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Economic growth and atmospheric pollution in Spain: discussing the environmental Kuznets curve hypothesis

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ABSTRACT: The environmental Kuznets curve (EKC) hypothesis posits an inverted U relationship between environmental pressure and per capita income. Recent research has examined this hypothesis for different pollutants in different countries. Despite certain empirical evidence shows that some specific environmental pressures have diminished in developed countries, the hypothesis could not be generalized to the global relationship between economy and environment at all. In this article we contribute to this debate analyzing the trends of annual emission flux of six atmospheric pollutants in Spain. The study presents evidence that there is not any correlation between higher income level and smaller emissions, except for SO_2 whose evolution might be compatible with the EKC hypothesis. The authors argue that the relationship between income level and diverse types of emissions depends on many factors. Thus it cannot be thought that economic growth, by itself, will solve environmental problems.

KEY WORDS: Environmental Kuznets curve, atmospheric pollution, Spain.

1. Introduction: the environmental Kuznets curve hypothesis

Several recent studies have suggested that there is an inverted U relationship between environmental pressure, or quality, and per capita income level[1]. According to the environmental Kuznets curve (EKC) hypothesis, at the first stage of economic development environmental pressures increase as per capita income increases, but after a critical turning-point these pressures diminish along with higher income levels. The name is due to the similarity with the relationship between the level of inequality and per capita income considered by Kuznets (1955). The explanatory factors that most frequently appear in the literature are: first, environmental quality is considered as a luxury good whose demand increases at higher income levels; second, production composition changes with economic development and the increasing importance of the service sector, which is a "more environmental friendly" sector, reduces the environmental impact of economic activity; and third, technological progress linked to economic growth causes a decrease of environmental pressures.

These explanations have been used by the most optimistic authors to suggest that economic growth is itself the solution to environmental problems, because environmental improvement will be an almost unavoidable consequence of economic growth (Beckerman, 1992). Nevertheless, this ingenuous interpretation has numerous theoretical and empirical problems.

[1] Some of the first studies were by Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), Panayotou (1993), Selden and Song (1994), and Holtz-Eakin and Selden (1995). Special issues of *Ecological Economics* (1995, 1998) and *Environment and Development Economics* (1996) have discussed the theory. The World Bank (1992, 1995) discusses the economic policy implications. Ekins (1997), Stern et al (1996) and Stern (1998) make critical reviews of the literature.

From a theoretical point of view, we can contest the previous explanations. Rich people have incentives to improve the environment to the extent that they themselves are affected by this degradation, but this is not the case when these effects move in time or space to other citizens and, in any case, environmental quality is a public good and the role of environmental policies is crucial (Arrow et al, 1995; Perrings and Ansuategui, 2000). In addition, the service sector is an aggregate that includes activities with strong environmental impact (such as air transport or mass tourism) and the change in the composition of production could explain at most the decrease of environmental impact per unit of GDP, but not in absolute terms. This absolute level is the relevant variable for measuring the implications of income growth (de Bruyn et al, 1998). Furthermore, the observed EKCs could result (at least partly) from a displacement of the most polluting industries from the rich countries toward the poorest ones, without the composition of consumption (and its pollution content) varying substantially (Arrow et al, 1995; Stern et al, 1996; Ekins, 1997; Suri and Chapman, 1998). On the other hand, techniques with most environmental impact could be introduced by the richest countries. Moreover, environmental degradation is not only explained by current flows of emissions or concentrations of pollutants, but also depends on prior environmental pressures that affect the capacity of assimilation and the resilience of ecosystems. This is particularly relevant when irreversible changes take place (Arrow et al, 1995). The interdependence between economy and environment needs to be considered: if economic growth causes irreversible, or almost irreversible, environmental degradation, this may affect future growth (Stern et al, 1996).

From an empirical point of view, although there is certain evidence that some environmental pressures have diminished in developed countries, none of the pollutants examined in the literature fulfills the EKC hypothesis unequivocally (Ekins, 1997). In general, the outcomes are more favorable to this hypothesis for pollutants with local and regional impacts and low cost of abatement. This is the case of sulfur atmospheric emissions but even in this case recent evidence suggest that the EKC hypothesis is not clear because the results are sample dependent and very different depending on the specific model considered (Stern and Common, 2001).

It is important to stress that, when there is a negative correlation between the importance of an environmental problem and per capita income, this does not tell us much about the causes underlying this correlation. The estimates are usually based on a simple model that calculates the hypothetical total effect of per capita income on the level of emissions. It is assumed that this model reflects other structural model in which per capita income affects factors (such as technology, the composition of economic products or environmental policies) whose changes, in turn, influence environmental pressure or quality (de Bruyn et al, 1998). The virtue of the simple model is that the whole influence (direct and indirect) of per capita income on environmental pressure is captured in the estimate. The defect is that one cannot identify the cause of this relationship .

Different studies show very varied behavior patterns, even among the same groups of pollutants. De Bruyn and Heintz (1999) attribute the differences to the use of emission or concentration indicators; different estimation methods employed; different sets of countries included in the panel; different methods employed to transfer the national per capita income data to comparable monetary units; and the use of different variables besides income. Generally, the EKC hypothesis is weakened when one introduces more additional variables, besides income. According to some authors, this suggests that, in some cases, the EKC simply could arise due to the omission of relevant variables in the estimate. In panel data estimates, there are omitted variables correlated with GDP and these variables are not common to all countries. Thus, omitted variables may result in biased estimate of the EKC in non-random samples of countries (Stern and Common, 2001).

The majority of studies stress the importance of *environmental policies* in making possible the 'de-linking' between economic growth and environmental deterioration. There is no evidence that this 'de-linking' arises in an endogenous way from the growth process, but rather a definite environmental policy making future growth compatible with sustainable development is required (Ekins, 1997) specially taking into account that the studies that support the EKC generally find inversion points that are a very long way from current income in the developing countries. This indicates that much higher levels of environmental degradation will be reached unless ambitious environmental policies are followed (Selden and Song, 1994; Stern et al, 1996).

Most authors state that it is more than probable that local and national policies and international treaties have played a major role in the decrease in some pollutants. These policies could be analyzed as independent shocks that, like other important shocks (for example, changes in some key prices or important technological innovations), can take place at very different income levels and probably affect simultaneously countries with quite different income levels[2]. Lastly, Torras and Boyce (1998) find that social factors such as civil rights, education and inequality are important: according to these authors, ceteris paribus more equality is associated with less environmental pressure.

