

INCOME GROWTH AND ATMOSPHERIC POLLUTION IN SPAIN: AN INPUT-OUTPUT APPROACH

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Abstract

The relationships between economic growth and environmental pressures are complex. Since the early nineties, the debate on these relationships has been strongly influenced by the Environmental Kuznets Curve hypothesis, which states that during the first stage of economic development environmental pressures increase as per capita income increases, but once a critical turning-point has been reached these pressures diminish as income levels continue to increase. However, to date such a delinking between economic growth and emission levels has not happened for most atmospheric pollutants in Spain. The aim of this paper is to analyse the relationship between income growth and nine atmospheric pollutants in Spain. In order to obtain empirical outcomes for this analysis, we adopt an input-output approach and use NAMEA data for the nine pollutants. First, we undertake a structural decomposition analysis for the period 1995-2000 to estimate the contribution of various factors to changes in the levels of atmospheric emissions. And second, we estimate the emissions associated with the consumption patterns of different groups of households classified according to their level of expenditure

Keywords: input-output analysis; atmospheric pollution; income growth, Environmental Kuznets Curve; Spain.

1. Introduction

The relationships between economic growth and environmental pressures are undoubtedly complex. Economies are in constant evolution as the relative weight of their different economic sectors shift and new technologies are introduced. We cannot, therefore, automatically assume that a given degree of economic growth will result in an equivalent increase in environmental pressures.

Since the early nineties, the debate on the environmental effects of economic growth has been strongly influenced by the *Environmental Kuznets Curve* (EKC) hypothesis, which states that an inverted U relationship can be found between environmental pressures and per capita income: economic growth initially has negative environmental effects, but once a critical level of per capita income has been reached the environmental situation improves as per capita income increases (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992). However, while empirical evidence of the decrease in some environmental problems in rich countries has been reported, none of the pollutants considered have been shown to unequivocally follow the evolution predicted by the EKC hypothesis (Ekins, 1997; De Bruyn and Heintz, 1999; Stern and Common, 2001). Many authors claim that the hypothesis could be appropriate only in the case of pollutants with local and short-term effects and with relatively low costs of mitigation, such as SO₂, whereas, emissions would tend to monotonously increase with the level of income for those pollutants with more global and long-term effects and for which reduction is more complicated, such as CO₂. The EKC hypothesis cannot, therefore, be generalised to describe the relationships between the economy and the environment.

The EKC hypothesis not only maintains that economic growth can coexist with a reduction in the environmental pressures generated by rich countries, but it also affirms

that per capita income growth is the main determinant of this decline in environmental pressures. There are three possible factors to explain the EKC hypothesis: first, technological change; second, final demand structure; and third, individual preferences.

The first claim is that higher rates of per capita income are usually linked with *technological changes* that generate less environmental pressures. However, several counter-arguments can be made. Although new theories of economic growth stress the key role of knowledge accumulation in growth, and while it seems reasonable to believe that this knowledge might lead to a more efficient use of resources, it would be incorrect to assume a causal relationship from economic growth to more efficient resource use. It should also be stressed that predicting the complex effects of technological change is not easy. For instance, in energy economics, in what has been termed the *rebound effect* (Schipper, 2000)¹, it has been noted that an increase in efficiency in the use of a natural resource will tend to stimulate its demand, thereby reducing - or, in extreme cases, even cancelling out - the mitigating effect of increased efficiency. Moreover, technological change is often not simply concerned with the efficiency of resource use, but rather involves the development of new processes and products that might pose a greater environmental threat, such as the use of new chemical substances or nuclear power.

The second claim is that as per capita income increases, the autonomous evolution of the *final demand structure* involves less pressure on the environment. Here, a key factor would be the increasing share in demand experienced by the service sector at the expense of that of the industrial sector. However, such a claim requires further empirical research as some service activities might generate as much, or perhaps more, environmental pressure than many industrial activities. In any case, at most, this argument only would explain the reduction in environmental pressures *per unit of*

¹ Hertwich (2005) argues that an input-output analysis might be used to study the rebound effect.

income as income increases. It would not explain a reduction in absolute terms, unless we assume that the most environmentally problematic sectors are those producing inferior goods - an assumption that is far from probable (Torras and Boyce, 1998). Thus, applying De Bruyn and Opschoor's (1997) relevant differentiation, a change in the demand structure would perhaps account for a *relative delinking* between economic growth and environmental pressures, but not an absolute one (see also Roca and Alcántara, 2002). In other words, if the more "problematic" goods and services are not inferior goods, the final demand structure might explain an income elasticity of environmental pressures that was lower than one but not a negative elasticity.

The third claim, concerning *individual preferences*, is that once a certain income level is achieved, consumers decide to renounce the consumption of certain private goods and services in order to "consume" more environmental quality. But, environmental quality is normally a *public good*, the adequate provision of which cannot be decided in the market arena, but rather has to be resolved in the political sphere. Hence, the claim that individuals can decide to "buy" environmental quality is a metaphor that cannot be taken too far (Roca, 2003). A further issue concerning individual preferences is the fact that environmental costs are sometimes displaced to other territories - i.e., *spatial* displacement, or, in the case of long-term environmental problems, to other generations - i.e. *intergenerational* displacement. The spatial displacement of environmental costs may occur in one of two ways. On the one hand, it may be the unavoidable result of the very nature of the environmental problem, as is the case of global warming or atmospheric and river pollution that crosses borders. On the other hand, international trade can lead to the displacement of environmental costs with the importation of pollutant intensive commodities (Arrow *et al.*, 1995, Stern *et al.*, 1996; Suri and Chapman, 1998; Muradian and Martínez-Alier, 2001). In both cases,

when environmental degradation affects other individuals - in other countries or those belonging to other generations - the consumer preferences over consumption of private commodities or environmental quality are no longer the main factor. In fact, the more environmental problems affect other individuals, the less likelihood there is of economic growth leading to political decisions that reduce environmental pressures. It is hardly surprising then that the majority of the environmental pressures that contribute to global and long-term problems - such as greenhouse gas emissions - correlate positively with per capita income, even at very high income levels.

The aim of this paper is to analyse the relationship between income growth and atmospheric pollution in Spain. In so doing it examines the emission of nine gases: the six greenhouse gases - carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) - and three gases associated with local and regional environmental problems - sulphur oxides (SO_x measured in units of SO₂ equivalent), nitrogen oxides (NO_x) and ammonia (NH₃). We adopt two distinct, but complementary, perspectives: a longitudinal study together with a cross-section analysis. First, we conduct a structural decomposition analysis for the period 1995-2000 in order to examine the contribution of a range of factors involved in economic growth to the evolution of atmospheric emissions. Unfortunately, we do not have at our disposal data to undertake this analysis for a longer period. Second, we analyse the emissions associated with the consumption patterns of different household groups based on their levels of expenditure. Both approaches are particularly pertinent to the EKC debate as they include significant elements for estimating the dimension of key factors in the EKC hypothesis. Having said that though, this paper does not seek to test the existence of an EKC in Spain since

the SDA is conducted over a very short period of time and our study of household emissions is a comparative static analysis.

The importance of this study lies in the fact that, as far as our knowledge, this is the first analysis of environmental pressures and household consumption patterns and the first structural decomposition analysis to be undertaken with economic and environmental data from Spain. Similarly, while the structural decomposition analysis reported for other countries have tended to examine CO₂ emissions only, here we consider several gases.

