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# World Polarization in carbon emissions, potential conflict and groups: an updated revision

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## World Polarization in carbon emissions, potential conflict and groups: an updated revision


### Abstract

Typically, conflicts in world environmental negotiations are related, amongst other aspects, to the level of polarization of the countries in groups with conflicting interests. Given the predictable relationship between polarization and conflict, it would seem logical to evaluate the degree to which the distribution of countries – for example, in terms of their $CO_2$ emissions per capita – would be structured through groups which in themselves are antagonistic, as well as their evolution over time. This paper takes the concept of polarization to explore this distribution for the period 1992-2010, looking at different analytic approaches related to the concept. Specifically, it makes a comparative evaluation of the results associated with endogenous multi-polarization measures (i.e. EGR and DER indices), exogenous measures (i.e. Z-K or multidimensional index) and strict bipolarization measures (i.e. Wolfson's measure). Indeed, the interest lies not only in evaluating the global situation of polarization by comparing the different approaches and their temporal patterns, but also in examining the explanatory capacity of the different proxy groups used as a possible reference for designing global environmental policy from a group premise.



**JEL codes:** D39; Q43; Q56.

**Key words:** polarization; carbon emissions; conflict;

## 1. Introduction

The analytical approach to the notion of conflict has taken various forms. One of the most influential of these is the approach suggested initially by Esteban and Ray (1994), which was later developed theoretically, methodologically and empirically in subsequent works (Esteban and Ray, 1999; Duclos, Esteban and Ray, 2004 and 2008;and Esteban, Gradin and Ray, 2007). Essentially, based on this approach, polarization in any distribution, and hence potential conflict [1] would be attributable to two essential factors: alienation and identification (or the AI approach). The alienation would consist of an inter-group feeling of difference and consequently would be associated with the disparity between groups in terms of the variable under analysis. This factor would thus be similar to the conventional inequality factor (Cowell, 1995) based on the concept of distance. Secondly, polarization is based on the parameter of identification, which is associated with the level of cohesion within each group, inducing a feeling of belonging. Polarization and conflict would therefore be a matter of groups and would depend positively on both the level of alienation and the level of identification.

In the global environmental sphere, it would seem that this concept is particularly useful. Typically, global negotiations on reducing and controlling pollution, associated with the global problem of climate change, are structured

[1]In particular, Esteban and Ray (1999) proposed a behavioural model in which conflict depends critically on the level of polarization. In Esteban and Ray (2008) this relationship was updated with a general conflict-and-peace model, establishing a close relationship, in particular, between polarization and the intensity of conflicts.

through alliances of countries with conflicting interests and hence groups. For example, in the Kyoto Protocol I negotiation process there was the group of countries which were committed to the objectives to control polluting emissions (Annex B) and the rest. Indeed, the most typical feature of subsequent negotiations has been the approximate consolidation of a polarization of positions between developed and low-developed countries, based on their different environmental responsibilities and levels of development. In general terms, groups might be formed based on different criteria, whether these are similarities or uniformities; for example, in terms of polluting behaviour, based on geographical or cultural proximity, or on administrative factors, different expected impacts in different countries, the economic importance of fossil fuel extraction sector, pressure from public opinion amongst others. Consequently, it would seem useful to evaluate the level of polarization between countries in terms of pollution by examining various *a priori* possible grouping alternatives (polluting or exogenous similarities) and based on different synthetic measures. We believe that this is a useful exercise not only in academic terms but also politically. In particular, this exercise would not only contribute to understanding the potential level of conflict in the distribution of countries by pollution levels, and hence elicit ideas for measures to attenuate it, but by the process of building and using different theoretical groupings it offers the opportunity, depending on their level of relevance, to obtain some useful guidelines for designing global policy.

