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DECOMPOSITION ANALYSIS OF CO_2 EMISSIONS FROM THE GREEK MANUFACTURING SECTOR

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ABSTRACT

The aim of this paper is to identify the factors that have influenced changes in the amount of carbon dioxide (CO_2) emitted from the Greek manufacturing sector as a whole and from three representative subsectors. By means of an algebraic decomposition method the changes recorded during the period 1985-95 are analysed into four distinct factors: output level, energy intensity, fuel mix and structural change. The results show that the observed reduction of industrial CO_2 emissions is not only due to the decrease of industrial energy intensity but also to the recession of the Greek manufacturing sector. The two other factors, namely sectoral and fuel shifts were driving emissions upward, primarily because of the increasing share of electricity - intensive sectors and the growing dependence of electricity generation from lignite. It is concluded that for the reduction of industrial CO_2 emissions in the long term, policy measures should aim at further promoting energy saving technologies and encouraging the use of natural gas and renewable energies.

KEY WORDS: CO_2 emissions, Greenhouse effect, Decomposition analysis, Industry

INTRODUCTION

After the energy crisis, most developed countries have tried to minimise their energy dependence in order to reduce the associated economic burden and for saving scarce energy resources. Efforts were principally aimed at the promotion of energy saving measures and, in most cases, a considerable decrease of the countries' energy intensity was manifested. Nevertheless, the observed reduction in energy use has also been influenced by other factors related to the rate and orientation of the overall economic development in these countries.

During the eighties, energy analysts and policy makers have extensively used decomposition approaches as an attempt to quantify the relative contribution of all these factors to the change in energy consumption. The aim was to better understand past trends in order to estimate the future and to design suitable policies for further enhancing the disconnection between economic growth and energy use.

Decomposition analysis has been applied basically to the industrial sector which was the main driving force of economic growth and one of the major energy demand sectors. In addition, manufacturing processes are more sensitive to price changes and more able to react by promoting technological and structural innovations.

Decomposition approaches can be broadly classified into two categories:

(a) Techniques based on *input-output analysis* which are capable of identifying the impact of technological changes and structural shifts in the macro-economic context on the level of energy consumption (Park, 1982; Gowdy and Miller, 1987). Despite their simplifying assumptions input-output based techniques have a sound theoretical background and provide a thorough insight into the relationships connecting energy use and macroeconomic variables. Their main drawback is that they do not allow for cross-national comparisons since input-output tables of different countries are hardly comparable to each other.

(b) *Disaggregation techniques* based either on simple algebraic methods, such as those proposed by Hankinson and Rhys (1983), and by Park (1992; 1993), or on indices, such as the Divisia approach (Boyd *et al.*, 1988; Li *et al.*, 1990) or the Laspeyres approach (Howarth *et al.*, 1991). Although much less sophisticated than the input-output based techniques and failing to examine important macroeconomic parameters, disaggregation methods achieved to identify the most crucial factors that may have influenced changes in energy consumption. Furthermore, due to their simplicity, data collection and computational effort do not set any serious problems, while they enable comparisons across nations.

In the nineties, the growing environmental degradation observed at the local, national and global level has shifted the concern of energy analysts and policy makers towards the environmental side-effects of energy use. It is namely recognised that reducing energy use is no more enough to ensure economic and social welfare. Thus, the qualitative dimension of energy use has become increasingly important. A source of major environmental concern is the global warming effect and the new question raised is how to disentangle economic growth and energy consumption from greenhouse gases emissions.

As a response to the new policy needs, decomposition analysis has been extended in order to identify the factors influencing changes in greenhouse gases emissions and in particular in carbon dioxide (CO_2) which is the major contributor to the greenhouse effect. In the literature there are mostly applications of input-output based techniques which have been modified by including the emission factors associated to the different energy flows through the economy (Casler and Rose, 1998; Chang and Lin, 1998). In addition, Greening *et al.* (1998) have used the Divisia approach in a cross-national comparison of industrial CO_2 emissions in 10 OECD countries, while Liaskas *et al*. (2000) have proceeded to an analogous comparison for the EC countries by extending the algebraic method proposed by Park (1992).

The purpose of this paper is to use Park's extended method in the case of the Greek manufacturing sector and its subsectors for the time period 1985-95. The principal objectives of the study are to identify the major factors that have influenced changes in the amount of industrial CO_2 emissions, to analyse likely discrepancies between different branches and to indicate measures in order for the Greek industry to comply with the Kyoto commitments.

