Regional decomposition of CO_2 emissions in the world: a cluster analysis.

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Abstract:

The purpose of this paper is to study the possible differences among countries as CO_2 emitters and to examine the underlying causes of these differences. The starting point of the analysis is the Kaya identity, which allows us to break down per capita emissions in four components: an index of carbon intensity, transformation efficiency, energy intensity and social wealth. Through a cluster analysis we have identified five groups of countries with different behavior according to these four factors. One significant finding is that these groups are stable for the period analyzed. This suggests that a study based on these components can characterize quite accurately the polluting behavior of individual countries, that is to say, the classification found in the analysis could be used in other studies which look to study the behavior of countries in terms of CO2 emissions in homogeneous groups. In this sense, it supposes an advance over the traditional regional or rich-poor countries classifications .

Keywords: Cluster analysis, CO_2 emissions, geographical emissions, greenhouse effect

1. Introduction

There is now a high level of general awareness of the fact that carbon dioxide (CO_2) is the most significant of the so-called greenhouse gases generated by human activity. Emissions of this gas, which are the result of the burning of fossil fuels, nearly quadrupled in the period from 1950 until the mid-nineties. There is a broad consensus among scientists that the capacity of the natural cycles of the biosphere to absorb CO_2 has been exceeded as a result of anthropogenic emissions. If this trend continues, estimates made by the Intergovernmental Panel on Climate Change (IPCC) predict that current concentrations levels will have doubled by the end of this century. This would imply an average increase of between 1º C and 3.5º C in the temperature of the planet (Flavin & Dunn, 1998).

The objective of the 1992 framework convention on climate change was, "in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere, at a level that would prevent dangerous anthropogenic interference with the climatic system". In 1997, the Kyoto Protocol established that the countries specified in its Annex B, as a whole, would reduce their 1990 CO_2 emissions by 5.2% in the 2008-2012 period. This goal was not overly ambitious given the magnitude of the problem; nevertheless, the numerous differences that exist between the Annex B countries may well make this objective difficult to achieve.

The scope of the problem has led to a flood of publications over the last several years. Some address the problem of climate change in general, and others are particularly concerned with its relationship with economic activity. A range of methodologies is applied to the study of this relationship, and many publications demonstrate a close link between CO_2 emissions and a country's economic growth.

Among the papers studying this association are those published by Tucker (1995), Faber (1991), Selden & Song (1994), Holtz-Eaking & Selden (1995) and Duarte & Feijoo (1998).

Reducing emissions while at the same time maintaining a society's standard of living, however, requires a delicate balance between policies that in many cases have contradictory effects. In the process of designing relevant environmental policies, it is difficult to ignore the short-term trade-offs involving economic growth and energy consumption, tied to CO_2 emissions resulting from the burning of fossil fuels. These trade-offs are reflected in the approaches which focus on the sharing-out of "environmental space" (Alcántara & Roca, 1999), and in those which address the criteria that should underlie the rules for the assignment of emission quotas[1].

The dynamic analysis of relationships between economic activity and CO_2 emissions involves at least three different elements: the dynamic of the processes involved, the trade-offs to be considered, and the judgments that are made about such trade-offs (Goldemberg, Squitieri, Stiglitz, Amano, Shaoxiong & Saha, 1996). In effect, implementation of environmental policies aimed at reducing CO_2 emissions must involve changes in the economic structure that they will directly or indirectly affect. These changes will have an impact on the nature of development in a society and on the way in which that development is achieved. Accordingly, the trade-offs between environmental policy and development, and the ethical judgments made concerning policies and results clearly assume a particular relevance. There is a broad consensus with regard to the relationship between economic growth and CO_2 emissions; and it is

[1] Coppel, J. & Hiro, L. (1995), in an OCDE project, propose six rules for assignment of quotas, some of which would lead to significant changes in the current emission percentages for different countries and regions.

generally recognized that the problem is global in scale and that all countries must therefore contribute to improving the situation. Nevertheless, there are other reasonable considerations to be taken into account: not all countries have the same level of production; their processes of production are different; and it is not possible to establish shared measures of environmental improvement.

The means of achieving a particular level of emissions are not the same for all countries or regions. In order to meet emission reduction targets, key variables related to the production of greenhouse gases must be identified for each country or group of countries. This stage of analysis must occur before the existing situation can be understood, and it provides a basis for the design of the most appropriate policies. This paper will focus on identifying such key variables. Taking the Kaya identity (1989) as a starting point, it is proposed that CO_2 emissions be decomposed into distinct components related to the technical characteristics of processes of production (carbon intensity, transformation factor, energy intensity) and/or the wealth of a particular country.

Within this framework, this paper seeks to examine the polluting behavior of different countries by using the decomposition of per capita CO_2 emissions derived from the Kaya identity. The Kaya identity is one of many formulations of an I = P A T model, in which I = impact, P = population, A = affluence, and T = technology. IPAT models have frequently been used to analyze the environmental impact of economic activity (Herendeen, 1998; 28-40)[2].