The rest of the paper is organised as follows. In section 2, we present a brief overview of the recent evolution in atmospheric pollution in Spain. In section 3, we describe the National Accounting Matrix including Environmental Accounts framework and the input-output approach. In section 4, we present the structural decomposition analysis outcome and, in section 5, we analyse the emissions associated with household consumption patterns. Finally, in section 6 we present and discuss our conclusions.

2. Atmospheric pollution in Spain. A global perspective

In this section, we describe atmospheric pollutant emission trends in Spain, extending the analysis undertaken by Roca *et al.* (2001) and Roca and Padilla (2003).²

Figure 1 shows the overall trend in the emission of the six gases (measured in CO₂-equivalent tonnes) regulated by the Kyoto protocol for the period 1990 to 2004.

² The data used in this section include process emissions as well as energy emissions. Data for 1990-2004 are drawn from the *Banco Público de Indicadores Ambientales* of the Spanish Ministry of Environment. For the period 1980-1990 we use data provided directly by the Spanish Ministry of Environment. The latter have not been officially revised. Our data series (in which 1980 acts as base=100) establishes a link between the 1980-1990 and 1990-2004 series.

The European Union (EU) as a “bubble” has undertaken to keep the 2008-2012 average emission of these six greenhouse gases to a level that is 8% lower than that of the base year considered, i.e. 1990.³ Yet, Spain, with per capita emissions lower than the EU average, was granted permission to increase its emissions by 15%, while other countries found themselves in a position of having to achieve reductions that greatly exceeded 8%. However, Spain has greatly exceeded this accepted level.

In the EKC debate, though, it might well be argued that the data to be analysed should not be those describing total emissions but rather those that describe per capita emissions. Moreover, the EKC hypothesis argues that the supposed reduction in environmental pressures is accounted for by the changes involved in economic growth rather than by the simple passing of time. In Figure 2 we can see the relationship for the years 1980 to 2003 between “real” per capita income and per capita emissions⁴ of the three main greenhouse gases - CO₂, CH₄ and N₂O -⁵ and also of three other atmospheric

³ The undertaking refers to the aggregation of the six gases, which are summed in accordance with their global warming potential values as established by the IPCC. The conversion factors are: 1 for CO₂, 21 for CH₄, 310 for N₂O and 23,900 for SF₆. For the PFC group, values oscillate between 6,500 and 9,200 depending on the gas in question, while for the HFC group, values range between 140 and 11,700. The chlorofluorocarbons (CFCs) were not included in the Kyoto protocol as they had been regulated by an earlier international agreement, the Montreal Protocol. For HFCs, PFCs and SF₆, 1995 can be taken as the base year.

⁴ The indicator of “real” per capita income used is per capita gross domestic product (GDP) at market constant prices. Population and GDP data are taken from the Spanish statistics office, *Instituto Nacional de Estadística* (INE). Given the change made by the INE in the GDP year base, we have chosen to link the 1980-1995 serie at constant 1986 prices with the 1995-2003 serie at constant 1995 prices.

⁵ We are unable to include the other three greenhouse gases considered by the Kyoto protocol - SF₆, HFCs and PFCs - because we do not have data for the period 1980-1990.

pollutants - SO₂, NO_x and NH₃ - associated with local and regional environmental problems including acidification, eutrophication and troposphere ozone concentration.

Figure 2 reveals quite distinct trends. Only SO₂ per capita emissions fell as the EKC hypothesis would lead us to expect. The trend in N₂O per capita emissions, meanwhile, is unclear. For the remaining gases, emissions increased considerably and there was no evidence of any change in this trend. NO_x and NH₃ emissions increased significantly but at a rate that was lower than that of GDP, i.e. indicating *relative delinking* but not *absolute delinking*. Throughout most of the period, CO₂ emissions increased roughly in line with GDP or even at a faster rate. The one exception to this was during the eighties, when the use of nuclear energy increased in Spain. This is a good example, perhaps, of how one environmental indicator improves to the detriment of another - in this case, increased nuclear risks. CH₄ emissions increased the most, in particular during the eighties and this is mostly due to emissions from waste management.

We are therefore drawn to the conclusion that the evolution in the emission of gases follows a range of different paths and that these, in general, are not an invitation for optimism. Clearly this issue need to be analysed more fully. But at this aggregate level of analysis, it is not possible to further our understanding of the factors that might account for these differences. Consequently, the relationship between income growth and atmospheric pollution in Spain needs to be examined in greater depth.

In the sections that follow, we adopt two distinct, but complementary, approaches that should contribute to the EKC debate. First, we conduct a structural decomposition analysis to estimate the contribution of several factors to the evolution of atmospheric emissions. Second, we analyse how the consumption patterns of different

household groups classified according to their levels of expenditure contribute to these atmospheric emissions.

3. Data base and methodology

This section describes the National Accounting Matrix including Environmental Accounts (NAMEA) system and the methodological approach that is adopted in the rest of this study, namely, that of input-output (IO) analysis. It also explains the procedures and data preparation required in applying these approaches.

3.1. NAMEA system

In the early nineties, Statistics Netherlands (CBS) developed the NAMEA, which was subsequently adopted by EU countries within the EUROSTAT environmental accounting project (Keuning *et al.*, 1999). In this framework, environmental information is compiled so that it is compatible with the presentation of economic activities in national accounts. In this way, the national accounting matrix (NAM) can be extended to include environmental accounts (EA), usually expressed in physical units.

The System of Economic and Environmental Accounts (SEEA) considers two types of NAMEA accounts: *hybrid supply and use tables* (HSUT) and *hybrid input-output tables* (HIOT).⁶ The former consist of a pair of tables, one showing those

⁶ The term *hybrid accounts* indicates that monetary and physical data are included in the same accounting framework, and at the same time differentiates them from the physical IO accounts (see Hoekstra and Van den Bergh, 2006). Elsewhere, this term is sometimes applied to “energy IO tables” in which certain flows between economic units are expressed in energy units rather than in monetary units (Casler and Willbur, 1984). Moreover, in the literature the HSUT are also referred to as *hybrid make and use tables*.

industries that supply commodities (supply table), the other showing economic units that use them (use table). In this case, two different classifications are used for industries (NACE) and commodities (CPA) respectively. In the second method, a symmetric IO table results from the transformation of the supply and use tables so that each industry represents one particular homogeneous type of good or service. However, neither the new SEEA nor the EUROSTAT makes any explicit recommendation as to which NAMEA type accounts should be used, rather EU countries are merely encouraged to do the most they can given the IO framework available for domestic use.

In the case of Spain, the NAMEA system is organised in accordance with the HSUT structure. The Spanish NAM has been compiled for the period 1995-2000 in both current and basic prices and includes 110 CPA products, 72 NACE industries and several final demand categories. At the same time, the air emission EA gather information about the emissions of the pollutants produced by 46 NACE industries and households. The former are emissions resulting from the production of goods and services, whereas the latter are produced by transport, heating and other household activities.⁷ The emission data are reported in physical units for the same six-year period and for different air pollutants.⁸

In the Spanish HSUT, emissions are allocated to heterogeneous industries, since they need to be attributed in a way that is consistent with economic data. This has significant consequences for the interpretation of environmental information. For

⁷ Transport emissions are allocated to households only when they are emissions from private cars and motorbikes. Heating emissions are allocated to households in the case of fuels used domestically.