The remainder of this paper is organised as follows: The analytical procedure applied is presented in the next section. A description of the Greek industry and its contribution to the total CO_2 emissions from the Greek energy system is given in section "The Greek Industrial Sector". The results of the decomposition analysis are presented and discussed in section "Application to the Greek Industrial Sector: Results and Discussion", while some concluding remarks are included in the last section.

DECOMPOSITION METHOD

The approach applied for decomposing changes in industrial CO_2 emissions into distinct effects of specific factors relies on a series of simple algebraic calculations derived from Park's method and uses as much as possible the same symbols. The analysis is performed at two distinct levels. First, the whole manufacturing sector is analysed with respect to all branches contributing to the industrial output. At a second step the same procedure is applied to specific industrial branches which are further divided into subsectors. Therefore, the term 'total' refers either to the whole manufacturing sector or to a specific industrial branch. Correspondingly, the symbol 'i' is used to denote either industrial branches or subsectors of a specific industrial branch.

More specifically, at each level the following input data are used:

E_t = total energy consumption in physical units in period t

C_t = total industrial CO_2 emissions in period t

P_t = total output in constant prices (manufacturing value-added) in period t

E_{it} = energy consumption in physical units of the i-th industrial sector in period t

C_{it} = CO_2 emissions of the i-th industrial sector in period t

P_{it} = output in constant prices of the i-th industrial sector in period t

From the above definition it results that:

$$C_t = \sum_{i=1}^{m} C_{it} \tag{1}$$

$$P_t = \sum_{i=1}^{m} P_{it} \tag{2}$$

with m = the number of industrial sectors comprised at each level of analysis.

Energy consumption is translated into CO_2 emissions by taking into account the emission factors characterising each fuel:

$$C_t = E_t \cdot \sum_{j=1}^{F} ef^j \cdot s_t^j \tag{3}$$

$$C_{it} = E_{it} \cdot \sum_{j=1}^{F} ef^j \cdot s_{it}^j \tag{4}$$

where

ef^j = emission factor of fuel j (constant values)

s^j_t = share of fuel j on total industrial energy consumption in period t

s^j_{it} = share of fuel j on energy consumption of the i-th industrial sector in period t

F = the number of different fuels contributing to total energy consumption

The energy intensity and the CO_2 emission intensity of i-th sector at period t are defined as follows:

$$e_{it} = E_{it} / P_{it} \tag{5}$$

$$c_{it} = C_{it} / P_{it} \tag{6}$$

A change in the total industrial emissions of CO_2 between a base period ($t=0$) and a later period ($t=n$) is stated as:

$$\Delta C = C_n - C_0 = \sum_{i=1}^{m} C_{in} - \sum_{i=1}^{m} C_{i0} \tag{7}$$

Replacing C_{in} and C_{iO} from equation 4:

$$\Delta C = C_n - C_0 = \sum_{i=1}^{m} E_{in} \cdot \sum_{j=1}^{F} ef^j \cdot s_{in}^j - \sum_{i=1}^{m} E_{i0} \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \tag{8}$$

Then, E_{in} and E_{iO} are replaced using equation 5:

$$\Delta C = \sum_{i=1}^{m} P_{in} \cdot e_{in} \cdot \sum_{j=1}^{F} ef^j \cdot s_{in}^j - \sum_{i=1}^{m} P_{i0} \cdot e_{i0} \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \tag{9}$$

The share of each industrial sector on the total industrial output is given by the ratio:

$$\alpha_{it} = P_{it} / P_t \tag{10}$$

Replacing P_{it} in (9) according to equation (10) we obtain:

$$\Delta C = P_n \cdot \sum_{i=1}^{m} \alpha_{in} \cdot e_{in} \cdot \sum_{j=1}^{F} ef^j \cdot s_{in}^j - P_0 \cdot \sum_{i=1}^{m} \alpha_{i0} \cdot e_{i0} \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \tag{11}$$

It can be seen from the last equation that the change in total CO_2 emissions is a function of four variables: The total output (P_t), the share of each sector on the total output (a_{it}), the energy intensity (e_{it}) and the fuel share (s^j_{it}) in each industrial sector.