[2] It should be recognized that there are relevant aspects of the problem that are not taken into account by models of this type (Meadows, D., 1995; cited in Herendeen, R.A., 1998). While these clearly merit re-examination in future papers, IPAT models remain a very useful tool for identifying general principles of behavior.

Our objectives are to provide a response to the question of what the main determinants of CO_2 emissions are for each country, and, if possible, to identify groups of countries whose behavior is similar and differs significantly from that of other groups of countries. Moreover, although our analysis does not concentrate on the temporal perspective (we do not develop a time series analysis), we will also attempt to determine whether or not the groups obtained are stable over time. To that end, we do the same cross- section analysis for four selected years, namely 1980, 1985, 1990 and 1995 trying to find out if our classification is representative of the behavior of the countries in the last decades of the twentieth century.

Finding groups of countries for which some identifying factor is clearly evident will allow for a greater degree of specification of the environmental problem, and may also help guide the development of environmental policies that are more geographically focused. A final step in this analysis will be to show the relative contribution of each of these groups to global emissions. Cross analysis of groups and contributions to CO_2 emissions will also provide a basis for setting objectives and policy priorities.

Data are analyzed for the years 1980, 1985, 1990 and 1995, and 103 countries throughout the world are included. To obtain data related to the variables analyzed (CO_2, total energy, final energy, population and GDP), we have drawn on all of the global information available in the databases of the World Resources Institute (1998) and the World Bank (1999). 191 countries report such information to these two institutions; this analysis, however, does not include those countries for which complete data is not available for the years covered in the study.

In this manner, the sample of 103 countries located throughout the five continents was selected (see Annex 1). This sample is highly significant for the purposes of this study: in the years 1980, 1985, 1990 and 1995, the countries included account, respectively, for 97.4, 97.4, 97.6 and 98.4% of global CO_2 emissions.

Section 2 of this paper outlines the most significant aspects of the theoretical model used and the empirical analysis carried out. The initial variables included and their units of measure are also specified. In section 3, the main results of the cluster analysis are discussed: the manner in which groups were obtained, their behavior over time, and the changes in their relative contributions to total CO_2 emissions. Section 4 presents the conclusions of the study.

2. Methodology

The forces that affect the evolution of CO_2 emissions can be synthesized in the following expression (Kaya, 1989):

$$CO_2 = (CO_2/E) \times (E/Y) \times (Y/N) \times N \qquad (1)$$

in which CO_2 is the gross volume of emissions of this gas resulting from primary energy consumption; E is physical consumption in tons oil equivalent (TOE), terajoules (TJ) or another energy equivalent; Y is GDP measured in PPP; and N is population.

The first factor on the right of the expression (1) measures the carbon intensity of the economy[3], the second the energy intensity and the third affluence in terms of goods and services available in the society. In this formulation, N is a scaling factor. Other interesting applications of the model are, for example, Gürer and Ban (1997), Ogawa (1991), Nakicenovic et al. (1993) or Hoffert et al. (1998).

[3] There is no single criterion for measuring carbon intensity, particularly when the indicator is used as the best explicative factor for emissions (Roca, J. & Alcántara, V., 2001). In fact, it measures the CO2 emission intensity per unit of primary energy.

The first two factors on the right of equation (1) correspond to T in the IPAT model. From the perspective of this paper, this formulation is limited: the relation *E/Y*, a measure of the energy intensity of the economy, conceals at least two significant elements which, from an analytic perspective, are worth highlighting. Primary energy (E) is equivalent to the final energy used by economic agents plus losses in generation and distribution of final energy. The energy needs of a society depend, therefore, on both the transformation factor and the efficiency in the final use of energy. We cannot say efficiency in both cases because the concepts captured by each factor are very different. As Hamilton & Turton (2002) stated, the transformation factor is a "conversion-efficiency effect that represents the amount of primary energy required to deliver energy for final consumption and reflects both conversion efficiency and the fuel mix. The share of electricity in the final consumption is the main influence". Thus, the transformation factor will not reflect, in the majority of the cases, a real efficiency but rather an indicator of the type of energy system which dominates in the country.

Both components can be made explicit by reformulating (1) as follows:

$$CO_2 = (CO_2/E) \times (E/F) \times (F/Y) \times (Y/N) \times N \qquad (2)$$

And therefore,

$$CO_2/N = (CO_2/E) \times (E/F) \times (F/Y) \times (Y/N) \qquad (3)$$

in which *F* is the final energy consumed by the society being studied. Expression (3) indicates that per capita CO_2 emissions, which will be referred to as C, depend on at least four factors: the impact per unit of total energy consumed, the first factor on the right of the equation, which will be referred to as K; transformation factor, the second variable, which will be referred to as S; final energy intensity (energy efficiency of technology), the third factor, referred to as I; and the wealth of the society, W.

Accordingly, the expression can be written as

$$C = K \times S \times I \times W \qquad (4)$$

Expression (4), the starting point for this study, takes into account all of the factors that, in principle, are of interest[4].

