the part of the increase caused by each factor (Rormose & Olsen, 2005). The latter will be the option followed in the present work.

Once we have applied SDA to analyse the change of CO_2 emissions between 1995 and 2000 in the 11 countries mentioned, we will dispose of enough information regarding the influence which variations in the productive and consumption factors considered have on the changes of both global and sector emissions. The weight that changes have in the values of each vector or matrix regarding increases or decreases in the emission vector will be an indicator of the influence which the variable they represent has on the volume of GHG generated by productive activities because of households.

Vector/Matrix	Represented Variable	Contributed explanation about Δe
C	Emission intensity by sectors	Changes in the combination of products generating GHG emissions used in productive processes
$(I\text{-}A)^{-1}$	Leontief inverse matrix	Structural variations in the interrelations among sectors and according to production
Ec	Consumption patterns	Modifications in the consumption patterns of households, classified according to their income level
Ddfh	Distribution of the corresponding final demand among households	Evolution of income distribution through the participation of each household in final demand attributable to the institutional sector (including NPISH)
Dfh	Final household demand	Changes in the values of final demand in each sector

3. Data

Data regarding GHG emissions are obtained from the National Accounting Matrix with Environmental Accounts (NAMEA) provided by Eurostat. Production vectors I-O and the vector of unitary coefficients of emission (***c***) are derived from NAMEA, while ***ec*** —which represents consumption patterns— and ***ddfh*** —which reflects demand distribution among households— are derived through the corresponding manipulations of analogous accounts in familiar income surveys undertaken in each country and harmonized by Eurostat, also using information from the corresponding input-output frameworks. The symmetric table of each country (from which $(I\text{-}A)^{-1}$ is derived), as well as final demand (***df***) and its components, comes from OECD statistical service (OECD input-output tables —2006 edition), being subsequently homogenized through its conversion to international dollars at constant prices as of 2000 and power purchase parity (PPP).

4. Main results

For the group of countries considered, CO_2 emissions directly and indirectly caused by resident households have increased in almost 8 % between 1995 and 2001, even exceeding 1.800 millions of tons. In nine out of the eleven countries analysed, CO_2 emissions have increased within the time period considered, although the highest relative increases have taken place in Spain (27 %), Greece (24 %) and, to a lower extent, in Portugal (14 %) and Italy (12 %). Only Denmark contributes a significant reduction of emissions (around 16 %), while Belgium reports very slight diminutions in its emissions (scarcely 1 %).

SDA reveals that —for the aggregate of the countries under study— the increase of final household demand has been the factor which has contributed most to the increase of CO_2 emissions related to the behaviour of such institutional sector. Precisely, the increase generated by this factor has meant a rise of 14.6 % in emissions, which is quite above the following determining factor: the relations shown by Leontief inverse matrix. In any case, this seems to be quite logical since demand increases entail —in spite of the effort to look for lower polluting effects— greater production and, therefore, greater GHG generation.

Table 2: Structural decomposition of variations in CO2 emissions caused by household demand for the period 1995-2000; data by countries

	1. C Emission intensity by sectors	**$(I-A)^{-1}$** Leontief inverse matrix	**EC** Consumption patterns	**DDFH** Distribution among households of the corresponding final demand	**DFH** Household final demand	**Increase 2000-1995**
AUSTRIA	-20.0 %	6.8 %	4.0 %	-0.2 %	15.3 %	6.0 %
BELGIUM	-30.2 %	16.0 %	-0.6 %	-0.1 %	14.0 %	-0.9 %
GERMANY	-11.0 %	4.8 %	-6.1 %	0.0 %	14.2 %	1.9 %
DENMARK	-19.2 %	0.2 %	-3.1 %	0.0 %	6.2 %	-15.8 %
SPAIN	-4.1 %	14.5 %	-3.2 %	0.1 %	20.0 %	27.3 %
FRANCE	-14.5 %	10.3 %	-6.0 %	0.0 %	11.5 %	1.3 %
UNITED KINGDOM	-5.9 %	-1.3 %	-5.6 %	-0.2 %	20.8 %	7.7 %
GREECE	20.6 %	-0.3 %	-0.5 %	-0.3 %	5.3 %	24.7 %
ITALY	-15.7 %	16.6 %	-1.8 %	0.7 %	13.0 %	12.8 %
HOLLAND	-8.4 %	5.3 %	-2.6 %	0.2 %	14.1 %	8.5 %
PORTUGAL	11.7 %	7.1 %	-11.1 %	0.2 %	6.8 %	14.7 %
Total	-9.6 %	7.2 %	-4.4 %	0.1 %	14.6 %	7.9 %