⁸ Note that totals provided in the NAMEA data are not identical that those reported by other statistics sources, including those used here in section 2. One of the reasons is that NAMEA refers to domestic economic activities, whereas air emission inventories include emissions from all sources in the national territory.

instance, emissions associated with electricity production as an ancillary or secondary activity are, nevertheless, allocated to the particular industry that undertakes this production according its principal activity and not to NACE 40.1 (*Production and distribution of electricity*). The same principle holds true for transport emissions, which are allocated to the economic agents that perform the activities that generate the emissions.

In addition, in line with the NAMEA framework and national accounting principles, air emissions due to incineration and the decomposition of waste in landfills (principally CH₄) are included within NACE 90 (*Sewage and refuse disposal, sanitation and similar activities*). However, such emissions might be considered separately from industry and household emissions. In this paper, in line with the Dutch NAMEA experience (Keuning *et al.*, 1999), we distinguish three sources of atmospheric pollutants: “industries”, “households” and “other sources”, and include CH₄ emissions from waste management in this final category.⁹

Although the supply and use table is more readily associated with data from other areas, such as environmental information, the symmetric IO table offers greater analytical power. Both the current European System of Accounts 1995 and the new SEEA agree that the HIOT is more appropriate than the HSUT for conducting analytical research, particularly when it is used to calculate indirect effects. Therefore, in order to exploit to the full the advantages offered by NAMEA and IO analysis, we first need to make a number of transformations to the Spanish NAMEA. These we describe below.

⁹ In the Spanish NAMEA the emissions of the NACE 90 are aggregated together with NACE 91 (*Activities of membership organization*), 92 (*Recreational, cultural and sporting activities*) and 93 (*Other service activities*) under the heading “*Other community, social and personal service activities*”. Since no more disaggregated data are available and the majority are NACE 90 emissions, all the CH₄ emissions from these four sectors have been classified as “other sources”.

3.2. Input–Output analysis

IO analysis provides a framework for considering specific questions about the relationship between economic structure and economic activity and so opens up a path for the study not only of economic production but also of the effects of production and consumption on the physical environment. In the early 1970s, Wassily Leontief himself and other authors extended the IO model to consider some links between the economy and the environment (Leontief, 1970), in particular atmospheric pollution (Leontief and Ford, 1972).

Formally, for an economy of n sectors the standard IO model is represented by the following expression:

$$q = (I - A)^{-1}y \quad (1)$$

where $q_{n \times 1}$ is gross output vector, $y_{n \times 1}$ is final demand, $A_{n \times n}$ is matrix of technical coefficients and $I_{n \times n}$ is the identity matrix. The elements of the Leontief inverse matrix, $(I - A)^{-1}$, capture both the direct and indirect effects of any change in the exogenous final demand vector. This expression (1) can easily be extended to account for k atmospheric polluting emissions. So, let $V_{k \times n}$ be a matrix of direct air emission coefficients whose lj element is the amount of pollutant l generated per monetary worth of industry j 's output. Thus, the level of atmospheric emissions associated with a given vector of total outputs ($E_{k \times 1}$) can be expressed as:

$$E = Vq \quad (2)$$

or as a function of final demand as:

$$E = V(I - A)^{-1}y = Fy \quad (3)$$

It should be noted that in expression (3) the final demand vector y_{nxl} includes private consumption, public consumption, investment and exports. Moreover, the total technical coefficient matrix A_{nxx} includes both domestic and imported inputs. Thus, here we consider not only the emissions domestically produced by this economy but also those associated with the production of imported inputs and imported final goods and services. These foreign emissions can be interpreted in two ways. Firstly, they are actually emissions that are avoided as Spain purchases commodities abroad. And secondly, if we assume that the technologies and direct emission coefficients of other countries are the same as those in Spain, these emissions can be seen as the emissions effectively generated abroad in order to provide Spanish imports.¹⁰

Finally, matrix F_{kxn} is the total emission intensity matrix, which depends on both V_{kxn} and the Leontief inverse matrices. This matrix is of particular importance to an environmental IO analysis since it enables us to calculate the total emissions or emission multiplier to satisfy one unit of final demand of each sector.¹¹

In the Spanish NAMEA system economic and environmental data are both allocated to heterogeneous industries (see discussion in section 3.1 above). Thus,

¹⁰ This assumption is frequent when specific knowledge of foreign technology is not available (Munksgaard *et al.*, 2000). However, the technologies employed in countries from which imports originate might differ markedly and, in fact, such a consideration is increasingly common in the literature, see e.g. Ahmad and Wyckoff (2003), Lenzen *et al.* (2004), Nidjam *et al.* (2005) and Peters and Hertwich (2006a, 2006b).

¹¹ The fixed capital inputs required to substitute the depreciation of capital are not taken into consideration here. IO conventions consider these inputs as part of the final demand (included in investment). By not taking this limitation into account, it might be said that we consider the components of final demand as “vertically integrated sectors”, to use the terminology of Pasinetti (1973) (see also De Juan and Febrero, 2000).

Spanish NAMEA data need to be adapted to the IO model by assigning secondary productions (and associated emissions) to those industries of which they constitute the principal products. This involves rearranging the corresponding intermediate consumption and the respective atmospheric polluting emissions. In this paper, the matrices of technical coefficients $A_{n \times n}$ and direct emission coefficients $V_{k \times n}$ are estimated for 46 industries in line with the “technology industry hypothesis”, according to which all products from one industry are assumed to be produced with the same technology.¹²

In common with the standard IO model, the environmental IO model helps identify those that contribute directly to the emission of pollutants, while highlighting the indirect role played by intermediate consumption. Therefore, the more an industry uses products whose production is pollution intensive, the greater will be the pollution generated indirectly to satisfy final demand. Tables 1 and 2 present the Spanish industries with the greatest total emission intensities in 2000. More specifically, we show only those that have an emission multiplier $F = V(I - A)^{-1}$ which is more than twice the mean of the economy. The ranking of sectors for greenhouse gas emissions are presented in Table 1, while Table 2 shows the rankings for the other three gases considered in this article.

Tables 1 and 2 show how the expenditure of one monetary unit in the purchase of a range of different goods and services - classified by sectors or industries - can have very different implications in terms of the quantity and type of emissions. For instance, one euro spent in the “*Electricity, gas, steam and hot water supply*” sector (mainly electricity production) was found to generate much higher emissions of CO₂ and SO₂ than the same euro spent in any other sector. For these two pollutants, the manufacture

¹² For a detail analysis see chapter 5 in Miller and Blair, 1985.

of mineral and refined petroleum products also gave rise to a high intensity of emissions. The emission intensity of NO_x was also considerable in the “*Electricity, gas, steam and hot water supply*” sector and even higher in fishing and water transport. As expected, the activities that generated the highest levels of CH_4 , N_2O and NH_3 emissions were those related to the agricultural sector and the manufacture of food products. Meanwhile, SF_6 , HFCs and PFCs emissions were closely linked with specific manufacturing activities: SF_6 with the manufacture of machinery, electrical and optical equipment; HFCs with the manufacture of chemicals, rubber and plastic products; and PFCs with aluminium production (included in the manufacture of basic metals).