On this basis, two analyses have been carried out: a factor analysis of main components and a cluster analysis. In the first analysis, we have attempted to determine whether the four magnitudes on the right of expression 3 and 4 are interrelated (and, if so, to what extent), or whether they are independent factors that explain distinct concepts (as in fact turned out to be the case). In the second analysis, we attempt to classify the different societies considered (countries) in homogenous groups, according to which factor had the greatest influence on per capita CO_2 emissions.

The principal components analysis, the most widely used factor analysis method, attempts to identify the underlying dimensions or factors that explain the correlations among a set of observed variables. Each variable is expressed as a linear combination of factors. In general, for the standard variable *Xi,* the model can be written as:

$$X_i = A_{i1} F_1 + A_{i2} F_2 + \ldots + A_{ik} F_k + U_i \qquad (5)$$

where *F* are the so-called common factors: all of the variables are expressed in function of them. *U* is the unique factor – the part of the variable that cannot be explained by the set of common factors; and *A* are the constants used to combine the *k* factors.

[4] A similar expression, though based on only three components, is used by Proops, Faber & Wagenhals (1993) to decompose changes in CO2 emissions in Germany and the United Kingdom. The methodology used in this study and its objectives are, however, completely distinct.

The first step in the process of identifying common factors is to seek the factor that can explain the greatest variance possible for all of the original variables (the one that captures the most information in terms of the model). A second factor is then sought to capture as much information as possible concerning what remains to be explained and is not correlated with the previous factor. This procedure is followed until a number of factors equivalent to the number of original variables have been identified[5]:

$$X_1 = A_{11} F_1 + A_{12} F_2 + \ldots + A_{1n} F_n$$

$$X_2 = A_{21} F_1 + A_{22} F_2 + \ldots + A_{2n} F_n$$

$$\ldots$$

$$X_n = A_{n1} F_1 + A_{n2} F_2 + \ldots + A_{nn} F_n$$

All of the information in the model is now captured by a series of new variables – the factors. These are not intercorrelated, and the first ones should capture more information than the last ones.

If the original variables are strongly intercorrelated, the first factors will be capable of explaining much of the variability for all of the variables, leaving little information for the last factors. In this case, the dimension of the analysis can be reduced by eliminating the last factors without excessive loss of information. The retained factors, which explain the set of variables, are called common factors; and the part of each variable that remains unexplained is represented by the "unique" factor, as expressed in (5).

5 In mathematical terms, this is achieved by diagonalising the matrix of correlations in the following manner: [R] = [VP] * [I] [VP]' where R is the matrix of correlations; I is the matrix identity, * is the vector of values that indicates the information captured in each factor; and VP is the matrix of vectors associated with these values.

However, if there is no redundant information between the original variables, a number of factors equivalent to the original number of variables will be necessary in order to explain the model. In this case, each of the original variables is independent of the others; in other words, each original variable is a distinct concept that can provide distinct information. In order to test the independence of the factors in all the years studied, a Bartlett test of sphericity has been carried out. This test is used to examine the hypothesis that the variables are uncorrelated in the population. In other words, the population correlation matrix is an identity matrix; each variable correlates perfectly with itself but has no correlation with the other variables. The test statistics for sphericity is based on a chi-square transformation of the determinant of the correlation matrix. A large value of the test statistic will favor the rejection of the null hypothesis. If this hypothesis cannot be rejected, then the appropriateness of factor analysis should be questioned.

In general, factor analysis is used to find common factors that make it possible to reduce the dimension of the model. In this paper, we use this type of analysis to attempt to demonstrate that the four magnitudes into which per capita CO_2 emission has been divided (the right-hand side of expressions (3) and (4)) represent distinct concepts, are uncorrelated variables, and can be incorporated in a cluster analysis without concern for problems of interrelationships.

The second technique applied in this paper is cluster analysis. The primary objective of this analysis is to classify objects into relatively homogenous groups, called clusters, based on the set of variables considered. Objects in a cluster are relatively similar in terms of these variables and different from objects in other clusters. Cluster analysis is also called classification analysis, or numerical taxonomy. There are various distinct classification algorithms, which differ in the approach taken to grouping observations, the manner in which the distance between groups is calculated, or the criteria used to classify observations in a particular group.

We have used the method of mutual exclusion known as K-means. This method attempts to classify each observation in one of the specific k-groups – that in which it is most similar according to its variance[6]. One advantage of this method is that it makes it possible to deal with a large number of cases. It is necessary, however, to determine in advance the number of groups desired. Another of the main criticisms made of this method is that different results can be generated simply by varying the initial algorithm (modifying the order of the observations or of the variables).

Finally, care must be taken with the units of measure of the different descriptive variables: those which have a greater variance will participate in a more active manner in the classification of observations. These potential shortcomings can be avoided by standardizing the descriptive variables and the specifying in advance the initial cluster centers.