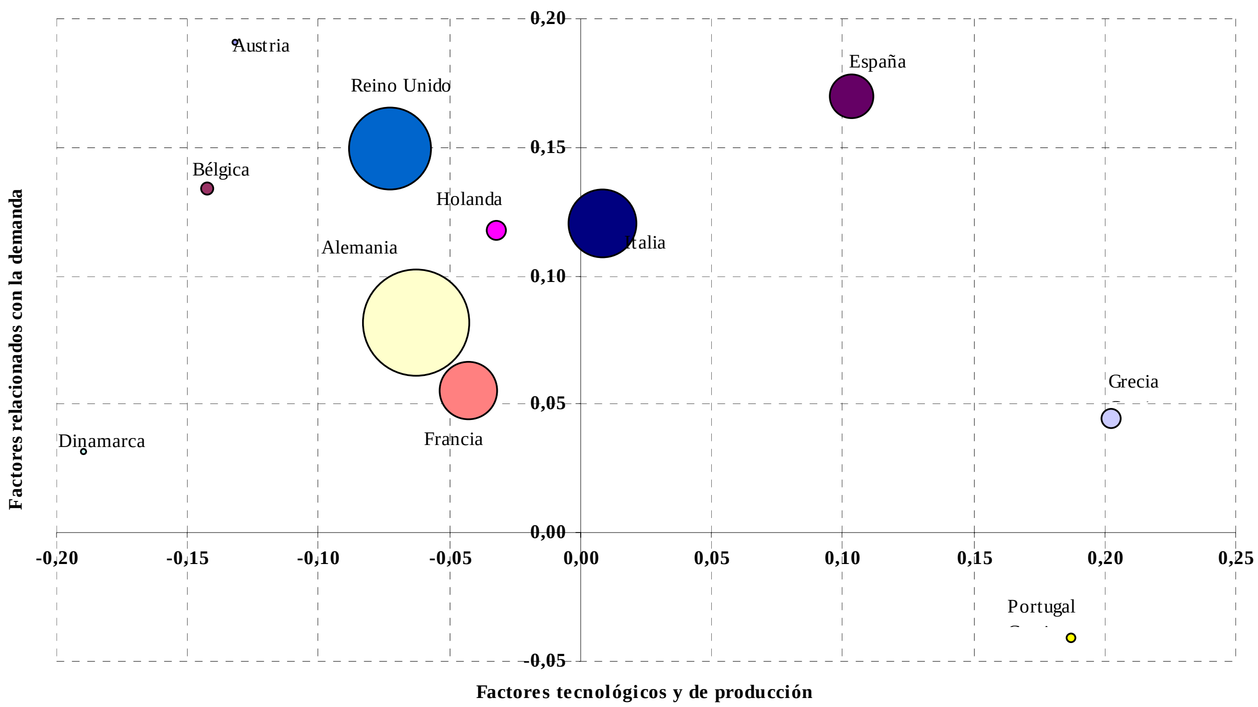
As a whole, those factors directly related to household behaviour regarding consumption have been the cause of a 10.3 % increase in CO_2 emissions in the economies of the main countries of the EU. Against the important, negative effect (regarding the increase of emission levels) of the final demand volume, the consumption-structure factor —which gathers changes in different household expenditure patterns— has meant a 4.4 %-reduction in emissions. This figure points out a significant change in the patterns of behaviour of consumers, who have modified their consumption structures in favour of products involving less polluting production systems.

In any case, modifications in income distribution within the period considered had no significant influence. The slight income redistribution which took place between 1995 and 2000 has scarcely involved any increase in CO_2 emissions, which reflects scarce income distribution towards households with greater tendency to consumption and, therefore, greater generators of atmospheric pollution.

Regarding the factors which represent technological and production aspects, emissions per unit of product and production relations, their contributions to CO_2 emissions have had opposed signs. On one hand, the intensity in GHG generation has diminished around 9.6 % between 1995 and 2000 as a result of technological improvement in the production of goods and services, which were mainly aimed at reducing energy consumption and using less polluting production techniques.

However, structural variations in interrelations between sectors and according to production, reflected through the expression $(I\text{-}A)^{-1}$, caused an over-7 %-increase in CO_2 emissions. In spite of the reduction observed in CO_2 volume generated per unit of product, manufacture structures have changed in the reference period towards the use of with relatively higher capacity of atmospheric pollution.

Graph 1: Positioning of the analysed countries according to the aggregated values of participation of technological and production factors and factors related to demand; CO_2 emissions



Note: The bubble area denotes the relative weight of CO_2 emissions of the countries in 2000

Regarding the effect of the different addends in each of the countries considered, it can be said that such effect is very unequal. While changes in demand factors have produced increases in CO_2 emissions in all countries analysed except in Portugal, due to the effect of the volume increase of such demand (except in the case of Austria, where variations in consumption patterns also influence such increase), technological factors have allowed reductions in emissions in most of the cases considered. In this case, the factor which has enabled such reduction has been emission intensity, although its effect has been the contrary in Greece and Portugal.