When referring to the methodological literature on measuring polarization, in synthetic terms one finds three non-excluding lines of contributions: the first of these are endogenous polarization measures, which follow the principles established in the pioneering paper by Esteban and Ray (1994). To be specific, this approach encompasses the EGR index (Esteban, Gradín and Ray, 2007) and the DER index (Duclos, Esteban and Ray, 2004). The former essentially build the ER polarization indices (Esteban and Ray, 1994) but take endogenous groups (thus minimizing internal errors) and adjust the polarization measure by the grouping error factor. The DER indices are continuous by nature and do not need to establish a number of exogenous groups but rather are based on establishing individual windows (country by country) of identification-alienation. One of the differentiating features of these latter ones, which makes them especially appealing for analysis, is that they can be decomposed in two dimensions of the polarization, i.e. alienation (how different countries are) and identification (how homogenous they are). Secondly, mention should be made of the Zhang and Kanbur indices (2001), which typically are used with exogenous groups, i.e. pre-established (for example, geographical, administrative or institutional groupings of countries). These indices make use of the inequality components arising from the group inequality decomposition (Shorrocks, 1980 and 1984) and would be consistent with the two factors underlying the AI approach to polarization. Thirdly, mention should be made of the strict bipolarization indices, as proposed by Wolfson (1994,1997). In this respect, the focus is somewhat different. These measures estimate the level to which the distribution under study resembles a bi-modal distribution, with the two groups positioned at the ends of the range.  Thus, if the actual distribution resembles a symmetrical distribution with two groups (similar size) the value of this measure will approach one. Therefore, the Wolfson index only measures the degree to which the distribution under study approaches this distribution of two groups. In the case, for example, where the distribution was perfectly tripolar its value will be less than one. It has also been noted that the formulation of this measure is slightly different from the EGRs, for example, as used as a reference for the definition of the groups the median of the distribution rather than the average.

It would therefore be logical to examine these series of measures to investigate the international polarization of $CO_2$ emissions and compare the relevance of different *ex-ante* groupings, with the aim of establishing environmental policy guidelines. These groupings would be both endogenous and exogenous. In other words, they would be based on the level of similarity (and divergence) of the countries either optimally or based on predetermined structural groupings (i.e. geographical or institutional). In the latter case, for example, this might entail taking regional groupings of countries or grouping them according to their level of development and income, such as those used by multinational institutions such as the World Bank and the International Energy Agency.

In the environmental sphere, international polarization has already been the subject of research in various studies. Without making an exhaustive listing, the works of Ezcurra (2007), Duro and Padilla (2008 and 2013) and Duro (2010) should be mentioned. Ezcurra (2007) analysed the international distribution of $CO_2$ per capita for 87 countries but only using EGR indices for the period 1960-1999. Duro and Padilla (2008) used these same measurements (i.e. EGRs) up to 2005 and 116 countries. Duro (2010) examined international polarization but using Z-K indices up to 2006 (116 countries) and the nine regional groups defined by the IEA. Finally, in a recent work (2013), Duro and Padilla examined EGR indices for EU countries as well as Z-K indices for three geographical groups (so a less territorial coverage). Thus, there is no contribution worldwide to evaluate the polarization under all approaches together, both endogenous and exogenous, that uses other measures (i.e. DERs and Wolfson indices) and update calculations from 2005. In particular, the point is that different measures and approaches may yield conflicting results and/or provide more complete information on the determinants and patterns. Specifically, given that the groups can be formed with different countries and the same number of groups may be different in the different measures and approaches the results at the end can vary. So, different formulas, different groups and different number of groups are features that can throw differences in the results that need to be taken into account.

Therefore, this paper aims to update and complete the previous literature associated with the global polarization of carbon emissions. Firstly, it will use the three families of indices reviewed above to provide a more comprehensive perspective of this phenomenon. Specifically, as well as using the well-known EGR indices for endogenous polarization for groups of 2,3 and 4 and the Z-K index for different geographical groupings according to level of development, the DER indices will be used which apart from not needing groups to be formed can also be decomposed by polarization factors. A new feature in this sphere will be the use of the Wolfson's index to verify the degree of bi polarization.