The article is organized as follows. Section 2 reviews the data and approach used in the empirical analysis. Section 3 presents a first look at the trends in Spain for the period

[2] Unruh and Moomaw (1998) show that the 1973 shock of oil prices had an enormous influence on the behavior of CO_2 emissions in all the OECD countries they studied, in spite of the important differences in per capita income.

1980-1996. Section 4 analyses with more detail, the behavior of the different atmospheric pollutants and discusses the results. Section 5 summarizes the main conclusions.

2. Atmospheric pollution in Spain: a longitudinal perspective

One conclusion of the previous section is that the empirical evidence on the EKC is partial and very limited. Most studies have been performed with panel or cross section data from a series of countries (or from different US states as Carson et al, 1997). Even though some of these studies give arguments favorable to the hypothesis, they do not guarantee that individual countries behave over time in accord with the relationship calculated for the panel of countries (de Bruyn et al, 1998). It would be more appropriate to study the relationship between economic growth and each type of environmental pressure, analyzing the experience of individual countries and using both econometric and historical analysis (Stern et al, 1996). In the words of Dijkgraaf and Vollebergh (1998): "authors make the implicit assumption that lies behind pooling: the effect of a change in GDP per capita for the cross-section members is the same (…) Therefore, the curvature and the turning points are identical for each country. The question, not answered by the empirical studies, is what the intuition behind this implicit assumption is. It seems strange that countries, which are very different in geographical conditions, culture and history would react identical" (p. 3-4). These authors find that the pooled estimation of CO_2 emissions and income level using OECD countries data from 1960 to 1990 hides that the relationship is very different for the different OECD countries. Other studies which also adopt a longitudinal analysis are: de Bruyn et al (1998), about various atmospheric pollutants for four developed countries, Lekakis (2000) on Greece and Vincent (1997) on Malaysia. The conclusions from longitudinal analysis were generally even more skeptical about the inverted U-shaped EKC than from panel data.

We will analyze the recent trends of six atmospheric pollutants in Spain, in terms of their annual pollution flows and not of their concentrations. Concentrations of pollutants depend on pollution flows but the relationship is complex and depends, among other factors, on the bigger or smaller space and temporal concentration of these flows and on dispersion and transformation processes (for example, some "primary" pollutants give place to other "secondary" ones). The first studies tended to consider ambient pollution data from urban areas but as Stern (1998) states: “This is appropriate in as far as the effects on human health in urban areas is concerned. However (…) declining ambient concentrations of pollutants do not mean necessarily that the overall pollution burden is declining” (p. 182).

We selected the pollutants according to their environmental relevance and data availability, so we only included pollutants for which we had annual flow estimates going back to 1980. These pollutants considered are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and non-methanic volatile organic compounds (NMVOC). In the case of CO_2, we used a longer series, covering the period 1973-96, provided by the International Energy Agency (IEA, 1997) which only considers fossil fuel emissions. For the other five pollutants, the data from 1980 to 1996 were provided by the Inventory of Pollutants to the Atmosphere CORINE-AIRE[3] (according to the IPCC methodology) of the Spanish Ministry for the Environment. This inventory was approved by the European Community in 1985 within

[3] According to this methodology, SO_2 and SO_3 emissions are considered as part of SO_2 data (in SO_2 equivalent) and NO and NO_2 emissions are considered as part of NO_X data (in NO_2 equivalent).

the CORINE project for collection, coordination and coherence of information on the situation of the environment and natural resources in the Community. These data can be considered the best available official figures (although their reliability must be treated with caution) and allow us a certain sector and space break-down of emissions. The inventory establishes the following classification of polluting activities: electricity generation; commercial, institutional and residential combustion; industrial combustion; industrial processes without direct combustion; extraction, first treatment and distribution of fossil fuels; use of organic solvents; road transport; other means of transport; waste management; agriculture and cattle-raising; nature. We ignored natural-based emissions, since the relevant emissions for the study of the relationship between economic growth and environmental pressure are the anthropocentric ones.

The first three pollutants considered (CO_2, CH_4 and N_2O) are of special relevance because they are (together with CFCs, whose commercialization for internal use is already forbidden in Spain as in many other countries) those that most contribute to enhancing the greenhouse effect. The flows of these three gases are the first three indicators that Eurostat considers in the topic "climatic change" inside its project of environmental pressure indicators for the European Union (Eurostat, 1999). Furthermore, Spain has, like all the countries in Annex 1 of the convention on climatic change, a specific commitment to limiting greenhouse gas emissions acquired as a part of the EU in the agreements of Kyoto (December 1997). The commitment refers to the emissions of six greenhouse gases (the three main ones are precisely CO_2, CH_4 and

N_2O)[4] that globally should not have increased in Spain by more than 15% in 2008-2012 over the 1990 level[5].

SO_2, NO_X and NMVOC are the three compounds considered most relevant by the aforementioned Eurostat project (Eurostat, 1999) in its chapter on "atmospheric pollution". Their effects are not mainly global, but regional and local. SO_2 is associated with acidification and is one of the main causes (along with the emission of particles) of winter smog. NO_X is also an important component of acidification and, together with NMVOC, is a precursor of the formation of tropospheric ozone (O_3), which affect human and animal health and vegetation.

3. A first overall analysis of the trends in Spain for the period 1980-96

A first look at the trends during this period enables us to advance some conclusions about the assumption that at high income levels economic growth is “de-linked” from environmental pressure (Figure 1). Anthropocentric emissions of methane increased a lot, almost 70%; anthropocentric emissions of two other gases (CO_2 and NO_X) also increased significantly (by around 20%). The 1996 emissions for N_2O and volatile organic compounds were very similar to the 1980 figures. Only in the case of SO_2 did emissions decrease very significantly, as could be expected if the EKC was fulfilled and supposing that at the beginning of the eighties Spain had already reached a sufficiently high per capita income as to be located in the falling section of the curve.

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[4] The other three are HFCs, PFCs and SF_6.

[5] Bear in mind that the EU has assumed its commitment to 8% reduction as a "bubble", so while some countries (such as Spain) are allowed to increase, others are required to reduce much more than 8%.

It can be argued that the data to be used for EKC debate should not be emission data, but per capita emission data. However, since the Spanish population increased very moderately between 1980 and 1996, we can see that Figure 2's trends are practically identical to Figure 1's, although the final index values are always a bit lower. The important thing to highlight is that there is no tendency to lower emissions, except in the case of SO_2 and maybe very slightly in volatile organic compounds in the nineties.