4. A longitudinal perspective: structural decomposition analysis

Since the late seventies, energy and environmental analyses have increasingly used decomposition analysis techniques to study the contribution of a range of factors to energy use and environmental pressures. Indeed, Ang and Zhang (2000) listed more than a hundred studies, some of which adopted an IO methodology; in this latter case, the name commonly used to refer to the decomposition analysis we undertake is structural decomposition analysis (SDA) (Hoekstra, 2005).

The purpose of SDA is to break down the variation of an aggregate variable to reveal the contribution of different effects. In this section, we conduct an SDA in order to analyse the evolution in Spain of the atmospheric pollutants considered in section 2 – i.e., six greenhouse gases (CO_2 , CH_4 , N_2O , SF_6 , HFCs and PFCs) and three other air pollutants (SO_2 , NO_x and NH_3).¹³

¹³ Henceforth, we consider the “new” greenhouse gases (SF_6 , HFCs and PFCs) as one specific group. We refer to this group as the “*synthetic greenhouse gases*”.

Given i' as a row vector of n ones, the total emissions of an economy in any period t can be expressed as:¹⁴

$$E_t = [V_t(I - A_t)^{-1}][y_t / (i' y_t)][i' y_t] = F_t y_t^s y_t^v \quad (4)$$

In this expression, final demand is divided into a structure component (y_t^s) and a volume component (y_t^v). Thereby, the decomposition of the change in emissions between two periods is given by:

$$\Delta E = E_1 - E_0 = F_1 y_1^s y_1^v - F_0 y_0^s y_0^v = \Delta F_{effect} + \Delta y_{effect}^s + \Delta y_{effect}^v \quad (5)$$

In (5) the change in emissions is expressed as the contribution of the following effects. The first, ΔF_{effect} , that we call the *technological effect*, includes the joint effect of variations in V and the Leontief inverse matrix, i.e. changes in the total intensity of emissions or in the “cost” in emissions to provide the different types of commodities.¹⁵ Other studies choose to consider separately the two types of strongly related technological effects - i.e., changes in the V matrix and changes in the Leontief inverse matrix¹⁶. However, here we have chosen to consider this technological effect globally because, in environmental terms, what we are concerned with is the total variation in emissions due to technological changes and it is not important if this variation is due to

¹⁴ It should be remembered that this expression considers both domestically-produced emissions and emissions related to imported commodities assuming the use of the same technologies in all countries.

¹⁵ Note that each sector includes a range of different goods and services so changes in the intrasectoral composition would affect intensities even if there were no technical changes. This is a general limitation of the SDA which becomes more significant with increasing levels of aggregation in the IO tables.

¹⁶ For instance, Wier and Hasler (1999) call these effects “emission factor” and “input mix”. De Haan (2001) uses the terms “eco-efficiency” and “structure of production”.

changes in emissions coefficients or the Leontief inverse.¹⁷ Finally, we take into account two additional effects: changes in *final demand structure* (Δy_{effect}^s) and changes in *final demand volume* (Δy_{effect}^v). This decomposition enables us to analyse whether the two main factors which underpin the EKC hypothesis - *technological change* and *final demand structure* – tends to reduce emissions or not. If they do, this analysis should also enable us to determine whether they were of sufficient weight to counteract the effect of economic growth.

As discussed in the SDA literature, several techniques might be adopted for decomposing the total emission variation into its different factors. Arguably, the most “intuitive” method involves calculating the contribution of each factor by simulating the effects resulting from changes in one factor while the initial values of the other factors are held invariable. However, this approach - “Laspeyres” approach - does not provide us with a complete decomposition as the total change in emissions does not coincide with the sum of the different effects. This difference is known as the *residual* or *interaction* term, which might be very high when the different factors change considerably. For this reason many studies choose to apply other decomposition methods in an attempt at reducing or eliminating this *interaction* term. One alternative is to calculate the effects as the average of the “Laspeyres” approach and the “Paasche” approach (see e.g. Wier and Hasler, 1999); however, while this method reduces the interaction effect, it is not entirely eliminated. Another alternative involves, first, calculating the effects with the Laspeyres approach and then sharing out the *interaction* term among the different effects in line with the “jointly created and equally

¹⁷ In order to compare this variation with that reported elsewhere we computed the relative weight of the changes in V and in the Leontief inverse. For the majority of gases the changes in the Leontief inverse were significant but still much smaller than the changes in V .

distributed” principle (Sun, 1998). This alternative, called the “refined Laspeyres method” by Ang and Zhang (2000), gives an exact decomposition.

The latter, however, is not the only possibility for obtaining a complete decomposition. Dietzenbacher and Los (1998) show that when three effects are considered, there might be six different exact decomposition forms ($3!$ or in general $n!$ where n is the number of effects considered). They claim that all these possible forms are “equivalent, in the sense that no form is to be preferred on theoretical grounds to the others” (p. 314). They also show that outcomes of the different forms can differ greatly. Hence, the best option seems to involve calculating the average effects of all these six exact decomposition forms. This average results in exactly the same outcome as Sun’s proposal (Hoekstra, 2005; p.141). In this section, we adopt this “refined Laspeyres method”, which can be expressed as:

$$\begin{aligned}
 \Delta F_{effect} &= (\Delta F y_0^s y_0^v) + \frac{1}{2} (\Delta F \Delta y^s y_0^v) + \frac{1}{2} (\Delta F y_0^s \Delta y^v) + \frac{1}{3} (\Delta F \Delta y^s \Delta y^v) \\
 \Delta y_{effect}^s &= (F_0 \Delta y^s y_0^v) + \frac{1}{2} (\Delta F \Delta y^s y_0^v) + \frac{1}{2} (F_0 \Delta y^s \Delta y^v) + \frac{1}{3} (\Delta F \Delta y^s \Delta y^v) \\
 \Delta y_{effect}^v &= (F_0 y_0^s \Delta y^v) + \frac{1}{2} (\Delta F y_0^s \Delta y^v) + \frac{1}{2} (F_0 \Delta y^s \Delta y^v) + \frac{1}{3} (\Delta F \Delta y^s \Delta y^v)
 \end{aligned} \tag{6}$$

As discussed above, the availability of Spanish NAMEA data means we can only apply the SDA methodology to a study of the evolution in atmospheric emissions over a short period of time: 1995-2000. To the best of our knowledge, there are virtually no previous SDA studies of atmospheric pollution in Spain.¹⁸ It should be borne in mind

¹⁸ Alcántara and Roca (1995) examines energy use and CO₂ emissions in Spain between 1980 and 1990 using energy balances and an IO perspective to approximate the primary energy required - and the associated emissions of CO₂ - to provide the different forms of final energy and to distribute the primary energy into three uses: “economic sectors”, transport and residential use. An extension of this analysis was undertaken in Alcántara and Roca (2004). While other IO studies analyse energy and CO₂ emissions in Spain, all of them have other approaches (see, e.g. Manresa *et al.*, 1998; Labandeira and Labeaga, 2002; and Alcántara and Padilla, 2003).

that our analysis only takes into account domestic and imported “productive” emissions and that neither direct emissions from households nor CH₄ emissions from waste management are considered.¹⁹ As can be seen in Table 3, the emissions we do consider are the most significant, accounting for over 95 per cent of the total emissions of the economy for most of the gases with the exceptions of CO₂, NO_x and CH₄.²⁰

Table 4 shows the outcome of the SDA for Spain and for the period 1995-2000 using the method proposed by Sun (1998). In order to avoid the influence of price variations when analysing changes over time, IO tables must be expressed in constant prices. However, as the Spanish NAMEA data are only provided in current prices, we were obliged to deflate the 2000 IO table to 1995 constant prices applying the biproportional projection method proposed by Dietzenbacher and Hoen (1998).²¹

Obviously, in all cases the *volume effect* acted in the same direction and resulted in increased emissions. For the majority of gases, we can conclude – in line with other studies - that the *technological effect* was also significant, causing emissions to fall. However, this effect was only strong enough to counteract that of volume in the case of SO₂. In the cases of CO₂, CH₄, N₂O and NO_x the *technological effect* was significant but much less so than the volume effect. We also found exceptions to the beneficial effects of technology: the cases of NH₃ and, in particular, of the group of synthetic

¹⁹ See section 3.1. In the case of CH₄ more than 90% of “direct” emissions are due to waste management.