Secondly, the aim is also to focus the analysis on the explanatory capacities of the different groups, both endogenous and exogenous, in order to obtain policy implications as well as academic ones. Thirdly, the evidence will be extended up to 2010. The period under analysis starts in 1992, the first year for which data are available for all currently recognized countries following the break-up of the former USSR and Yugoslavia. Finally, the territorial coverage of data is larger than in the previous literature, with 196 countries included in the analysis (nearly 97% of world carbon emissions)

The paper is structured as follows: the second section reviews the main methodological aspects associated with the polarization approach and the different measures available. The third section sets out the main results associated with the implementation of these measures on the international distribution of $CO_2$ emissions per capita in the period 1992-2006. The last section contains the main findings obtained and their policy implications.

## 2. Methods

The notion of polarization is fundamentally different from that of inequality and closer to the notion of potential conflict and its intensity in the event of an outbreak (Esteban and Ray, 1999 and 2008). The standard notion of inequality, in particular, is based on different axioms, such as the Pigou-Dalton Principle on redistribution. According to this principle, any redistribution – such as, in this particular case, $CO_2$ per capita from a large emitter to a smaller one – must be captured in terms of a reduction in inequality. This principle, which is at the core of the conceptualisation of inequality in its traditional sense (Cowell, 1995) is not satisfied by the notion of polarization. In particular, this is defined in terms of the degree by which a distribution – once again, in this case of $CO_2$ per capita – is grouped around two (or more) conflicting poles. In this way, the more cohesive these groups are, and the bigger the distances between them, the greater the polarization will be. It is the notion of identification which, in short, implies a reduction in inequalities, which is the key to understanding the fundamental discrepancy between the concepts of inequality and polarization[2].

In order to make this notion operational, Esteban and Ray (1994) initially proposed the family of ER indices, which formally sum all antagonisms between all countries (notation already adapted) of the different groups, where antagonism is viewed as a combination of inter-group alienation, and identification with the group itself:

$$ER(\alpha) = \sum_{i=1}^{n}\sum_{j=1}^{n} p_i^{1+\alpha} p_j \left|\frac{e_i}{e} - \frac{e_j}{e}\right|, 1 \leq \alpha \leq 1.6 \qquad (1)$$

where $p_i$ and $p_j$ are the relative populations of countries i and j; $e_i$ and $e_j$ are the $CO_2$ emissions per capita of countries i and j; e is the world-wide average; $\alpha$ is the parameter that measures the sensitivity of the index to polarization, the value of which falls between 1 and 1.6 by construction (Esteban and Ray

[2] In particular, Esteban and Ray (1994) established the analytic foundations of this concept: Given this approach the basic features of polarization will be the following: 1) the issue is that of groups. An isolated observation should have little weight in terms of polarization; 2) Polarization implies a high degree of homogeneity within the groups, i.e. a great sense of identity; 3) Polarization implies a high degree of heterogeneity between groups, i.e. a great sense of alienation; 4) the polarization problem implies a small number of significantly sized groups.

(1994); The larger the value of $\alpha$, the greater the importance we are giving to the clustering of groups of countries and so the greater the departure from inequality measurement will be.

In fact, the term $p_i^{\alpha}$ stands for the sense of identification and so accounts for the clustering effect by which each country identifies with its own group. On the other hand, the second term pf the expression (1) would capture the alienation effect, which is measured in terms of the distance between observations.