As we have indicated, this method requires that the number of groups to be worked with be determined. A trial-and-error approach can be taken, or the results of previous studies can provide a basis for this determination. In this case, given that there have been no previous studies with the same characteristics; a relatively large number of groups (10-12) were specified for the first analysis. The results obtained indicated

[6] The K-means algorithm is an iterative method which, from an initial position, assigns observations to different groups in such a way as to minimize the residual variance (distance between the observations and the center of the group). The classification arrived at in this manner provides the basis for calculating new group centers and the observations are then reclassified. This process is repeated until the transfer of observations between groups no longer reduces the residual variance, or until a set criterion for stopping is satisfied (similarity between centers obtained in two successive steps; achieved reduction of variance; or maximum number of iterations).

that there were a number of groups for which the effect of each of the descriptive variables was more intensive; for the other groups the remaining variables were around the mean level. By following this procedure, it was possible to determine the ideal number of groups to work with – four groups in which the effect of each of the four available variables (K, S, I and W) was intensified, and a fifth group to capture the rest of the observations. The technique also makes it possible to identify the expected initial centers for each of these groups (in the variables with an intensified effect, a value of two deviations over the mean was proposed, and for the other variables a value of zero, in relation to the mean).

After observations have been classified in groups, comparative statistical techniques can be applied. These will indicate the differences that exist between the groups, and their characteristics in relation with other variables. More concretely, we have specified a Scheffé multiple comparison test. The Scheffé method tries to assign the cases to a group or to another one comparing the means. This procedure is conservative for comparisons of means because it requires larger differences between the means of the groups than other usual procedures.

As has been mentioned above, the data used in the analysis were obtained from the databases of the World Resources Institute (1998) and the World Bank (1999). The initial variables used were total commercial energy consumption in petajoules (E), total final energy consumption in metric tons of oil equivalent (F), total population in thousands of inhabitants (N), and gross domestic product in millions of US dollars at 1990 constant prices and PPP (Y). The indicators C, K, S, I and W, derived from the Kaya identity in the manner previously indicated, are based on these variables.

3. Empirical analysis

The factor analysis reveals that the four variables in the analysis (K, S, I and W) are uncorrelated enough for each to be considered a different concept. Annex 2 shows the correlation matrix and the Bartlett test of sphericity for the four periods studied. The results show that in 1980 we cannot reject the hypothesis of independence of the variables at 90% of confidence and in 1985 at 99% of confidence. The results also reveal a tendency in the nineties to a stronger, but still small, relationship between wealth and carbon intensity and energy intensity, which could be justified by an increase in the energy participation and in the carbon participation in the economic development during this decade.

The cluster analysis carried out allowed us to identify five groups of countries. The distinguishing characteristic of the countries in the first group is their index of carbon intensity (K). The second group is distinguished by its level of energy transformation (S); the third by energy intensity (I); the fourth by the degree of wealth (W); and the fifth group includes those countries that were not distinguished by any particular component. Table 1 shows the groups obtained for the years 1980-1995, and indicates the final cluster centers measured in standard units. Table 2 shows the evolution of the original variables for each group of countries, which permits a better understanding of the mean values each group takes. Moreover, in Annex 3 we include the results of the Scheffé test. As we can see, in all the cases, the variable selected to form the groups is dominant in the explanation of the behaviour of the group. That is to say, the difference of a selected group with respect to the rest of the countries in terms of this variable is higher than the other common factors that this group has with other countries. In this sense, the procedure reveals the adequacy of the selected factors in forming the groups and explaining the differences between them.

(Table 1 about here)

The results obtained suggest that there are three areas that merit consideration: the general characteristics of the clusters obtained; the countries that make up the groups, and the extent to which these groupings are consistent over time; and, finally, the changes observed in the groups over the four periods studied (i.e., the changes of their final centers).

The first significant point to be noted is that there are interesting groupings of countries that are each distinguished by one of the four components.

The first group encompasses those countries which stand out as a result of their high index of carbon intensity. For the years 1980, 1985, 1990 and 1995, this variable differs from the mean by 3.129, 3.147, 4.537 and 5.345 standard deviations respectively. In other words, this group is characterized by very high levels of emissions per unit of energy in comparison with the rest of the world. For this group, the rest of the variables are near zero, which indicates behaviors relatively similar to the mean behaviors of other countries. Additional characteristics that these countries have in common are a relatively high level of energy transformation efficiency (total energy per unit of final energy is relatively low), and a low level of energy intensity (final energy per unit of output). In 1980, these countries were relatively wealthy, and, over the period studied, the group gradually moved toward positions of less relative wealth.

Group 2 encompasses those countries that are distinguished by a high ratio of total energy per unit of final energy. This ratio depends on the characteristics of the energy system and especially on the proportion of electricity and the way of obtaining this electricity[7]. For group 2, the rest of the factors are generally situated near the mean

[7] This indicator might lead to a misunderstanding because it does not distinguish between fossil energy and other types of energy; especially in countries with an important share of nuclear energy. This should be taken into account in a more detailed analysis of the groups here established.

levels, though the level of carbon intensity is somewhat higher than the mean, while energy intensity and per capita income are lower.