Applying the total differential formula, equation (11) can be decomposed as follows:

$$\Delta C = (P_n - P_0) \cdot \sum_{i=1}^{m} \alpha_{i0} \cdot e_{i0} \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \quad \text{output effect}$$

$$+\ P_0 \cdot \sum_{i=1}^{m} (\alpha_{in} - \alpha_{i0}) \cdot e_{i0} \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \quad \text{structural effect}$$

$$+\ P_0 \cdot \sum_{i=1}^{m} \alpha_{i0} \cdot (e_{in} - e_{i0}) \cdot \sum_{j=1}^{F} ef^j \cdot s_{i0}^j \quad \text{energy intensity effect}$$

$$+ P_0 \cdot \sum_{i=1}^{m} \alpha_{i0} \cdot e_{i0} \cdot \sum_{j=1}^{F} ef^{j} \cdot (s_{in}^{j} - s_{i0}^{j}) \text{ fuel mix effect}$$

$$+ \textit{Residuals (R)} \qquad (12)$$

Residuals are then divided into 11 combinatorial product terms of the four variables where each term represents the joint effect of two variables. For example the term which expresses the joint effect of changes in output and changes in energy intensity is the following:

$$R_{13} = (P_n - P_0) \cdot \sum_{i=1}^{m} \alpha_{i0} \cdot (e_{in} - e_{i0}) \cdot \sum_{j=1}^{F} ef^{j} \cdot s_{i0}^{j} \qquad (13)$$

In the same way the rest interaction terms (R_{12}, R_{14}, R_{23}, R_{24}, R_{34}, R_{123}, R_{124}, R_{134}, R_{234}, R_{1234}) are formed.

Under the *ceteris paribus* condition (all variables except one remain unchanged) each term of equation (12) expresses the change in CO_2 emissions attributed to the specific variable.

THE GREEK INDUSTRIAL SECTOR

During the last 25 years, energy consumption in Greece has increased much faster than in other EU countries (70% in Greece in contrast to 14% for EU). Because of the rising living standards, the rates of increase were particularly high in the residential and the transport sectors (mean annual rate 3% and 5.5% for the residential and the transport sector respectively). On the contrary, as shown in Figure 1, energy consumption in the industrial sector has been stabilized, especially after 1985.

During the period 1985-95, CO_2 emissions from the industrial sector have shown a slight descending trend. Nevertheless, this sector's contribution to the total CO_2 emissions in the country is still quite significant. In 1990 (considered as a reference year for recording CO_2 emissions), the direct contribution of the industrial sector was around 13%, with electricity generation being responsible for about 50% of the total CO_2 emissions recorded in the country. By distributing emissions from electricity generation to the final demand sectors the total (direct and indirect) contribution of the Greek industry to the production of CO_2 emissions rises to 35%. These percentages make clear that any effort to abate the global warming effect, in compliance with the commitments deriving from the Kyoto protocol, should encompass specific policy measures for the industrial sector.

For maximising the effectiveness of such measures, it is necessary to systematically analyse past experiences and to discern the factors having influenced the reported trends. More specifically, it is useful to know at what extent the observed decrease is due to the reduction of industrial energy intensity