However, the ER indices typically imply that groups are already defined. But, in most of practical situations distributions are not grouped *ex ante*. Thus, it would be necessary to consider a mechanism consistent with this approach, which allows to consider endogenous groups. To address this technical problem, Esteban, Gradin and Ray (2007) proposed the EGR indices:

$$EGR(\alpha,\beta)=\sum_{i=1}^{n}\sum_{j=1}^{n}p_i^{1+\alpha}p_j\left|\frac{e_i}{e}-\frac{e_j}{e}\right|-\beta(G-G_s) \qquad (2)$$

where G is the Gini coefficient (measuring the overall cross-country inequality); $G_s$ is the simplified Gini, applied only to measure the differences between the groups and $\beta$ is a parameter that shows the EGR sensitivity to the groups' cohesion (or the groupings' error) . Note that $G-G_s$ would be a proxy of the error committed by grouping (ie, the magnitude of differences within groups or, in other words, a cohesion component), which reduces polarization.

Two steps need to be taken before applying the formula. The first is to establish *ex ante* the number of groups. Typically, the literature tends to deal with 2, 3 or 4 groups. Whatever the case, the final decision is empirical and needs to be adapted to each case. Secondly, once the number of groups has been decided upon, they need to be delimited optimally. The delimitation procedure should minimize the inequalities within each group and hence the error factor on grouping. In particular, Esteban, Gradin and Ray (2007) recommend using the method proposed by Davies and Shorrocks (1989). Indeed, the error made on grouping, and hence the level of group cohesion, is the second term of the expression 1.[3]

In the wake of this approach, Duclos, Esteban and Ray (2004) developed a family of measures (i.e. DER indices), and a formal complementary framework, which seems also interesting to consider. Specifically, as in ER and EGR, DER indices are defined as the sum of all effective antagonism of $e_i$ towards $e_j$, under *f* though:

$$DER = \iint f(e_i)^{1+\alpha} f(e_j)\left|e_i - e_j\right| de_j de_i \text{, where } \alpha \in [0.25,\ 1] \qquad (3)^4$$

Their particularity is that DER indices are designed for continuous distributions (and based on density functions), while the previous EGR indices (and ERs) are designed for discrete distributions. In practical terms this point implies that the

[3]In fact, based on this method the optimal structure of the two groups would use the mean as the inter-group separation value.

[4] As in the case of expression (1) in the case of the DER the parameter $\alpha$ must be located between 0.25 and 1 by construction dictated by the model used.

discontinuities of the groupings disappear. By way of example, consider a case of bipolarization with EGR indices where the groups have been delimited by the mean (i.e. EGR (2)). What sense of identification have the countries that are above and below the mean (but very close to each other? In fact the countries mentioned, despite being grouped separately, may actually be closer to a member of another group rather than to one of their own. DER indices correct these discontinuities by using a “window of identification” for each observation (country). These indices thus would measure polarization from an *individual* alienation-identification perspective in which countries identify themselves only with those of similar carbon emissions. Thus, a country located in $e_i$ experiences a sense of identification that depends on the density $f(e_i)$ at $e_i$. Hence identification and alienation are derived according to country’s particular situation in the estimated empirical distribution.

An additional interesting feature of this measure is that it can be easily decomposed into the antagonism factors in the following way:

$$DER = a \cdot \iota \cdot [1 + \rho] \tag{4}$$

where *a* is the average alienation factor; *i* is the identification, and *p* is the standardized covariance.

The covariance term in (4) may be hypothetically positive or negative. For example, one might imagine a bi-modal distribution in which a country with a high level of emissions converges towards the higher mode. This would imply an individual increase in identification and a decrease in alienation with respect to the observations situated around the lower mode. Meanwhile, convergence towards the upper mean mode, but from observations of lower emissions, would imply an individual increase in identification, with respect to the upper mode, but greater alienation with respect to the lower mode.