The EKC holds that it is economic growth and not just the passage of time that explains the supposed decrease in environmental pressure. In 1996, per capita income was considerably higher than in 1980, but in the 1980-1996 period there were very different stages in the rate of variation of per capita income. Therefore, it is interesting to see the direct relation between per capita emissions and per capita real GDP[6] (Figure 3). The resulting figures are more complex but we can again affirm that there does not appear to be any correlation at all between increasing income and lower emissions. The exception is SO_2 whose evolution is compatible with the EKC hypothesis.

4. Analysis of the trends of the atmospheric pollutants

4.1. CO_2 emissions

In this section, we will analyze in detail the behavior of CO_2 emissions in Spain for the period 1973-1996. Several studies have estimated the relationship between per capita CO_2 emissions and per capita GDP using data from a panel of several countries. Their findings are contradictory, but in general they do not support the EKC hypothesis.

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[6] We use the GDP at 1986 prices. For this data and for population series, see Instituto Nacional de Estadística, Banco de datos Tempus. For international comparison it is worth taking into account that the Spanish per capita GDP in 1990$ PPA was 8,734 in 1973; 9,487 in 1980; and 13,216 in 1996 (Calculated from IEA, several years).

Rather, they seem to indicate that CO_2 emissions will generally continue to increase while countries pursue economic growth policies. Some studies find a close positive relationship between CO_2 emissions and per capita GDP (Shafik, 1994); others find that the transition income values needed to start stabilizing emissions are very high (Holtz-Eakin and Selden, 1995); and others even find evidence of a N-shaped curve, meaning that after a second transition level emissions tend to grow again (Grossman and Krueger, 1995).

If we look at the evolution of per capita CO_2 emissions between 1973 and 1996 as per capita income varies (Figure 4), we find three stages: a strong emissions growth until the end of the seventies; a subsequent relative emissions stabilization; and a later tendency to increase. This is different from other rich countries, which in most cases had a "peak" of emissions in 1973 (Moomaw and Unruh, 1997). This shows a specific delay in the Spanish economy's adjustment to the new situation of sharp increases in energy prices. The same evolution can be described alternatively through the indicator of CO_2 "emissions intensity" or CO_2/GDP. This indicator first increases, only diminishes significantly at the beginning of the eighties and then is more or less stable later on (Figure 5). In other words, economic growth only transitorily involves an increase of emissions proportionally less than GDP growth.

For a more detailed analysis, we will model the econometric relationship between emissions and income, as articles that try to contrast the EKC usually do. This is done through a model of the following type:

$$(CO_2/P)_t = \beta_0 + \beta_1 (GDP/P)_t + \beta_2 (GDP/P)_t^{\,2} + \beta_3 (GDP/P)_t^{\,3} + \varepsilon_t \quad (1)$$

where t = 1, ..., T refers to years, $(CO_2/P)_t$ to per capita CO_2 emissions, $(GDP/P)_t$ to per capita GDP and ε_t is an error term.

As we might expect from a graphic analysis, the model does not satisfy the minimum econometric requirements for Spanish data[7]; and nor does it when we estimate the model with the variables in logarithms[8]. Thus, it becomes necessary to look for additional explanatory variables.

The previous result does not necessarily imply that income and emissions are not related to each other, but rather that the relationship may be hidden by the influence of other variables. Since CO_2 emissions are not only explained by energy consumption -- predictably, closely linked with income -- but also by the structure of energy supply, the changes in this structure could explain the changes in the relationship between income and emissions. During the period analyzed, characterized by the energy crises of the seventies, there were changes in the primary energy structure: there was a strong growth in nuclear power during the eighties and an increase in the use of coal in the first eighties (Figure 6).

To catch the combined influence of the variation of per capita income and of the main changes in energy structure on the variation of per capita emissions, we calculated the following model:

$$\ln(CO_2/P)_t = \beta_0 + \beta_1 \ln(GDP/P)_t + \beta_2 \ln Nuclear_t + \beta_3 \ln Coal_t + \varepsilon_t \qquad (2)$$

where $Nuclear_t$ and $Coal_t$ are two indicators of the weight that nuclear energy and coal have inside the energy system at each moment. Specifically, we used the share of nuclear power and coal in total primary energy (based on IEA, several years). As the series are in logarithms, we can interpret the coefficients in terms of elasticities: the

[7] The variables on equation (1) are integrated of different order (see Appendix A) so this model does not cointegrate.

[8] In the model in logarithms, the square and cubic terms are not significant and display multicolinearity problems. Taking $\ln(GDP/P)_t$ as the only explanatory variably, the Durbin-Watson statistic (0,59) indicates autocorrelation in the estimated errors.

percentage increase in the dependent variable that would cause a one per cent variation in each of the independent variables.

We carried out a time-series analysis to avoid spurious regressions, in that the relationships between variables of the model could be merely casual and not causal. As we can see in Appendix A, the conclusion we drew was that the four series are not stationary in levels, but are stationary in first differences, i.e. they are all integrated at order 1. Therefore, we could carry out the calculation with the proposed model in which the dependent variable is per capita CO_2 emissions and the explanatory ones are, besides per capita income, the shares of nuclear power and coal in total primary energy, with all the variables in logarithms. The results are summarized in Table 1[9].

The calculation has high goodness of fit. The estimated coefficient shows that the relationship between GDP and CO_2 emissions is very strong. In addition, the coefficient indicates that the elasticity between the two variables is positive and even superior to the unit. Consequently, the CO_2 emission intensity of the GDP even tends to increase as GDP increases. Furthermore, we see that nuclear power indeed played an important role in the reduction of CO_2 emissions, while the increase in coal use worked in the opposite direction.[10]

An analysis of the energy data shows that economic growth in Spain has not "de-linked" from energy use even in the weak sense, largely because of the greater energy used by road transport (Alcántara and Roca, 1995).

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[9] The Dickey-Fuller statistic of the residuals generated (-6.00) indicates that they are stationary. Therefore, the series are co-integrated and the estimated parameters are consistent.

[10] Following a reviewer's suggestion, we estimated a seemingly unrelated regression (SUR) on the three equations estimated in our work (see Appendix B). The results are almost identical to the ordinary least squares estimates.