Group 3 includes those countries that use the most energy per unit of GDP. The mean values of the standardized variable for this group were 3.075 in 1980, 2.755 in 1985, 2.755 in 1990 and 2.286 in 1995. In other words, countries in this group have a level of energy intensity at least two deviations higher than the global average. While this is the main distinguishing characteristic, group 3 is also characterized by a certain inefficiency in the transformation of energy (component S somewhat higher than the other groups), and by the fact that the countries included are relatively poor.

The countries in group 4 are distinguished by high per capita income. In all cases, this variable is situated more than 1.5 deviations above the mean. These can, therefore, be classified as wealthy countries. As for the other components, these are countries with relatively low levels of energy intensity, low levels of carbon intensity and a relatively good capacity for energy transformation. The contribution of countries in this group to global CO_2 emissions is determined primarily by their high level of economic activity.

The last group encompasses countries that are not distinguished by any of the components. These countries are characterized by values near the mean in all of the factors.

Having defined the emission patterns of these broad groups, the next question to address is that of what countries make up each group, and to what extent the groupings are maintained over time.

The results presented in Table 1 indicate that the five groups identified are stable over time: the blocks are made up of stable groupings of countries to which others with similar behavior may be added in one year or another as a result of circumstances arising at a particular point in time.

In group 1, for instance, it can be observed that in every period Angola and Nigeria are distinguished by their high index of carbon intensity. Gabon is also a member of this group until the last period, when a low level of transformation efficiency becomes its key distinguishing characteristic. Similarly, from 1990 on, Iraq ceases to belong to this group, and, in 1995, its main distinguishing characteristic becomes a high level of energy use per unit of production.

As for group 2, which is distinguished by a low level of efficiency in transformation, there are countries that are to be found in the group in almost all of the periods: Algeria, Côte d'Ivoire, Nicaragua, Oman, Singapore, South Africa and Venezuela. Kuwait becomes part of this group in 1990, and Korea in 1995.

The countries found in group 3 are those with an elevated level of energy intensity. In 1980, these are Albania, Bulgaria, China, Korea Dem, Poland, Romania and Vietnam. These countries continue in the same group in 1985, with the addition of Lebanon. In 1990, Lebanon becomes part of group 1, but is to be found in group 3 once again in 1995: in general, it is part of the stable block. Membership in the group remains stable in 1995 with two exceptions: high energy intensity ceases to be a distinguishing characteristic for Albania, and Iraq becomes part of the group.

Group 4, made up of countries for which a high level of per capita production is the main factor behind their contribution to CO_2 emissions, is also a relatively stable group: the USA and most of the countries in the European Union are part of this group in all of the periods. Fixed members of the group are Australia, Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Japan, Luxembourg, Netherlands, Norway, Sweden, Switzerland, the United Kingdom, the USA, Canada and New

Zealand. Spain enters this group in 1990, and Hong Kong and Ireland in 1995; Kuwait ceases to be a member in 1990.

(Table 2 about here)

As for the evolution of centers over time, measured in the original variables, it can be observed that there is growth in the center of group 1. In successive periods, this group is, moreover, made up of fewer and fewer countries. Over time, then, countries for which the distinguishing characteristic is an elevated level of carbon intensity tend to be fewer, but those remaining are further and further from the mean: their emissions are progressively more closely related to this component.

Countries that belong to group 2, improve their ratio over the 1980s; this trend continues into the early 90s, but changes in 1995, when the center is once again more elevated than in previous periods.

The countries with an elevated level of energy intensity, group 3, reduce this level somewhat over the period: the center of the group goes from 1.532 in 1980 to 0.887 in 1995, suggesting an improvement in the use of energy in the least efficient countries in the world. Over the period of the study, the richest countries show little variation in number or in per capita income (the center is 18.088 in 1980 and 22.880 in 1995).

Given these observations, the first conclusion we can highlight is the existence of stable blocks of countries over the period of the study. Each group is characterized by the fact that its CO_2 emissions are, to a significant extent, linked to a particular explicative component. This link is also what differentiates each group from the others. There are, therefore, distinct types of contributions to CO_2 emissions, identified for specific groups of countries. This implies a need for distinct policies and actions for the various groups.

As we have seen (and as has been frequently observed), there is a group of countries for which CO_2 emissions can be attributed to the rate of economic growth. For these countries, which we include in group 4, there is a clear relationship between economic growth (in monetary units) and CO_2 emissions.

For other countries, however, emissions are attributable not so much to the rate of growth as to the level of efficiency, in energy and environmental terms, with which that growth is being achieved. Group 1 countries, for instance, base their growth on energy sources with a high carbon content; those in group 2 are characterised by a low level of efficiency in energy transformation, i.e., they require large amounts of energy to obtain a unit of final energy. For these groups, attention must clearly focus on the type of energy used and the way in which transformation is carried out.

We also have a group of countries that are not very productive in their use of energy – countries specialized in intensive production of energy. This development model and inefficiency in the use of energy resources are the main causes of CO_2 emissions.