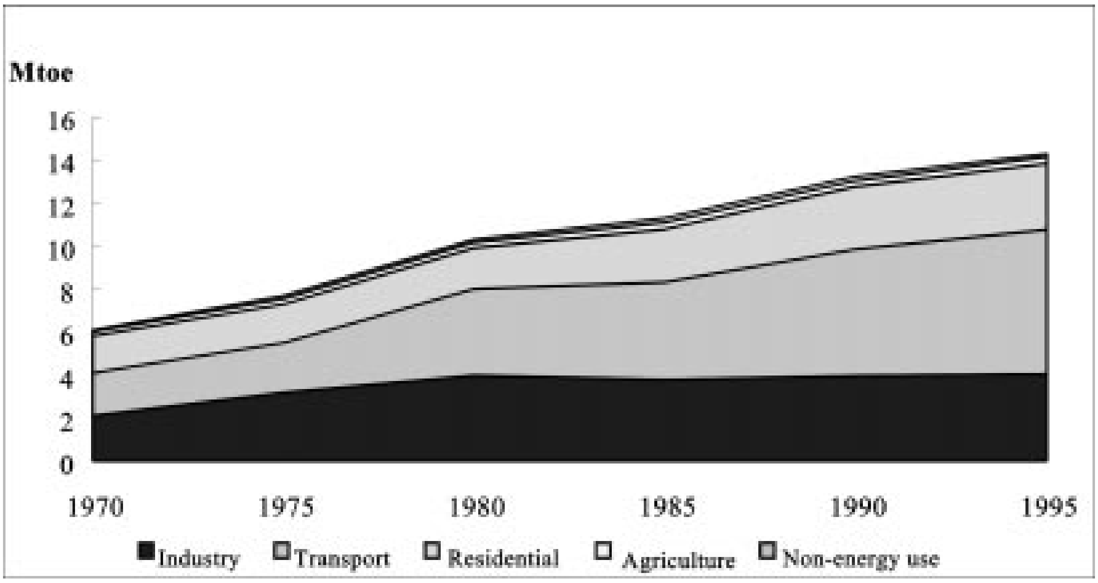

Figure 1. Energy consumption in Greece (Mtoe=Million tons of oil equivalent)

and if this positive effect was augmented or counterbalanced by changes in other parameters, such as structural shifts, fuel mix and production output. Moreover, the analysis should go further to identify the reasons explaining differences between industrial branches and to accordingly specify the appropriate policies. As shown in Figure 2, the changes in CO_2 emissions are not the same in all industrial branches. In some cases (e.g. foods and beverages, plastics) emissions have increased during the examined decade, in others they have been stabilised at approximately the same level (e.g. metal industry) while a decreasing trend is discernible only in the sector of non-metallic minerals and in the chemical industry.

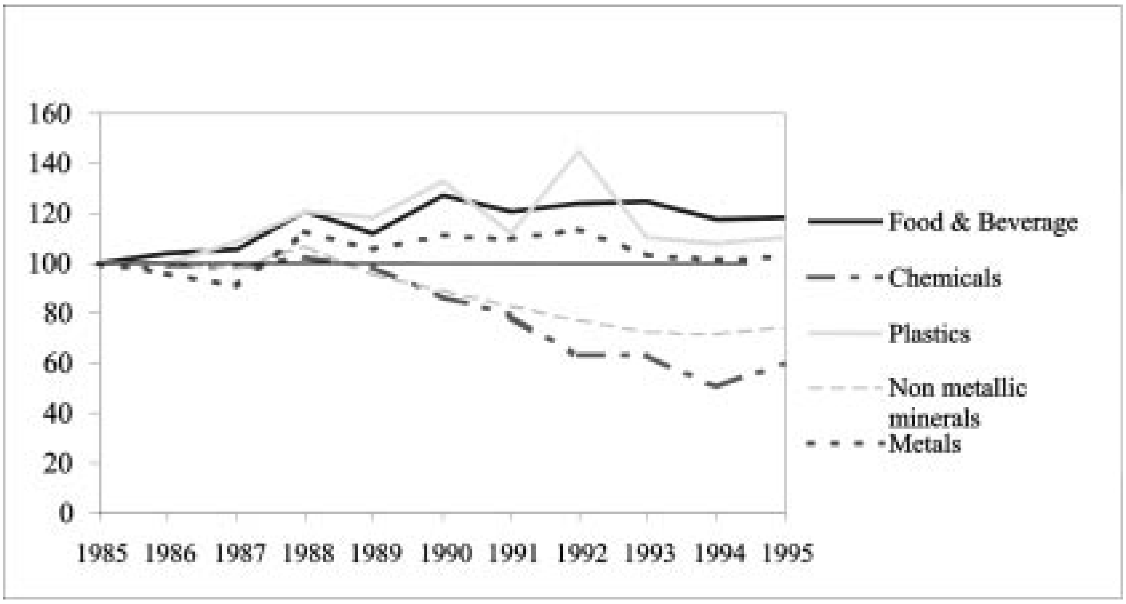

Figure 2. Relative change of CO_2 emissions in the main industrial branches (1985=100)

APPLICATION TO THE GREEK INDUSTRIAL SECTOR: RESULTS AND DISCUSSION

The proposed decomposition method has been applied first to the whole industrial sector and, subsequently, to three characteristic industrial branches, each one presenting a different trend in the evolution of CO_2 emissions:

- The branch of non-metallic minerals showing a descending trend and representing the 42 % of total industrial CO_2 emissions in 1995.
- The branch of basic metal industry (both ferrous and non-ferrous) showing approximately stable CO_2 emissions and representing 27% of the total in 1995.
- The branch of foods and beverages showing an ascending trend and representing the 8 % of total industrial CO_2 emissions in 1995.