4.2 Sulfur dioxide (SO_2)

This pollutant has two characteristics that make particularly feasible the idea that, above a certain income level, emissions will decrease. First, its emissions mainly affect local and regional population (although they also can cross borders). Second, there are a limited number of important emission sources and investment can easily reduce their emissions even with just simple "end of pipe" measures. Figure 1 shows that the temporal evolution of SO_2 emissions in Spain for the period 1980-1996 is characterized by a clear tendency for emissions to drop.

As for the weight of the different groups of polluting activities, in Table 2 we can see that most emissions have their origin in a very specific sector: electricity generation. Although the emissions of this sector diminished a lot between 1980 and 1996, both in relative and absolute terms, conventional thermoelectric power stations are still the largest SO_2 polluting sources. It is the existence of very polluting coal power plants -- some of them are among the most polluters in the European Union -- which explains why per capita emissions in Spain are well above the European Union average (Eurostat, 1999, Table in p. 18). The high spatial concentration of emissions shows the same: emissions in four of the 52 Spanish provinces represent more than half the total emissions (Table 3). Industrial combustion also represents a significant amount, though much less than the electricity sector. Other sectors have a much lower relative contribution which did not change substantially during the period.

For a better analysis of the relationship between emissions and economic growth, we also performed an econometric analysis. Nevertheless, our results should be treated cautiously, given the few data available. First, we calculated a model in which the dependent variable is per capita SO_2 emissions, and the explanatory variable per capita

GDP[11]. However, this calculation had autocorrelation problems. Then, we introduced an indicator of coal consumption. However, and contradicting our initial expectations, the inclusion of different specifications of such variable (such as per capita consumption and coal share on total electricity generation, and the same specifications for brown coal) did not turn out to be significant, whereas the per capita electricity generated in conventional thermal power stations ($(\text{Thermal}/P)_t$) was significant.

$$\ln(SO_2/P)_t = \beta_0 + \beta_1 \ln(GDP/P)_t + \beta_2 \ln(\text{Thermal}/P)_t + \varepsilon_t \qquad (3)$$

This calculation, taking the variables in logarithms shows an inverse relationship between the level of per capita sulfur dioxide emissions ($\ln(SO_2/P)_t$) and the level of per capita GDP ($\ln(GDP/P)_t$) and, as expected, the coefficient is positive for the case of the variable $\ln(\text{Thermal}/P)_t$ (Table 4). Thus, at a higher level of per capita GDP there were lower SO_2 emissions; and at a level of higher electricity generated by thermal power stations, higher emissions. The Durbin-Watson statistic figure does not indicate the presence of autocorrelation problems[12] and the adjusted coefficient of determination (adjusted R^2) has a great value. Therefore, the fit of the model is very good.

Nevertheless, correlation is not equal to causation and the negative correlation between the level of emissions and the per capita GDP does not tell us too much about the factors that caused this decrease. The reduction in these emissions in Spain is not unique at all, but rather a general characteristic of developed countries (de Bruyn, 1997). In fact, the speed of reduction -- and the reduction itself -- of emissions cannot be explained without reference to the existence of international agreements and Spain's membership in the EU, since there are objectives established by EU institutions. In the first protocol on sulfur emissions (1985), a reduction of 30% by 1993 from 1980 figures

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[11] All the variables are integrated at order 1 (see Appendix A).

[12] Moreover, we included an AR(1) term to cover residual autocorrelation, but it was not significant.

was set as a target, while in the second protocol (1994) more complex, not uniform, commitments were set, based on the RAINS model which take into account climate characteristics and sulfur effects on diverse ecosystems. For Spain, this meant a minimum reduction of 35% by 2000 from 1980 figures (de Bruyn 1997, p. 493 and 496).

Perhaps there is some relationship between income level and emissions. In fact, according to de Bruyn (1997), in the above-mentioned negotiations of the second protocol, the final commitments for each country were not completely independent of the previous objectives of each country; he concludes that in general these objectives were more ambitious for the richest countries, although this is only one of the factors involved (another was the initial level of pollution in terms of greater emission per square kilometer). In any case, the relationship between income level and reduction of emissions would be very indirect (through environmental policy priorities).

Undoubtedly, the probable tougher limits on emissions of atmospheric pollutants in the European Union will imply an important SO_2 decrease, since it could mean the shutdown of several Spanish power stations in the next few years. The advance of southern European countries in environmental policies is largely due to legislative advances in the EU, which has already been pointed out by other authors (Lekakis, 2000). However, local demands are also very relevant. For example, years ago affected populations and environmental groups protested against the high emissions from the coal power station of Andorra (province of Teruel, where almost a fifth of the country's total sulfur emissions are concentrated: Table 3). This protest led to legal actions and, finally, the company made an important commitment to invest in desulfuration of gases (Cinco Días, 15-10-1998).

4.3. Nitrogen oxides (NOx)

Nitrogen oxides, like SO_2, have more local and regional effects than global ones, so it could be expected that it would be among the pollutants for which the EKC hypothesis is more likely to be fulfilled. However, the temporal evolution of NO_X emissions, as we have already seen, does not show any downward trend; on the contrary, emissions in 1996 were higher than in 1980.

An important difference with sulfur emissions is that NO_X pollution is more diffuse. The transport sector, more specifically road transport, is the sector that most contributes to the emission of nitrogen oxides. It is not only the major sector, but is also the sector in which emissions have dramatically increased in the last years. From a share of 34% of total emissions in 1980, the figure increased to 45% in 1996. This evolution is not surprising; although currently many vehicles have reduced significantly their emissions per kilometer: the expansion of road transport -- of goods and of people -- in recent decades has been such that higher “environmental efficiency” has been more than rubbed out by the higher “activity scale”.[13] In addition, emissions caused by electricity generation have considerable importance (Table 5).

Spatial analysis shows that the emissions of these gases are greater in those provinces where there are cities with a major highways network and high populations, and so more use of vehicles (Table 6). A higher relative level of emissions is also found in provinces with important coal-fired power stations (such as Coruña, León or Asturias).

We calculated an econometric regression to explain per capita NO_X emissions ($\ln(NO_X/P)_t$), including variables linked to both the transport sector and power stations[14]. As is shown in Table 7, the independent variables of the estimated model are $\ln(Transport/P)_t$, i.e. the per capita consumption of energy of the transport sector (data

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[13] The use of fuel by cars and trucks in Spain went up from 306 Kg of petrol equivalent per person and year to 551 kg between 1985 and 1996 (an 80% increase!). (See Eurostat, 1999, p. 22).