Finally, group 5, made up of approximately sixty countries that do not stand out in any component, warrants specific attention that goes beyond the scope of this study. While this group's contribution to global emissions diminished during the 90s, per capita emissions increased throughout the period analysed, leading to an increase in participation to global emissions in 1995. Given the particular characteristics of this group, a specific analysis would be useful in order to attempt to identify trends that may have a bearing on the future.

Up to this point, we have identified several blocks of countries and attempted to define their most characteristic behaviors. The question that remains to be examined is the extent to which the factors and the groups identified are of value in explaining emissions from a global perspective. Table 3 indicates the contribution of each group to total emissions for the periods analyzed.

(Table 3 about here)

As can be observed, in all of the periods, the group of the richest countries is responsible for the largest proportion of global CO_2 emissions. In 1980, they generated 51% of emissions, and, though this proportion decreases slightly, in 1995, these countries still account for 45% of emissions. These results confirm once again the degree of responsibility of developed countries for global emissions.

Another noteworthy point is the difference between the evolution of group 3 and that of group 5. In 1980, the group that we have called "others" accounted for 30.23% of total emissions. This suggests that these emissions were the result of different factors that are not easily identified, and which are therefore difficult to monitor. In this period, group 3, the group of countries with the highest level of energy intensity, produced 13% of total emissions. In 1995, however, these percentages have virtually been reversed: the 60 countries making up the "others" group now account for 19% of total emissions, while the contribution of energy intensive countries has risen to 30% of global emissions. This suggests that there is a second block of countries strongly implicated in the greenhouse effect – those that do not use energy efficiently.

Finally, it is also interesting to observe the evolution of groups 1 and 2. These groups, though of limited significance at a global level, also evolved in different manners. In 1980, each group accounted for approximately 1.6% of total emissions. It can be observed that while the carbon intensity effect (K) diminishes until 1995 (reaching 0.54% in this year), the impact resulting from inefficiency in transformation processes nearly triples, reaching 4.3% of emissions in 1995. Clearly, the results indicate two different trends: on the one hand, it appears that over the period in question there have been advances in the search for energy sources that produce less CO_2; on the other hand, certain countries have, over the same period, opted for sources with lower energy quality, or for less efficient processes. This leads to greater consumption of energy in these countries and an associated rise in emissions of CO_2.

4. Conclusions

Our intent in this paper has been to study possible differences between countries as generators of CO_2 and to examine the underlying causes for these differences. Our starting point was the Kaya identity, which allowed us to decompose per capita emissions in four components: a certain index of carbon intensity, transformation factor, energy intensity and societal wealth. The analysis carried out has allowed us to show that there are stable groups of countries, and that for each of them it is possible to highlight one component that, in itself, comes close to determining CO_2 emissions: the four explicative factors were found to be independent and explain distinct concepts. This suggests that a study based on components can characterize quite accurately the polluting behavior of individual countries.

We have also been able to identify certain patterns in the behavior of the five groups. For instance, it can be extrapolated from the evolution of the actual centers of group 1, that the problem of high carbon intensity affects fewer and fewer countries, but is an increasingly serious problem for those it does affect. Countries distinguished by low transformation efficiency improve that ratio between 1980 and 1990; in 1995, however, this trend is reversed, and the efficiency ratio worsens once again. Throughout the study period, countries with high energy intensity move toward productive processes that are less intensive in energy terms. Finally, for all of the years analyzed, there is a stable group of countries for which income is the key explicative factor for

CO_2 emissions. On average, per capita income in these countries barely changes over the period in question.

As for the contribution of each of the groups to total emissions, in each of the years examined, practically half of total emissions can be attributed to the countries with highest per capita income. Nevertheless, throughout the period there is growth in the emissions generated by the most energy intensive countries and by those with a low level of transformation efficiency.

Clearly, this analysis reveals the need for distinct policies for the reduction of CO_2 emissions. The cluster analysis carried out has allowed us to identify for each country the key areas where a focused effort is likely to lead to the greatest progress in the reduction of emissions.

Further stages in this research will, of course, be necessary to more closely consider the reasons why a particular country's behavior is distinct from that of other groups, and to examine questions related to the significant variables for a country. This work should be regarded as an initial alternative approach to the analysis of global CO_2 emissions. We have, however, found evidence that the four factors highlighted in the analysis could constitute an appropriate basis for strategies designed to reduce emissions. Formulating the environmental problem in these terms and taking suitable action in response to such an analysis may well be an effective means of achieving the objective of reducing global CO_2 emissions.