The obtained results are presented in Table 1. The positive or negative contribution of each factor to the amount of CO_2 emissions is expressed on a percentage basis, while the last three columns give the sum of all positive and negative effects and the corresponding net effect. It is clear that the higher the negative value of the net effect the most significant the decrease of CO_2 emissions.

For facilitating a cross-sectoral comparison the relative impact of each separate factor has been examined. The values in Table 1 confirm that the energy intensity effect is by far the most important factor explaining the change in CO_2 emissions during the examined period. Greek industry as a whole and in particular the cement industry dominating the branch of non metallic minerals, have achieved to substantially decrease their energy intensity. Only the branch of foods and beverages has shown an opposite performance along with an increase in CO_2 emissions. The relative contribution of the energy intensity effect is graphically depicted in Figure 3.

Table 1. Summary results of the decomposition analysis (1985-95).

		Contribution of each factor							
	ΔCO_2 (kt)	Output	Energy intensity	Fuel mix	Structure	Inter-action	Positive effect	Negative effect	Net effect
Industry	-3628	-23%	-30%	5%	30%	-11%	35%	-65%	-30%
Food & beverage	273	-7%	31%	28%	14%	-20%	73%	-27%	46%
Non-metallic minerals	-1753	-17%	-43%	17%	15%	-8%	32%	-68%	-36%
Metals	160	44%	-28%	-7%	7%	-14%	51%	-49%	2%

* negative sign indicates decrease in CO_2 emissions

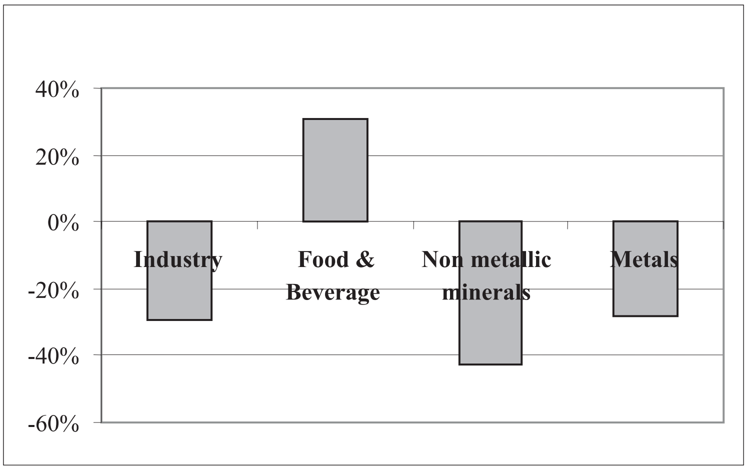

Figure 3. Energy intensity effect

The other major factor explaining the observed reduction of CO_2 emissions is the decline of industrial production occurred during the examined decade. As shown in Figure 4, the negative impact of the output effect is very apparent in the whole industrial sector and also in the branch of non metallic minerals.

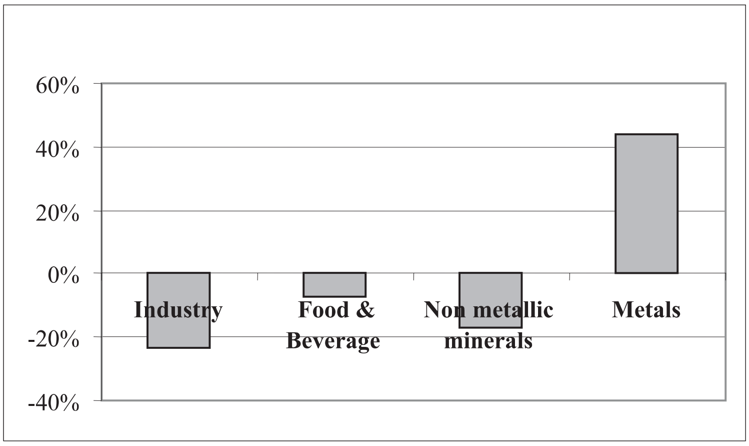

Figure 4. Output effect

It is also worth noticing that the metal industry was the only one among the examined branches which has increased its production rates and the resulting positive effect has overcompensated the benefits induced by the reduction of the energy intensity. On the opposite side, the impacts of the industrial stagnation were less in the branch of foods and beverages and could not significantly counterweight the other factors contributing to the increase of CO_2 emissions.