[14] Taking $\ln(GDP/P)_t$ as the only explanatory variable displays autocorrelation problems (the Durbin-Watson statistic figure in this case is 0.610).

from IEA, several years), and the already used $\ln(Thermal/P)_t$ (per capita electricity generation in conventional power stations), all the variables were taken in logarithms[15]:

$$\ln(NO_X/P)_t = \beta_0 + \beta_1 \ln(Thermal/P)_t + \beta_2 \ln(Transport/P)_t + \varepsilon_t \qquad (4)$$

Nevertheless, as in the case of SO_2 emissions, we should treat the results very cautiously, given the few data available. The Durbin-Watson statistic does not indicate the presence of autocorrelation problems, and the inclusion of an AR(1) term is not significant either.

The adjusted R^2 value is high and the positive sign of the estimated parameters fits with the expected ones. The inclusion of per capita GDP in the model was not significant[16]. Therefore, we can reject behavior such as the EKC predicts, and we can deduce that the likely influence of income level on emissions is indirect, as at higher income levels road transport and electricity consumption (nowadays, mainly obtained from the burning of fossil fuels) generally increase.

4.4. Methane (CH_4)

Methane is, together with CO_2, N_2O and CFCs, one of the gases that most contributes to the greenhouse effect. As a greenhouse gas, with global and long term effects and whose generation causes are also quite varied, it is one of the gases that is unlikely to follow the EKC hypothesis. This expectation is clearly confirmed in the following analysis.

As we observed in Figure 1, anthropocentric CH_4 emissions during the period constantly and markedly increased. If we break down emissions by sector, Table 8 shows that the main emission sources of this gas are agricultural and cattle-raising

[15] All the variables are integrated at order 1 (see Appendix A).

[16] The t-statistic associated to the variable $\ln(GDP/P)_t$ is –1.106.

activities, followed by waste management. This latter sector has grown more: from a 19% share of total emissions in 1980, it increased its share to 37%. This is not surprising given the enormous increase in urban waste generation linked to the increase of per capita consumption, the low rate of recycling and the fact that the main current destinations are dumps, without any exploitation of methane for energy use. If various projects to change the waste management are successful, the reduction of such emissions could be significantly high.

An econometric model that relates per capita GDP and CH_4 emissions does not offer satisfactory results in statistical terms (serious autocorrelation problems appear), although it seems clear that no mechanism has acted in the sense of "de-linking" economic growth and this type of pollution. Economic growth is associated in this case with more emissions.

4.5. Nitrous oxide (N_2O)

Nitrous oxide is another important greenhouse gas. International conventions on global warming have led to the collection of data and the study of their evolution. As occurs with other greenhouse gases, the characteristics of the problem make it particularly unlikely that the empirical relationship postulated by the EKC hypothesis can be found.

Figure 1 shows that anthropocentric N_2O emissions in Spain stayed more or less constant from 1980 until the start of the nineties. Then, there was a slight decrease caused by the reduction in emissions generated by agricultural activities and by industrial processes. According to Cristóbal López (1999, p.82), the industrial decrease was due to the evolution of nitric production, which decreased at the start of the nineties. However, from 1994 on the recovery of this sector caused emissions to increase. As a result, the 1995 level of emissions is not substantially different from 1980.

Table 9 shows the sector distribution of anthropocentric nitrous oxide emissions. These are mainly caused by use of agricultural fertilizers. The emissions of the agrarian and cattle-raising sector account for more than 80% of the total. Although there has not been an excessive increase in the level of emissions originating in this sector, we cannot talk about a decrease at all. The relationship of emissions with a specific sector that currently, in terms of monetary value, represents a very small part of total GDP makes it impossible to identify any clear relationship between the evolution of emissions and overall GDP.

4.6. Non-methane volatile organic compounds (NMVOC)

The NMVOC are some of the precursory compounds of tropospheric ozone (O_3). As Figure 1 shows, emission levels stayed more or less constant up to 1991, then for the next four years there was a slight decrease, and there was a renewed increase in 1994. Since then, they have dropped. Overall, we cannot observe any clear trend, since in 1996 emissions were similar to their 1980 level.

The main emitting sectors are agriculture and cattle raising, road transport and organic solvents (Table 10). There is a tendency towards change in the relative weights: agriculture and the cattle-raising sector lose weight (though it is still the major sector) and the weight of the other sectors increases. Road transport is overtaken by solvents, which becomes the second biggest (although we should not forget that one of the main consumers of these solvents is the automobile industry).

5. Conclusions

Recent data on trends of six atmospheric pollutants in Spain lead to the rejection of the most optimistic vision, whereby increase in income leads to a decrease in emissions. In fact, economic growth has only been accompanied by a decrease in emissions in one of the pollutants analyzed (SO_2). Even in this case it seems clear that the environmental policies coordinated between rich countries have played a very relevant role and that these policies have affected all these countries, regardless of their particular income levels. In this specific case, it could be argued that income level is a factor in the adoption of such policies, but it is difficult to view policies as an unavoidable effect of income levels. Moreover, some social protests against pollution have also been important: these protests were not made by sectors of the population with the highest per capita income but by those most affected by the problem, or most aware of its effects.

With the previous exception, the emissions of other pollutants have increased or, at least, have not diminished. This is so not only for those pollutants mainly related to global ecological problems, but for those whose effects have a mainly local impact.

However, the previous analysis also allows us to argue that economic growth, although it can be considered problematic, does not necessarily have to be accompanied by more emissions. The relationship between income level and diverse types of emissions depends on many factors. In some cases, emissions could be considerably reduced by specific measures (for example, replacing organic solvents with another type of substance). In other cases, there is a bigger challenge because the reduction implies relevant changes in the present transport pattern, in the sources of energy supply or in waste management policies. To confront all these questions, environmental policy measures are required. It is certainly not credible at all that economic growth by itself will solve them, because evidence shows it is more likely to worsen them.

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Appendix A

Statistics of the integration tests (Dickey-Fuller tests) for each of the series.

Variable	Series statistic in levels	Series statistic in differences
CO_2/P	-2.26	- 15.18 ***
GDP/P	0.56	- 1.87 *
$(GDP/P)^2$	0.23	- 1.50
$(GDP/P)^3$	0.53	- 1.31
ln (CO_2/P)	- 1.51	- 4.62 ***
ln (GDP/P)	-0.31	- 2.08 **
ln Nuclear	- 0.71	- 4.05 ***
ln Coal	- 1.16	- 4.42 ***
ln (SO_2/P)	-0.12	- 3.25 ***
ln (Thermal/P)	-2.13	- 3.16 ***
ln (NOx/P)	-0.94	- 3.46 ***
ln (Transport/P)	-0.15	- 2.06 **

* Reject the null hypothesis of Unit Root at 10 %.