²⁰ One could expect a share of direct CO₂ and NO_x emissions in total emissions larger than the share that Table 3 reports. One of the reasons that could explain these low relative values is that “emissions from industries” include emissions linked to the production of imported commodities.

²¹ We applied this method using the constant prices data provided by INE, i.e. value added by sector, total of valued added, total of final demand components and total of imports.

greenhouse gases.²² Likewise, in line with results of other studies, we can conclude that the *final demand structure effect* was relatively small in comparison with the technological effect for virtually all the gases. Moreover, this effect was found to increase emissions in the majority of gases, the exceptions being CH₄, N₂O and NH₃, which emissions are mostly connected with agriculture and cattle raising. From the perspective of final demand, this decrease in emissions was largely due to the declining relative weight of activities associated with the production, transformation and distribution of food products.

The evolution in *technological change* in Spain might be said to be compatible with one of the principles underpinning the EKC hypothesis in the case of most of the gases considered. But only in the case of SO₂ was this effect strong enough to generate *absolute delinking* between emissions and economic growth.²³ However, at this point we should reiterate that these data do not give any information about the factors that account for technological change. In the specific case of SO₂, one key factor is undoubtedly the existence of international agreements, which have affected developed countries (De Bruyn, 1997), and the compulsory objectives established by the European Union. However, the *final demand structure effect* did not decrease emissions for the majority of gases contrary to another of the principles underpinning the EKC hypothesis.

5. A cross-section perspective: household consumption pattern analysis

²² However, the differences between the three gases are important with an important decreasing of emissions due to technological effect in the case of PFCs.

²³ If we considered the three synthetic greenhouse gases separately, the emissions of PFCs also would constitute a case of absolute delinking due to technological effects.

In recent years, there has been an increasing interest in measuring the environmental effects of household consumption patterns. This involves studying the relative responsibility of different household-types for generating certain environmental pressures. Herendeen and Tanaka (1976) and Herendeen *et al.* (1981) are seminal works examining the “energy cost of living” for different types of household in the USA. These studies take into account not only the direct demand for energy products but, more importantly, the indirect energy requirements, i.e. the energy used to produce and distribute the commodities demanded by households. Subsequently, other articles have examined the same issue in other countries, taking into account not only energy but also the associated CO₂ emissions.²⁴ In all these studies, the methodology used for computing indirect energy or indirect emissions is based on IO analysis. In this section, we also use this methodology to analyse the impact of different Spanish household types on atmospheric pollution in 2000. We consider only emissions associated with private consumption,²⁵ including “direct” household emissions.

Specifically, we distinguish here between direct (E^{direct}) and indirect household emissions ($E^{indirect}$). The former include emissions produced by the household’s direct consumption; the latter are emissions associated with the production of the commodities acquired by households. Both emissions are obtained by combining data from various sources and with different classifications. Direct household emissions are calculated by applying the following expression:

²⁴ These include: Herendeen (1978) for Norway; Peet *et al.* (1985) for New Zealand; Vringer and Blok (1995) for the Netherlands; Wier *et al.* (2001) for Denmark; and Lenzen *et al.* (2006) which reports the outcomes of household energy requirements for five countries (Australia, Brazil, Denmark, India and Japan).

$$E^{direct} = \hat{G}P \quad (7)$$

where \hat{G}_{kxk} is a diagonal matrix of total household direct emissions of atmospheric pollutants and P_{kxh} is a coefficient matrix showing how these emissions are distributed among the different h types of households. \hat{G}_{kxk} is computed using Spanish NAMEA data. The components of this matrix are only significant for NO_x and CO₂, and in both cases the emissions are closely linked to energy use. For this reason, we only consider here the direct household emissions of these two gases, distributing them in accordance with the distribution of total monetary expenditure on “energy products”.²⁶ By contrast, the indirect emissions are defined as:

$$E^{indirect} = V(I - A)^{-1}MH \quad (8)$$

where $V(I - A)^{-1}$ is the emission multiplier defined in section 3; M_{nxs} is a composition matrix of aggregated commodity consumption that relates n CPA products with s COICOP products and has been provided by the INE;²⁷ and H_{sxh} is a matrix of the expenditure on s COICOP products made by each type of household, and which has been estimated from the Spanish consumer survey (*Encuesta Continua de Presupuestos Familiares* - ECPF). Finally, the total household emissions are obtained as:

$$E^{total} = E^{direct} + E^{indirect} \quad (9)$$

²⁵ Note that in the previous section we considered emissions associated with all the components of final demand.

²⁶ We consider total expenditure on 4521 (natural gas), 4522 (liquefied gas), 4531 (liquid fuels), 4541 (solid fuels) and 7221 (fuels and lubricants) COICOP products.

²⁷ Here n is equal to 46 CPA products and s is equal to 47 COICOP products.

We are concerned here with breaking down total emissions from household consumption by different household in order to study a question posed directly by the ECK debate: how do emissions change as households become wealthier and spend more money.²⁸ Households are, therefore, classified according to their level of expenditure. However, we should point out two aspects concerning such a classification. First, it might be argued that it would be more appropriate to consider the income rather than the expenditure variable; nevertheless, we have chosen to use the latter for two reasons. The first reason is that the source we have used - i.e. ECPF - provides more complete and reliable data on expenditure than on income. The second reason is that linking income and emissions taking into account only consumption expenditures could be interpreted as supposing that savings do not result in emissions when in fact investment can be as environmentally problematic as consumption, or even more so.

Second, household are different in size and composition. Thus, a decision has to be taken as to whether it is better to work with total household expenditure or to apply some type of transformation in order to calculate the “equivalent expenditure”. In this paper we adjust the data from each household in accordance with the “modified OECD scale”²⁹ (Wier *et al.*, 2001).

²⁸Clearly, income (and expenditure) levels are not the only factors influencing lifestyle. In order to consider other factors, alternative perspectives need to be adopted such as the multivariate econometric approach (Lenzen *et al.*, 2006) or household classifications compiled on the basis of several characteristics, e.g. Duchin (1998) classifies United States households using 40 “geo-demographic lifestyle clusters”.

²⁹ This approach takes into account economies of scale in consumption and the differences between children and adults. According to this scale, the first person over 14 years represents 1 consumer unit, other persons over 14 years 0.5 units and children under 15 years 0.3 units.