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Table 1. Analysis of final clusters 1980-1995

Indicators		*K*	*S*	*I*	*W*	COUNTRIES
YEAR 1980	GROUP 1	**3.129**	-0.578	-0.469	0.193	Angola, Gabon, Iraq, Libya, Nigeria, Saudi Arabia, Singapore
	GROUP 2	0.088	**3.060**	-0.324	-0.323	Algeria, Cameroon, Oman, South Africa, Trinidad and Tobago
	GROUP 3	-0.143	0.127	**3.075**	-0.676	Albania, Bulgaria, China, Korea Dem., Poland, Romania, Vietnam
	GROUP 4	-0.477	-0.130	-0.334	**1.747**	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Iran, Italy, Japan, Kuwait, Luxembourg, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, USA.
	GROUP 5	-0.182	-0.151	-0.186	-0.513	Others
YEAR 1985	GROUP 1	**3.147**	-1.126	-0.474	-0.357	Angola, Cameroon, Gabon, Iraq, Nigeria
	GROUP 2	-0.165	**1.896**	-0.163	-0.324	Côte d'Ivoire, Dominican Rep., El Salvador, Malta, Nicaragua, Oman, Philippines, Saudi Arabia, Singapore, South Africa, Trinidad and Tobago, Venezuela
	GROUP 3	0.182	0.357	**2.755**	-0.646	Albania, Bulgaria, China, Korea Dem., Lebanon, Poland, Romania, Vietnam
	GROUP 4	-0.539	-0.077	-0.407	**1.765**	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Iran, Italy, Japan, Kuwait, Luxembourg, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, USA
	GROUP 5	-0.064	-0.327	-0.209	-0.469	Others
YEAR 1990	GROUP 1	**4.537**	0.857	-0.665	-0.479	Angola, Gabon, Nigeria
	GROUP 2	0.190	**1.625**	-0.125	-0.381	Algeria, Congo, Côte d'Ivoire, Dominican Rep., India, Indonesia, Kuwait, Lebanon, Libya, Nicaragua, Oman, Philippines, Singapore, South Africa, Venezuela
	GROUP 3	0.309	0.322	**2.360**	-0.553	Albania, Bulgaria, China, Jordan, Korea Dem., Poland, Romania, Trinidad and Tobago, URSS, Vietnam
	GROUP 4	-0.755	-0.267	-0.488	**1.822**	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, USA
	GROUP 5	-0.080	-0.459	-0.242	-0.440	Others.
YEAR 1995	GROUP 1	**5.345**	-0.588	-0.563	-0.700	Angola, Nigeria
	GROUP 2	0.133	**2.342**	0.065	-0.153	Algeria, Côte d'Ivoire, Gabon, Korea, Kuwait, Nicaragua, Oman, Singapore, South Africa, Venezuela
	GROUP 3	0.162	0.109	**2.286**	-0.560	Bulgaria, China, Iraq, Lebanon, Poland, Romania, Trinidad and Tobago, URSS, Vietnam
	GROUP 4	-0.676	-0.334	-0.546	**1.719**	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Hong Kong, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, USA, New Zealand.
	GROUP 5	-0.021	-0.271	-0.176	-0.496	Others

Table 2. Evolution of relevant original variables by group

Groups	Period	Number of countries	K (TOEs/Petajoules)	S (Petajoules/TOEs)	I (TOEs/ million of 1990 US dollars)	W (Million of 1990 US dollars/thousands of inhabitants)	per capita CO_2 (TOEs/thousand of inhabitants)	% global CO_2
GROUP 1	1980	7	174.11	0.043	0.153	7.132	6.703	1.69
	1985	5	170.18	0.038	0.168	3.278	2.509	0.66
	1990	3	175.53	0.069	0.127	2.440	2.666	0.52
	1995	2	177.52	0.035	0.188	5.047	2.981	0.54
GROUP 2	1980	5	85.13	0.090	0.209	3.494	6.367	1.65
	1985	12	73.94	0.075	0.262	3.524	5.666	3.28
	1990	15	76.58	0.080	0.272	3.269	4.942	7.51
	1995	10	71.99	0.102	0.321	5.529	8.833	4.29
GROUP 3	1980	7	78.39	0.052	1.532	1.007	5.804	12.76
	1985	8	84.00	0.058	1.145	1.109	5.768	14.79
	1990	10	79.28	0.061	0.939	1.814	7.013	32.98
	1995	10	74.39	0.059	0.887	1.846	6.306	29.44
GROUP 4	1980	21	68.62	0.049	0.206	18.088	12.067	51.05
	1985	21	63.06	0.051	0.189	19.195	11.042	46.48
	1990	20	55.06	0.052	0.174	21.894	10.468	45.55
	1995	22	56.59	0.051	0.161	22.880	10.318	45.41
GROUP 5	1980	61	77.24	0.048	0.263	2.159	2.002	30.23
	1985	55	76.86	0.047	0.248	2.439	2.149	32.23
	1990	53	70.41	0.049	0.240	2.767	2.223	11.07
	1995	59	71.33	0.057	0.259	2.421	2.320	18.69

Table 3. % of CO_2 emissions for each group in relation to global emissions

	Group 1 (K)	Group 2 (S)	Group 3 (I)	Group 4 (W)	Group 5
1980	1.69	1.65	12.76	51.05	30.23
1985	0.66	3.28	14.79	46.48	32.23
1990	0.52	7.51	32.98	45.55	11.07
1995	0.54	4.29	29.44	45.41	18.69

Annex 1. List of countries.