** Reject the null hypothesis of Unit Root at 5 %.

*** Reject the null hypothesis of Unit Root at 1 %.

Appendix B

Seemingly unrelated regression results.

$$\ln(CO_2/P)_t = \beta_0 + \beta_1 \ln(GDP/P)_t + \beta_2 \ln Nuclear_t + \beta_3 \ln Coal_t + \varepsilon_t$$

Variable		Coefficient	t-statistic
constant	(β_0)	-13.70	-20.24
$\ln(GDP/P)_t$	(β_1)	1.24	12.68
$\ln(Nuclear)_t$	(β_2)	-0.13	-6.93
$\ln(Coal)_t$	(β_3)	0.19	4.99

R^2: 0.9224
Adjusted R^2: 0.9107
Durbin-Watson: 2.2717

$$\ln(SO_2/P)_t = \beta_4 + \beta_5 \ln(GDP/P)_t + \beta_6 \ln(Thermal/P)_t + \varepsilon_t$$

Constant	(β_4)	11.88	24.66
$\ln(GDP/P)_t$	(β_5)	-1.19	-17.49
$\ln(Thermal/P)_t$	(β_6)	0.61	9.02

R^2: 0.9726
Adjusted R^2: 0.9687
Durbin-Watson: 1.7140

$$\ln(NO_X/P)_t = \beta_7 + \beta_8 \ln(Thermal/P)_t + \beta_9 \ln(Transport/P)_t + \varepsilon_t$$

Constant	(β_7)	3.59	178.66
$\ln(Thermal/P)_t$	(β_8)	0.20	5.81
$\ln(Transport/P)_t$	(β_9)	0.50	23.27

R^2: 0.9690
Adjusted R^2: 0.9645
Durbin-Watson: 1.6872

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FIGURES AND TABLES

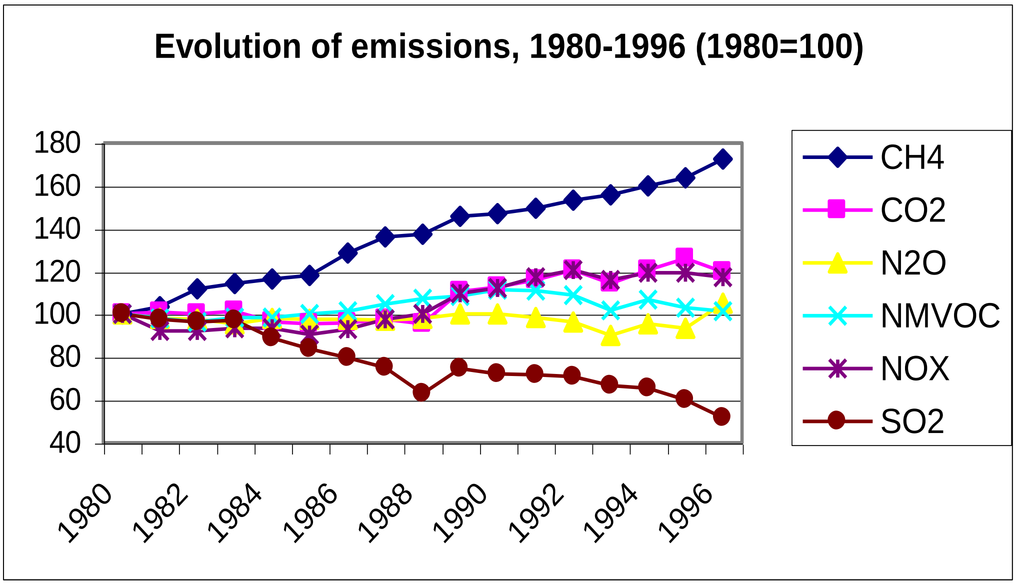

Figure 1.- Evolution of emissions, 1980-1996.