Our main findings for the different gases are organized as follows. We include graphs showing: 1) average equivalent emissions for the different household types ordered by equivalent expenditure deciles (Figures 3 and 5); and 2) average emissions intensity - i.e., total emissions divided by total expenditure - for the different household types ordered by equivalent expenditure deciles (Figures 4 and 6). Furthermore, as a synthetic quantitative indicator we show the expenditure elasticity of emissions using microdata of 9,628 different households (Tables 5 and 6); in this case, we also present outcomes using non-corrected expenditure data, i.e. total expenditure elasticity.³⁰ The graphs and the quantitative indicator are directly connected: an increasing function in Graph 1) means a positive elasticity; moreover, the elasticity will be higher or lower respectively than one if the function in Graph 2) is increasing or decreasing.

For each gas, the elasticity is defined according to the equation:

$$E = \alpha K^\beta \quad (10)$$

where E means total household emissions and K means household expenditure. The subsequent estimation is based on an application of the ordinary least-squares method to:

$$\ln E = z + \beta \ln K \quad (11)$$

For all the pollutants, emissions increased monotonically with household expenditure (Figures 3 and 5), and no turning point was recorded. However, if we analyse the evolution in emission intensity (Figures 4 and 6), we observe that in general the amount of pollutants emitted per unit of household consumption decreased with

³⁰ To date most studies have not corrected their data so as to take into account the demographic characteristics of the households. This presentation, therefore, ensures that our outcomes can be more easily compared with those of other studies.

expenditure level; the exception to this was the greenhouse synthetic gases: SF₆, HFCs and PFCs. The most significant - albeit moderate - decrease was reported for those pollutants closely associated with agriculture and cattle raising - CH₄, N₂O and NH₃, which is unsurprising given that one of the few consumption “laws” is that the proportion of money spent on food decreases with the level of expenditure.

The elasticity values³¹ oscillated from 0.71 to more than 1 when using equivalent data according to the modified OECD scale. These values were even higher when using uncorrected data, with the exception of the synthetic greenhouse gases (Tables 5 and 6). Technical changes (autonomous or induced by environmental policy) could act in the opposite direction but always these outcomes suggest that further increases in income and expenditure levels should lead to a rise in the pollution generated by private consumption.

As discussed above, studies conducted in other countries have similarly analysed expenditure elasticity for energy or CO₂ emissions; however, to our knowledge this is the first to examine other atmospheric pollutants. Given the strong relationship between energy requirements and associated CO₂ emissions we can compare our elasticity outcome for CO₂ - i.e., 0.91 - with the expenditure elasticity for energy obtained for several countries in a recent work by Lenzen *et al.* (2006)³². They report values which

³¹ We are assuming that one euro spent on one type of product will result in the same amount and type of pollution as another euro spent on the same type of product. Yet, Vringer and Blok (1995) stand: “However, it is conceivable that households with a higher income (or a higher expenditure level) systematically buy products that cost more per physical unit. The consequence of this is that the real elasticity of the energy requirement related to income (or expenditure level) can be smaller than the value computed here” (p. 901).

³² However, we should be very prudent with the comparison because of different data and because the methodology adopted in Lenzen *et al.* (2006) differs, as multivariate regressions are used. Moreover, if

range from 0.64 (Japan) to 1 (Brazil) with values of 0.78 for Australia and 0.86 for Denmark and India. Thus, our result lies within the range of those reported in this work, and the increase in emissions with increasing expenditure can be considered particularly high.

6. Conclusion

In this paper we have analysed atmospheric pollution in Spain, taking into consideration nine different gases. Our main interest has been in determining whether any evidence can be found for a delinking between income growth and atmospheric emissions, as the EKC hypothesis implies for rich countries. Using Spanish NAMEA data and an IO analysis, we have adopted two approaches. Firstly, we have undertaken an SDA for the period 1995-2000; secondly, we have conducted a cross-section study for 2000 to evaluate the atmospheric pollution associated with the consumption of different household types, classified according to their equivalent levels of expenditure.

For some pollutants - NH_3 , CH_4 and N_2O - both approaches provide some evidence that income growth is associated with a reduction in the intensity of gas emissions. This reflects changes in final demand structure and, in particular, a relative decrease in demand for food products. However, this trend only accounts for a weak relative delinking between economic growth and emissions and can by no means be interpreted as an absolute delinking. By contrast, the “new” greenhouse gases are mainly associated with manufactured products with an increasing weight in the consumption of wealthier households. For other pollutants - including the main greenhouse gas, CO_2 - we did not find in our SDA any change in the final demand we consider the expenditure elasticity of CO_2 emissions directly, our estimate is even higher, i.e. 0.99 (see Table 5).

structure that might lead to a reduction in emissions and, moreover, our estimate of household expenditure elasticity presented a value very near to one.

Both the cross section analysis and the estimation of the effect of final demand structure on SDA are alternative methods for determining the role of one of the factors that explains the relationship between income growth and emissions. We would expect similar outcomes from both approaches, but the outcomes will not be identical for several reasons. Firstly, the distribution of expenditure is not invariable. Secondly, household patterns of consumption change over time not only reflecting changes in levels of income and expenditure, but also shifts in other social factors. And, thirdly, the final demand structure effect can be attributed to both changes in private consumption composition as well as changes in the composition of other final demand components; besides, our SDA analysis has not taken into account direct private consumption emissions. In fact, we have obtained very similar findings for NH₃, CH₄ and N₂O and for the greenhouse synthetic gases. However, in the cases of CO₂, SO₂ and NO_x, the conclusions provided by both approaches are different.

The role of technological changes, however, can be estimated only from the SDA, but not from the static analysis of the consumption patterns of different households. For most of the air pollutants, the SDA carried out here shows that technological changes have reduced emissions. However, only in the case of SO₂ have these changes been sufficient to counteract the effect of economic growth and this sole example of absolute delinking would seem to be more obviously attributable to government policy and international agreements. Additionally, were we to consider the three synthetic greenhouse gases separately, the emissions of PFCs also would constitute a case of absolute delinking due to technological effects.

Acknowledgments

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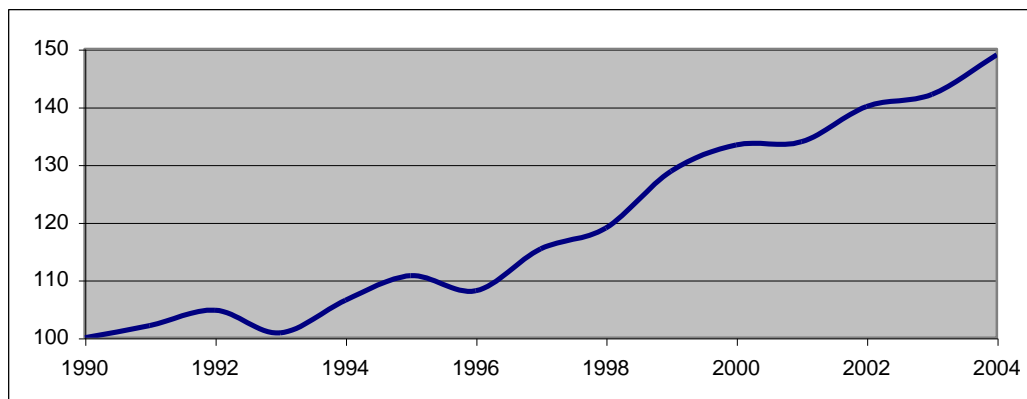
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Figure 1: Evolution of total CO₂-equivalent emissions of greenhouse gases, Spain 1990-2004