Albania, Algeria, Angola, Argentina, Australia, Austria, Bangladesh, Belgium, Benin, Bolivia, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Congo, Dem Rep, Congo Rep., Costa Rica, Cuba, Cyprus, Côte d'Ivoire, Denmark, Dominican Rep., Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Islamic Rep., Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea Dem People's Rep, Korea Rep., Kuwait, Lebanon, Libya, Luxembourg, Malaysia, Malta, Mexico, Morocco, Mozambique, Myanmar, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland Rep., Portugal, Romania, Saudi Arabia, Senegal, Singapore, Slovak Rep., South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syrian Arab Rep.,Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, U.S.S.R. (former),United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia, Zimbabwe.

Annex 2. Pearson correlation matrix and Bartlett test of sphericity

Year 1980					Year 1985				
	K	S	I	W		K	S	I	W
K	1	-0.110	-0.77	-0.078	K	1	-0.177	0.014	-0.181
S	-0.110	1	0.052	-0.060	S	-0.177	1	0.168	-0.024
I	-0.077	0.052	1	-0.232	I	0.014	0.168	1	-0.252
W	-0.078	-0.060	-0.232	1	W	-0.181	-0.024	-0.252	1
Bartlett test					Bartlett test				
Chi-squared				8.579	Chi-squared				15.826
Degree of fredoom.				6	Degree of fredoom.				6
Significance				0.199	Significance				0.015
Year 1990					**Year 1995**				
	K	S	I	W		K	S	I	W
K	1	0.242	0.068	-0.320	K	1	0.072	0.098	-0.342
S	0.242	1	0.170	-0.128	S	0.072	1	0.215	-0.079
I	0.068	0.170	1	-0.278	I	0.098	0.215	1	-0.315
W	-0.320	-0.128	-0.278	1	W	-0.342	-0.079	-0.315	1
Bartlett test					Bartlett test				
Chi-squared				26.836	Chi-squared				27.822
Degree of fredoom.				6	Degree of fredoom.				6
Significance				0.000	Significance				0.000

Annex 3.Scheffé procedure (Cluster centers). 95% confidence level.

1980	K			1980	S			1980	I			1980	W			
Group	N	1	2	Group	N	1	2	Group	N	1	2	Group	N	1	2	3
4	21	-0.477		1	7	-0.578		1	7	-0.469		3	7	-0.676		
5	61	-0.182		5	61	-0.151		4	21	-0.334		5	61	-0.513		
3	7	-0.143		4	21	-0.130		2	5	-0.324		2	5	-0.323	-0.323	
2	5	0.088		3	7	0.127		5	61	-0.186		1	7		0.193	
1	7		3.129	2	5		3.060	3	7		3.075	4	21			1.747
Sig		0.251	1.000	Sig		0.368	1.000	Sig		0.846	1.000	Sig		0.519	0.147	1.000

1985	K			1985	S				1985	I			1985	W		
Group	N	1	2	Group	N	1	2	3	Group	N	1	2	Group	N	1	2
4	21	-0.539		1	5	-1.126			1	5	-0.474		3	8	-0.646	
2	12	-0.165		5	55	-0.327	-0.327		4	21	-0.407		5	55	-0.469	
5	55	-0.064		4	21		-0.077		5	55	-0.209		1	5	-0.357	
3	8	0.182		3	8		0.357		2	12	-0.163		2	12	-0.324	
1	5		3.147	2	12			1.896	3	8		2.755	4	21		1.765
Sig		0.215	1.000	Sig		0.131	0.263	1.000	Sig		0.131	0.774	Sig		0.576	1.000

1990	K				1990	S				1990	I			1990	W		
Group	N	1	2	3	Group	N	1	2	3	Group	N	1	2	Group	N	1	2
4	20	-0.755			5	53	-0.459			1	3	-0.665		3	10	-0.553	
5	53	-0.080	-0.080		4	20	-0.267			4	20	-0.488		1	3	-0.479	
2	15		0.190		3	10	0.323	0.323		5	53	-0.242		5	53	-0.440	
3	10		0.309		1	3		0.857	0.857	2	15	-0.125		2	15	-0.381	
1	3			4.537	2	15			1.625	3	10		2.360	4	20		1.882
Sig		0.126	0.652	1.000			0.232	0.618	0.248			0.355	1.000			0.952	1

1995	K			1995	S			1995	I			1995	W		
Group	N	1	2	Group	N	1	2	Group	N	1	2	Group	N	1	2
4	22	-0.676		1	2	-0.588		1	2	-0.563		1	2	-0.700	
5	59	0.021		4	22	-0.335		4	22	-0.546		3	10	-0.560	
2	10	0.133		5	59	-0.271		5	59	-0.176		5	59	-0.496	
3	10	0.163		3	10	0.109		2	10	0.065		2	10	-0.153	
1	2		5.345	2	10		2.342	3	10		2.286	4	22		1.719
Sig		0.169	1.000	Sig		0.418	1.000	Sig		0.541	1.000	Sig		0.266	1.000