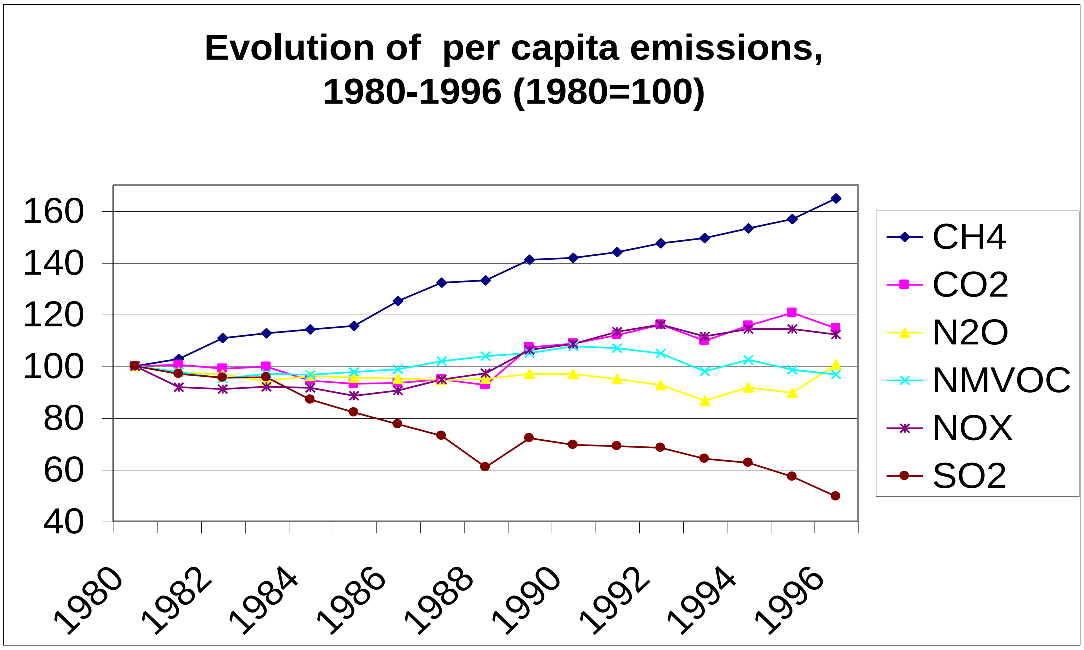

Figure 2.- Evolution of per capita emissions, 1980-1996

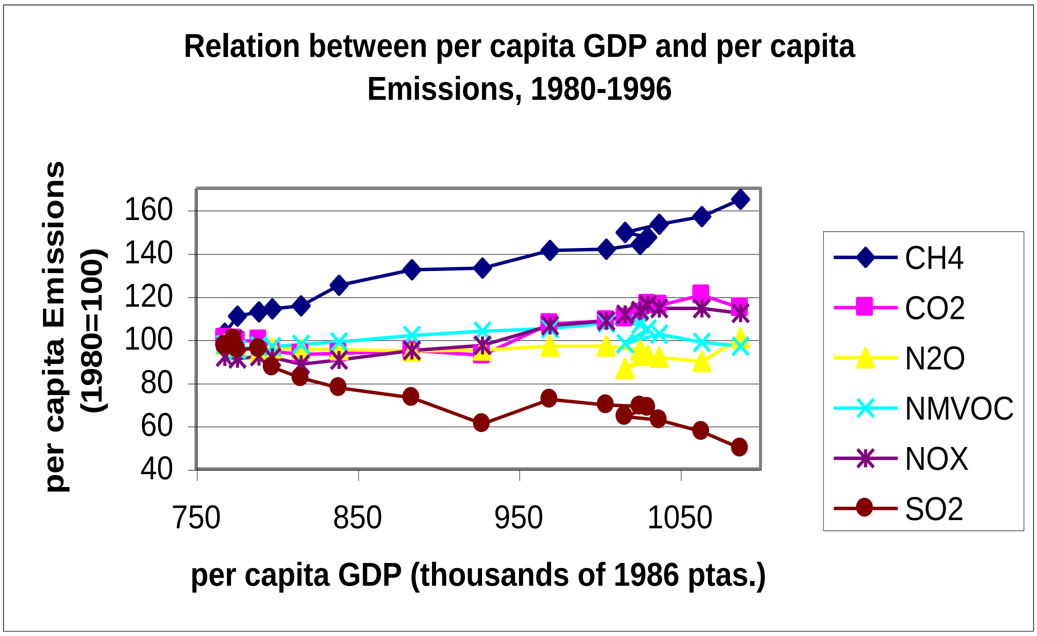

Figure 3.- Relation between per capita GDP and per capita Emissions

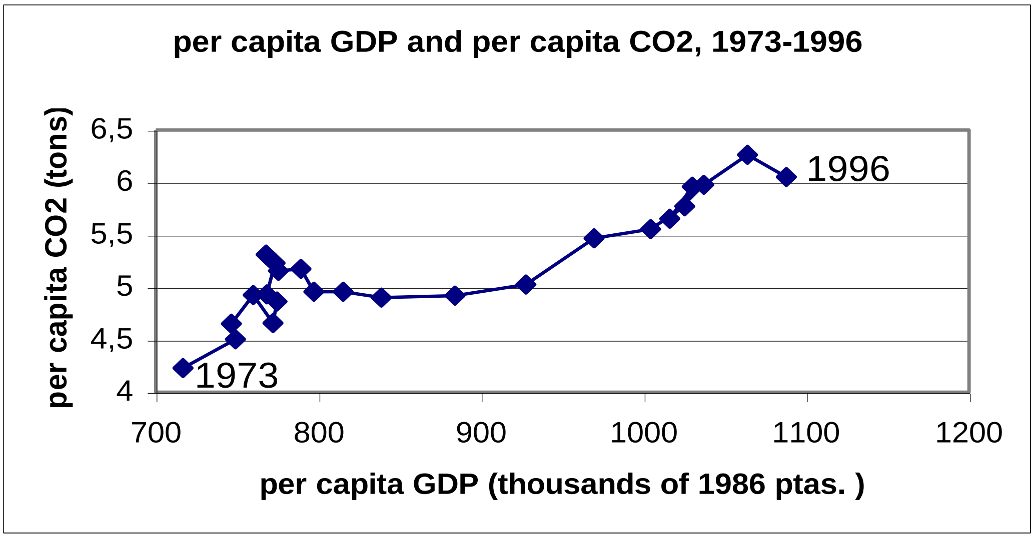

Figure 4.- GDP and CO_2 per capita emissions in Spain, 1973-1996.

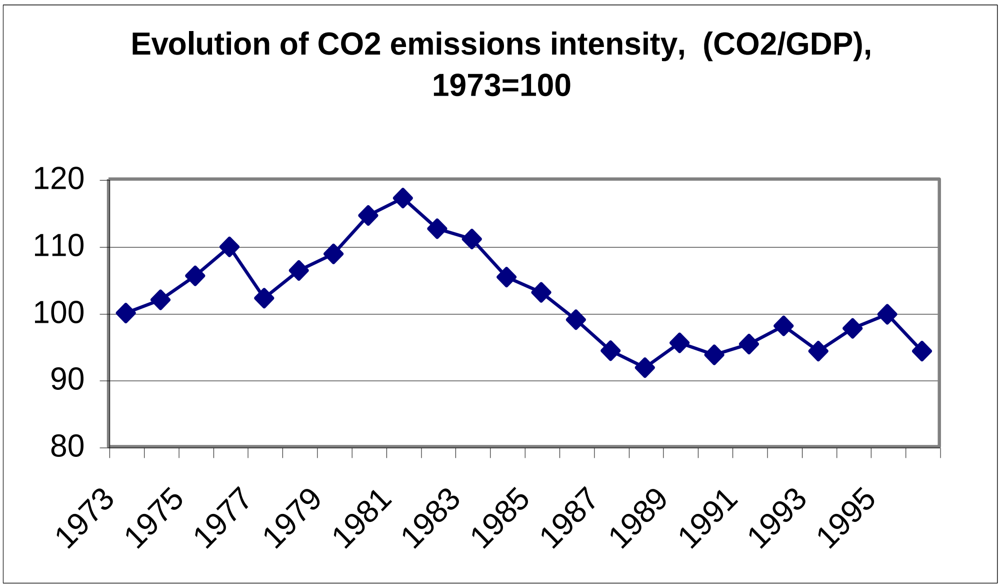

Figure 5.- Evolution of CO_2 emissions intensity, 1973-1996.