Figure 5 shows that the changes in the energy mix used by the Greek industry as a whole had only a small - although positive- effect on the production of CO_2 emissions. This is primarily due to the long lasting inertia characterizing the Greek energy system and especially to the absence of natural gas which, in the same time period, was rapidly penetrating in other European energy markets. On the other side, the increasing share of solid fuels (especially in the sector of non metallic minerals) and electricity have contributed to the rise of CO_2 emissions. In the case of electricity this is due to the growing exploitation of lignite in the power generation sector. The positive impact of the fuel mix effect is more pronounced in the branches of foods-beverages (increasing share of electricity) and of non-metallic minerals (increasing share of carbon). On the other side, in the metal industry, the fuel mix effect is relatively small but negative.

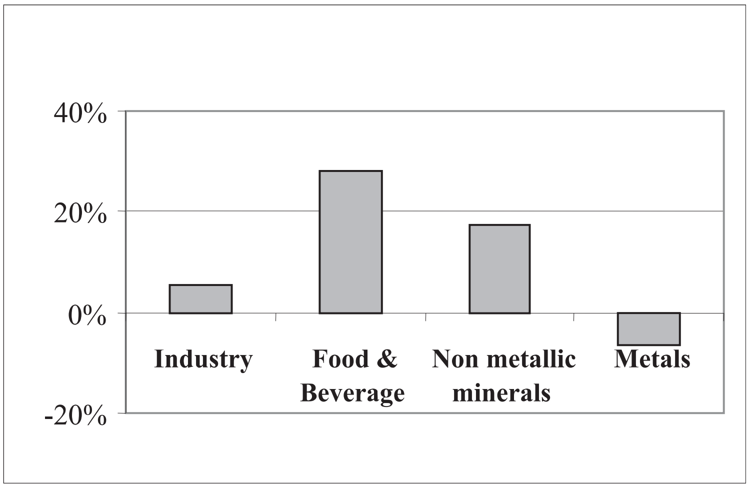

Figure 5. Fuel mix effect

Regarding the structural effect, Figure 6 shows that sectoral shifts in the Greek industry have considerably contributed to the increase of emissions eliminating the benefits resulting from the reduction of energy intensities. This means that the share of CO_2 intensive branches has increased pushing upward total emissions. In the case of Greece this is the result of the increasing share of electricity intensive branches. A similar positive effect (although at a lesser extent) is detectable in the three examined branches showing that in each one separately, subsectors associated with higher emissions have increased their share (e.g. cement within the branch of non-metallic minerals).

Finally, in all cases the combination of the examined factors, as expressed by the interaction effects, has contributed to the reduction of CO_2 emissions. As shown in Table 1, interaction effects are assigned with negative values which vary at relatively low levels, with the only exception of the foods and beverages sector, where they act as the most important counterweight to the other factors contributing to the increase of CO_2 emissions (energy intensity, fuel mix and structural effect).

An overall view on the relative impact of all the examined factors simultaneously in absolute terms (kt CO_2) is given in Figure 7. It can be seen, that total CO_2 emissions from the Greek manufacturing sector would have declined by approximately 8000 kt CO_2 during the period 1985-95 due to improved energy intensities and the reduction

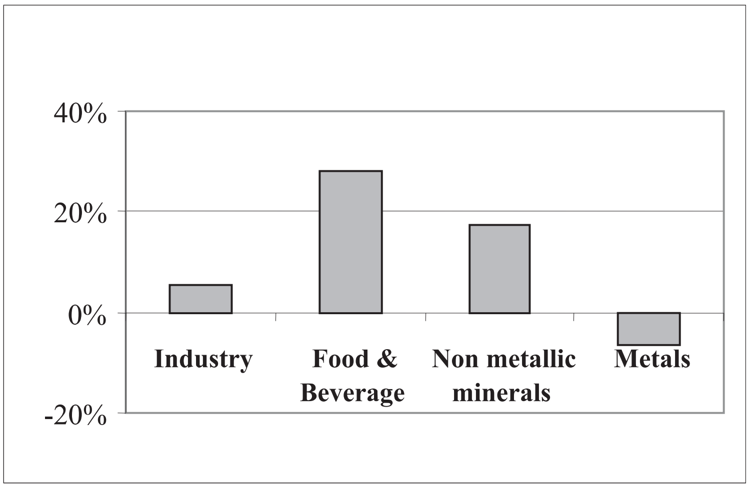

Figure 6. Structural effect

of the industrial production. Nevertheless, the worsening of the fuel mix and the structural shifts that took place in this same period have restricted the overall decrease to only 3,600 kt. A similar counterbalance is discernible in the branch of non-metallic minerals, while in the metal industry the observed growth of the industrial output has completely eliminated any reduction due to the improvement of the sector's energy intensity. On the other side, in the branch of food and beverages, the net balance of the above effects although positive and quite significant does not practically influence total industrial CO_2 emissions. This is because this branch is generally characterised by low energy and CO_2 intensities.