Finally, regarding the sector-related evolution of emissions caused by household demand in all countries considered, it is to stand out increases experienced between 1995 and 2000 in the sectors of energy production (42 %) and communications (38 %), followed at certain distance by that of manufactures (25 %). In any case, SDA reveals that a great effort to reduce emissions has been developed in the first two sectors. Such effort is to be identified with the reduction of pollution intensities per unit of product, a factor which is, however, negatively compensated by an increase of CO_2 generated because of the evolution of inter-sector relations, being of extreme character in the case of the energy sector. On the other hand, in these three sectors with greater emission increases due to household demands, the three defining factors of household behaviour contribute to such increase. In fact, it is observed that not only the logical increase attributable to the rise of final demand —accompanied by the scarcely significant variation corresponding to demand distribution— but also changes in consumption patterns has been negative, since it has produced increases in the kind of pollution analysed, in a very outstanding manner in the case of communications (11 %).

Table 3: Structural decomposition of variations in CO_2 emissions caused by household demand; 1995-2000 period; data by sectors

	C	$(I-A)^{-1}$	EC	DDFH	DFH	Incremento 2000-1995
1 AGRICULTURE, FISHING AND FOOD	2,4%	-4,9%	-11,1%	0,3%	13,1%	-0,3%
2+4 ENERGY AND PETROLEUM (2. MINNING AND QUARRING+4. COKE AND REFINED PETROLEUM)	-38,3%	61,0%	3,1%	0,1%	16,3%	42,2%
3 NON ENERGETIC, METALS AND NON METALS	-0,6%	-6,1%	1,5%	-0,1%	14,9%	9,7%
5 TEXTIL AND FOOTWEAR	-6,4%	-2,0%	-12,2%	0,0%	13,6%	-7,0%
6 PULP, PAPER AND PRINTING	-21,7%	-4,8%	-1,2%	0,0%	12,4%	-15,3%
7 CHEMICAL, PHARMACEUTICALS AND PLASTICS	-12,9%	-3,3%	0,7%	0,0%	14,8%	-0,6%
8 METAL PRODUCTS, MACHINERY AND EQUIPMENT	-10,9%	-2,6%	1,5%	0,0%	15,5%	3,5%
9 RADIO, TV AND COMMUNICATION EQUIPMENT	-22,2%	12,5%	8,4%	-0,1%	15,9%	14,6%
10 MEDICAL, PRECISION AND OPTICAL INSTRUMENTS	-21,4%	3,6%	1,1%	0,1%	14,2%	-2,3%
11 MOTOR VEHICLES AND TRANSPORT MATERIALS	-25,8%	6,4%	12,2%	-0,2%	16,1%	8,7%
12 MANUFACTURING, WOOD AND FURNITURE	5,5%	-1,7%	4,4%	0,0%	17,6%	25,7%
13 ELECTRICITY AND GAS	-4,4%	2,0%	-10,0%	0,2%	14,2%	1,9%
14 WATER	-5,5%	4,3%	0,8%	-0,2%	14,0%	13,4%
15 CONSTRUCTION	-8,5%	-3,3%	-1,5%	0,0%	14,1%	0,8%
16 WHOLESALE AND RETAIL TRADE	-17,0%	1,3%	-3,2%	0,2%	13,7%	-5,0%
17 HOTELS AND RESTAURANTS	-13,9%	-0,6%	2,5%	-0,7%	14,5%	1,9%
18 TRANSPORT SERVICES	-8,1%	5,7%	-2,4%	-0,2%	15,8%	10,7%
19 COMMUNICATIONS	-8,8%	19,1%	11,0%	0,2%	17,2%	38,6%
20 FINANCE AND INSURANCE	-40,5%	2,4%	4,7%	0,0%	13,5%	-19,9%
21 REAL STATE ACTIVITIES AND OTHER BUSINESS ACTIVITIES	-20,0%	10,6%	0,9%	0,1%	14,5%	5,9%
22 PUBLIC ADMINISTRATION	-21,8%	3,9%	5,7%	0,0%	14,9%	2,7%
23 EDUCATION	-14,6%	7,3%	1,4%	0,5%	16,7%	11,2%
24 HEALTH SERVICES	-17,6%	-6,7%	5,1%	-0,2%	13,5%	-5,9%
25 OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES	-8,3%	2,9%	3,5%	-0,3%	15,0%	12,9%
Total	-9,6%	7,2%	-4,4%	0,1%	14,6%	7,9%

5. Conclusions

From the analysis undertaken on the evolution of CO_2 emissions related to household demand and consumption in a significant set of EU countries, the following conclusions can be drawn as a summary:

— The joint effect of factors related to the behaviour of households regarding consumption is negative, involving an increase of emissions;

— The logical increase produced by demand increases has clearly exceeded the positive effect observed in the evolution of consumption patterns. Although changes in household consumption structures have allowed to reduce the volume of CO_2 emissions, the effect produced by demand increases has been much higher;

— Changes in demand distribution among households (mainly as a consequence of income redistributions) scarcely have any reflect on the evolution of the volume of emissions; and

— Regarding production, an oppose effect is also observed, although the joint result might be an emission reduction. While the intensities of pollution generation per unit of product have rendered positive contribution, allowing emission reductions, inter-sector relations have shown an opposite evolution, generating emission increases which, to a large extent, compensate the previous positive effect.

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