Units: 1990 base = 100

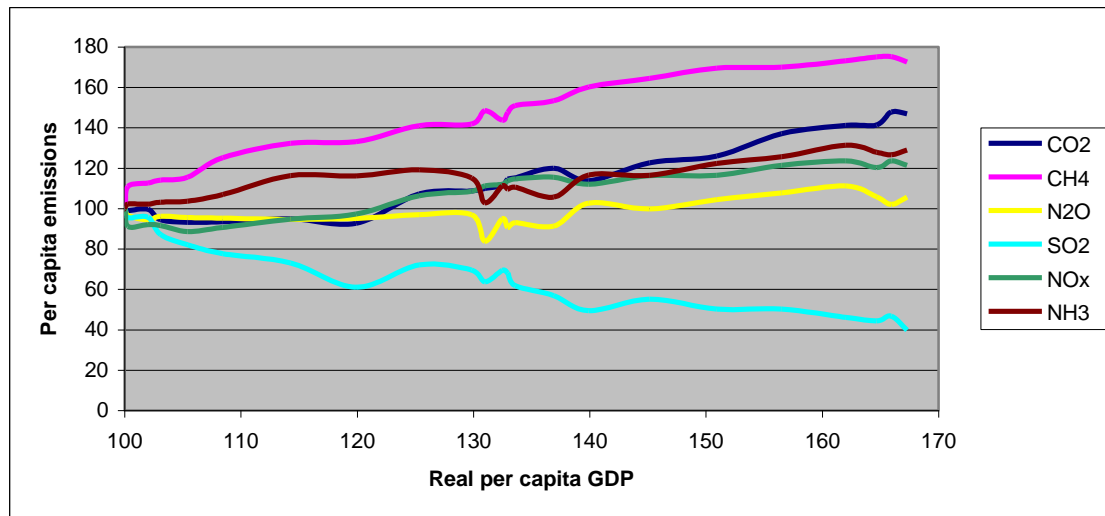


Source: Ministry of Environment data.

Note: The greenhouse gases considered are CO₂, CH₄, N₂O, SF₆, HFCs and PFCs.

Figure 2: Relationship between “real” per capita GDP and per capita emissions, Spain 1980-2003

Units: 1980 base =100



Source: Own elaboration from Ministry of Environment data and INE data.

Table 1: Ranking of total emission intensity of the greenhouse gases in terms of final demand, Spain 2000

Units: Index numbers, mean of the economy 2000 base = 100

CO ₂		CH ₄		N ₂ O		SF ₆		HFC		PFC	
Sector	Intensity	Sector	Intensity	Sector	Intensity	Sector	Intensity	Sector	Intensity	Sector	Intensity
Electricity, gas, steam and hot water supply	643	Agriculture, hunting and related services activities	1175	Agriculture, hunting and related services activities	1211	Manufacture of electrical machinery and apparatus	2287	Manufacture of chemicals and chemical products	1115	Manufacture of basic metals	1399
Manufacture of other non-metallic mineral products	325	Mining of coal and lignite; extraction of peat	1150	Manufacture of food products, beverages and tobacco	475	Manufacture of radio, television and communication equipment and apparatus	407	Manufacture of rubber and plastic products	488	Manufacture of fabricated metal products, except machinery and equipment	417
Manufacture of coke, refined petroleum products and nuclear fuel	262	Manufacture of food products, beverages and tobacco	450	Forestry, logging and related services activities	377	Manufacture of medical, precision and optical instruments, watches and clocks	380	Manufacture of textiles	354	Manufacture of electrical machinery and apparatus	336
Fishing	249	Forestry, logging and related services activities	359	Manufacture of chemicals and chemicals products	260	Manufacture of office machinery and computers	259	-	-	Manufacture of motor vehicles, trailers and semi-trailers	303
Manufacture of basic metals	207	-	-	-	-	Manufacture of machinery and equipment	248	-	-	Manufacture of other transport equipment	244
-	-	-	-	-	-	-	-	-	-	Manufacture of machinery and equipment	235

Source: Own elaboration from 2000 Spanish NAMEA.

Table 2: Ranking of total emission intensity of the other gases in terms of final demand Spain 2000

Units: Index numbers, mean of the economy 2000 base = 100

SO ₂		NO _x		NH ₃	
<i>Sector</i>	<i>Intensity</i>	<i>Sector</i>	<i>Intensity</i>	<i>Sector</i>	<i>Intensity</i>
Electricity, gas, steam and hot water supply	1142	Fishing	623	Agriculture, hunting and related services activities	1889
Water transport	270	Water transport	494	Manufacture of food products, beverages and tobacco	712
Manufacture of coke, refined petroleum products and nuclear fuel	268	Electricity, gas, steam and hot water supply	398	Forestry, logging and related services activities	575
Manufacture of other non-metallic mineral products	236	Mining of metal ores	272	-	-
Manufacture of basic metals	212	Extraction of crude petroleum, natural gas; uranium and thorium ores	243	-	-
-	-	Manufacture of coke, refined petroleum products and nuclear fuel	221	-	-

Source: Own elaboration from 2000 Spanish NAMEA. .

Table 3: Gas emissions as percentage of total emissions in the economy, Spain 1995 and 2000

Units: %

	1995		2000	
	Emissions from industries	Direct emissions from households and other sources	Emissions from industries	Direct emissions from households and other sources
<i>Greenhouse gases</i>				
CO₂	86.81	13.19	87.62	12.38
CH₄	76.23	23.77	74.83	25.17
N₂O	96.28	3.72	95.33	4.67
Synthetic gases*	99.62	0.38	99.67	0.33
Total in eq_CO₂	86.65	13.35	87.27	12.73
<i>Other gases</i>				
SO₂	98.43	1.57	98.91	1.09
NO_x	83.18	16.82	86.88	13.12
NH₃	99.41	0.59	99.10	0.90

Source: Own elaboration from 1995 and 2000 Spanish NAMEA.

*: Synthetic gases are total SF₆, HFC and PFC emissions measured in thousand tonnes of equivalent CO₂.

Notes: 1) "Emissions from industries" include assumed emissions linked to the production of imported commodities.

2) Direct emissions from households and other sources include household direct emissions and also CH₄ emissions from waste management.