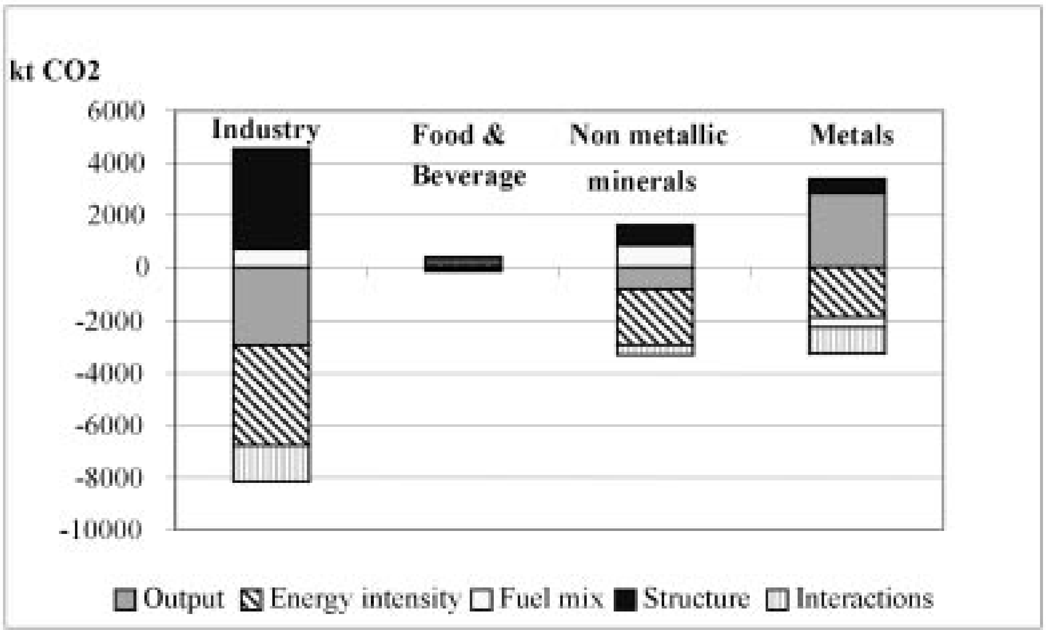

Figure 7. Combined effect of factors on the change of industrial CO_2 emissions (1985-1995)

CONCLUSIONS

The decomposition analysis presented in this paper leads to some interesting conclusions about the factors that have influenced recent changes in CO_2 emissions from the Greek manufacturing sector. It has been found that, contrary to the experience reported in most other European countries, the reduction of industrial energy intensity was not enough to secure the mitigation of CO_2 emissions from the industrial sector. In fact, in most industrial branches and in the manufacturing sector as a whole, the benefits deriving from improved energy intensities have been counterbalanced by the effects of structural changes and fuel shifts which have contributed to the increase of CO_2 emissions.

The above remarks make clear that the observed reduction of industrial CO_2 emissions is practically owed to the crisis that has marked the Greek manufacturing sector during the eighties. The self-evident conclusion resulting from this statement is that the expected accession of the Greek industry will be accompanied by a rise of CO_2 emissions. This trend is already manifested in the metal industry, where the positive production rates have been translated into a relative increase of CO_2 emissions, despite the considerable decline in the sector's energy intensity.

This means that in order to comply with the commitments deriving from the Kyoto protocol it is necessary to intensify efforts for further promoting energy saving measures and for enhancing the development of cleaner energy sources in the industrial fuel mix and in electricity generation. The penetration of natural gas and the increasing use of renewable energies are possible options to significantly reduce the carbon intensity of the energy mix used in the Greek industry. The promotion of policy measures aiming at the support of the emerging markets of natural gas and renewables is needed in order to achieve this CO_2 emission reduction purpose. Furthermore, sectoral policies in the Greek industry should aim at strengthening less energy intensive branches of high added value.

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