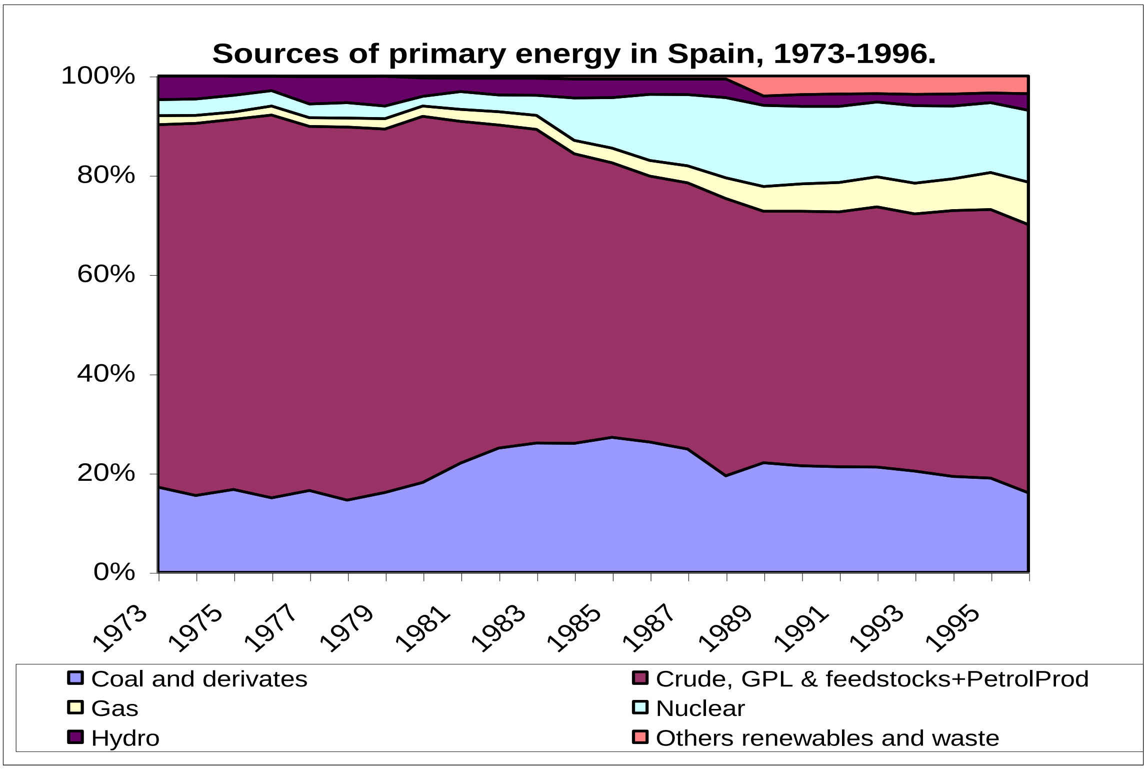

Figure 6.- Sources of primary energy in Spain, 1973-1996.

Table 1.- Estimation results. Dependent variable is ln $(CO_2/P)_t$ (1973-1996)

Variable		Coefficient	t-statistic
Constant	(β_0)	-13.70	-18.31
$\ln(GDP/P)_t$	(β_1)	1.24	11.48
$\ln(Nuclear)_t$	(β_2)	-0.13	-6.26
$\ln(Coal)_t$	(β_3)	0.19	4.54

R^2: 0.9224
Adjusted R^2: 0.9107
Durbin-Watson: 2.2725

Table 2.- SO_2 emissions in Spain, 1980-1996

	1980		1996	
	Tons	% of total	Tons	% of total
Electricity generation	2336147	78.75	1067901	69.37
Industrial combustion	375817	12.67	245582	15.95
Others	254730	8.57	225837	14.67
Total	*2966694*	*100.00*	*1539320*	*100.00*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 3.- Spatial concentrations of SO_2 emissions in 1996
(% of total)

	1996
Coruña	26.4%
Teruel	18.4%
León	7.2%
Asturias	6.4%
4 provinces subtotal	*58.4%*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 4.- Estimation results. Dependent variable is ln $(SO_2/P)_t$ (1980-1996)

Variable	Coefficient	t-statistic
Constant (β_0)	11.88	22.03
$\ln(GDP/P)_t$ (β_1)	-1.20	-15.67
$\ln(Thermal/P)_t$ (β_2)	0.60	8.02

R^2: 0.9726
Adjusted R^2: 0.9687
Durbin-Watson: 1.6930

Table 5.- NO_X emissions in Spain, 1980-1996

	1980		1996	
	Tons	% of total	Tons	% of total
Road transport	372469	34.14	575151	44.90
Other means of transport	258664	23.71	233081	18.20
Electricity generation	262307	24.04	265934	20.76
Others	197615	18.11	206697	16.14
Total	*1091061*	*100.00*	*1280862*	*100.00*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 6.- Spatial concentrations of NO_X emissions in 1996
(% of total)

	1996
Barcelona	7.0%
Madrid	6.4%
Asturias	6.3%
León	5.6%
Coruña	4.4%
5 provinces subtotal	*29.7%*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 7.- Estimation results. Dependent variable is ln $(NOx/P)_t$ (1980-1996)

Variable	Coefficient	t-statistic
Constant (β_0)	3.59	161.44
ln $(Thermal/P)_t$ (β_1)	0.20	5.20
ln $(Transport/P)_t$ (β_2)	0.49	20.71

R^2: 0.9690
Adjusted R^2: 0.9645
Durbin-Watson: 1.6832

Table 8.- CH_4 emissions in Spain, 1980-1996.

	1980 Tons	1980 % of total	1996 Tons	1996 % of total
Agriculture and cattle raising	754636	64.56	999471	51.62
Waste management	222764	19.06	711060	36.72
Others	191521	16.38	225755	11.66
Total	*1168920*	*100.00*	*1936286*	*100.00*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 9.- N_2O emissions in Spain, 1980-1996.

	1980		1996	
	Tons	% of total	Tons	% of total
Agriculture and cattle raising	106820	82.35	110624	80.99
Others	22899	17.65	25961	19.01
Total	*129719*	*100.00*	*136585*	*100.00*

Source: Own elaboration from Spanish Ministry for the Environment data.

Table 10.- NMVOC emissions in Spain, 1980-1996.

	1980		1996	
	Tons	% of total	Tons	% of total
Agriculture and cattle raising	812545	48.52	615480	35.00
Use of solvents	291429	17.40	401043	22.80
Road transport	324911	19.40	394144	22.41
Others	245700	14.67	347951	19.79
Total	*1674585*	*100.00*	*1758618*	*100.00*

Source: Own elaboration from Spanish Ministry for the Environment data.