Table 4: Decomposition of the emission changes in Spain 1995-2000 (as % of the total amount of emissions by all industries in 1995)

Units: %

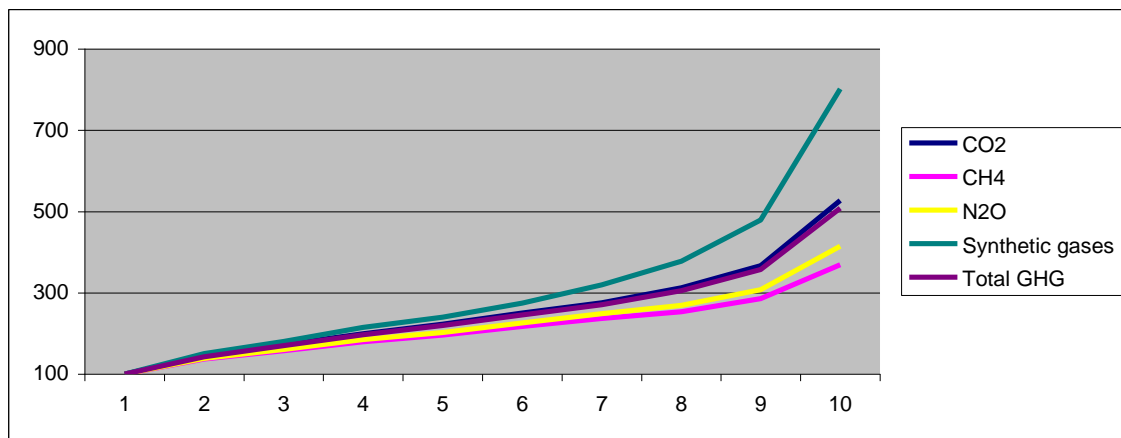
	Technological effect $\Delta F/E_{95}$	Final demand structure effect $\Delta y_s/E_{95}$	Final demand volume effect $\Delta y_v/E_{95}$	Total effect $\Delta E/E_{95}$
<i>Greenhouse gases</i>				
CO₂	-9.72	5.38	29.56	25.22
CH₄	-11.24	-4.17	28.05	12.65
N₂O	-6.86	-1.40	29.02	20.76
Synthetic gases*	39.88	12.72	36.86	89.46
Total in eq_CO₂	-8.64	4.10	29.52	24.99
<i>Other gases</i>				
SO₂	-38.20	5.26	25.89	-7.06
NO_x	-17.49	2.20	28.11	12.82
NH₃	4.25	-5.08	29.96	29.13

Source: Own elaboration from 1995 and 2000 Spanish NAMEA.

*: Synthetic gases are total SF₆, HFC and PFC emissions measured in thousand tonnes of equivalent CO₂.

Figure 3: Emissions of greenhouse gases of equivalent expenditure household deciles, Spain 2000

Unit: First decil base = 100

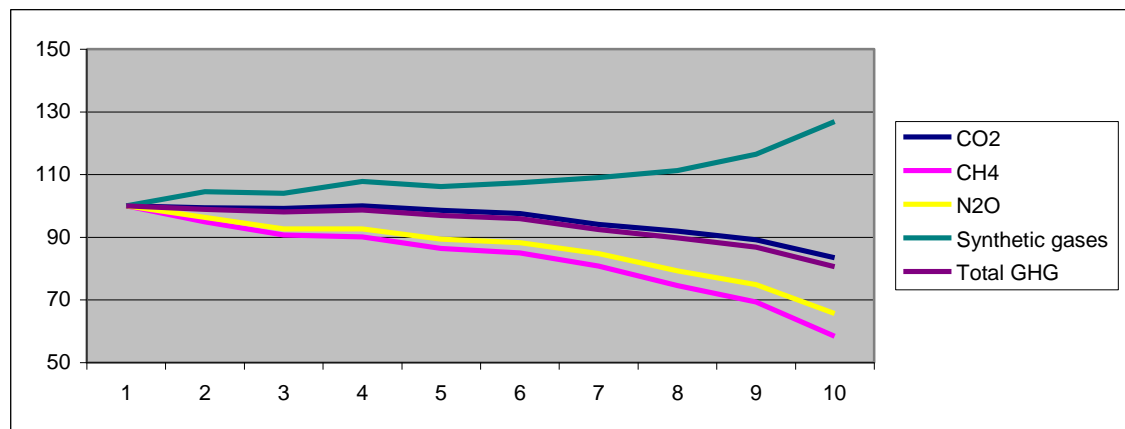


Source: Own elaboration.

**: Synthetic gases are total SF₆, HFC and PFC emissions measured in equivalent CO₂.*

Figure 4: Intensity of emissions of greenhouse gases of equivalent expenditure household deciles, Spain 2000

Unit: First decil base = 100



Source: Own elaboration.

**: Synthetic gases are total SF₆, HFC and PFC emissions measured in equivalent CO₂.*

**Table 5: Expenditure elasticity of greenhouse gas emissions,
Spain 2000**

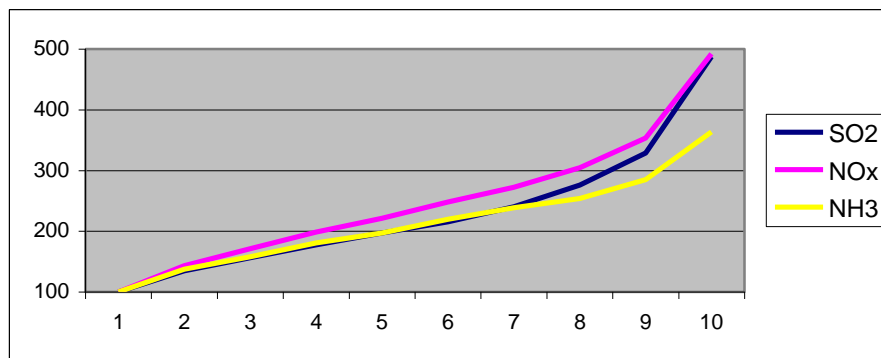
	Equivalent expenditure elasticity		Total expenditure elasticity	
	β Elasticity	R ²	β Elasticity	R ²
CO ₂	0.91	0.75	0.99	0.83
CH ₄	0.71	0.60	0.84	0.72
N ₂ O	0.78	0.71	0.88	0.80
Synthetic gases*	1.11	0.88	1.10	0.91
Total in eq_CO₂	0.89	0.79	0.98	0.86

Source: Own elaboration.

*: Synthetic gases are total SF₆, HFC and PFC emissions measured in equivalent CO₂.

Figure 5: Emissions of other gases of equivalent expenditure household deciles, Spain 2000

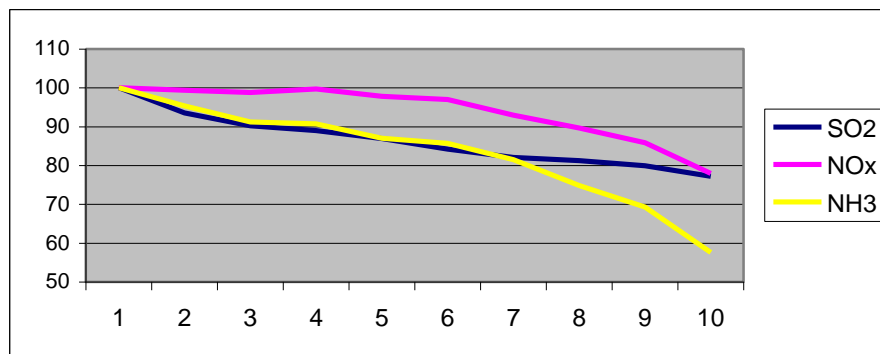
Unit: First decil base = 100



Source: Own elaboration.

Figure 6: Intensity of emissions of other gases of equivalent expenditure household deciles, Spain 2000

Unit: First decil base = 100



Source: Own elaboration

Table 6: Expenditure elasticity of other gas emissions, Spain 2000

	Equivalent expenditure elasticity		Total expenditure elasticity	
	β Elasticity	R ²	β Elasticity	R ²
SO ₂	0.86	0.86	0.88	0.90
NO _x	0.87	0.73	0.98	0.82
NH ₃	0.71	0.55	0.85	0.68

Source: Own elaboration.