In addition, the literature has generated different measures restricted to evaluating only the degree of bipolarisation and not, like earlier ones, more associated with an analysis of multi-polarization. In this case we would try to assess the extent to which a distribution is polarized into two homogeneous groups (cohesive), with similar size and different means. In fact, the exercise behaves as a test of the degree of similarity between the distribution analyzed and a perfect bi-modal distribution. In fact, and returning to the framework of EGRs, which implies an analysis of multi-polarization, a bi-polarized distribution would be the worst possible scenario in terms of potential conflict. So far a bi-polarization measure can be seen as an analysis of the actual distance from this scenario. Specifically, once of the most well known of these is Wolfson's measure (1994, 1997), whose additional advantage is its direct derivation based on the Lorenz curve. Its typical equation would be as follows:

$$W = \frac{0{,}5 - L(0{,}5) - G}{\frac{m}{e}} \qquad (5)$$

where *L(0.5)* is the Lorenz curve corresponding to the median; *G* is the Gini; *m*, in this case, is the median $CO_2$ per capita, and *e* is the mean $CO_2$ per capita.

It can adopt a minimum value of 0, in the case of a uniform distribution, or 1 in the case of symmetrical bimodal distribution, with a group with a mean value of 0 and another of 2$\mu$. Indeed, Esteban Gradín and Ray (1999) demonstrated that this measure could be rewritten as a specific example of the EGR family, where$\alpha=\beta=1$ and the distributive mean are replaced by the median[5]. This fundamental differences, indeed, can produce different results, for example, if we compare them with the emerged through application of EGR2 indexes. Indeed if we replace the mean by the median as a reference for defining the groups their content may vary and also the results

In addition to the previous approach and measures, which revolve around the determination of optimal groups, it could be interesting to evaluate the polarization of emissions but using pre-determined groups, which might be considered as reasonably relevant to real groupings. In this particular case, for example, it might be instructive to explore this phenomenon when, in the polarization of emissions, the groups are formed based on geographical areas or development levels. In the first case, we would be implicitly considering the existence of a feeling of identification and closeness among the countries that form a geographical or administrative area. In the second case, it may make sense to test the correlation between groups and development levels, given the possibility that countries would cluster according to these qualitative parameters and how this could explain international polarization. In this respect, international institutions such as the World Bank and the IEA provide groupings

[5] Meanwhile, Wang and Tsui (2000) developed general bipolarization measures based on Wolfson's approach.

of this nature. The point is that there is now a need to manage synthetic polarization measures consistent with this type of exogenous grouping. Among the alternatives suggested in the literature, for example, particular attention has been given to the measure suggested by Zhang and Kanbur (2001), hereinafter referred to as Z-K. It basically consists of using the group decomposition components (Shorrocks, 1980 and 1984) of the inequality, redistributed, to derive a measure consistent with the main axioms of polarization. Specifically, based on this form of decomposition, two added synthetic components would be distinguished: firstly, an inter-group component, which would measure the inequality attributable to the distances between the mean of the groupings (like an alienation factor); and secondly, an intra-group component, which would capture the average degree of internal inequality (like an identification factor). In the inequality, both components would have additives. In the polarization, the measure would be the ratio between the between-component and the within-component. In this way, the measure is consistent with the two central axioms outlined by the previous notion of polarization. Using the Theil index (Theil, 1967), which can be perfectly broken down in these terms, the measure would be expressed as follows:

$$Z - K = \frac{T_b}{T_w} \quad (6)$$

where $T_b = \sum_{g=1}^{G} p_g * \ln\left(\frac{e}{e_g}\right)$ and $T_w = \sum_{g=1}^{G} p_{g*} T_g$

where $g$ denotes a group, $p_g$ is the population share of group $g$, $e_g$ is the average emissions per capita for group $g$, and $T_g$ is the internal inequality of group $g$.

## 3. Results and discussion

The data used correspond to 197 countries, representing more than 97% of the world's $CO_2$ emissions. The data is sourced from the World Bank which, in turn, in the case of $CO_2$, are supplied by the IEA, and cover the period 1992-2010. This therefore provides data for all duly constituted and internally recognized countries.

Firstly, before going into the analyses and results of the different polarization measures and associated groups, we believe it would be opportune to provide some guidance on the way that emissions are distributed[6]. To do so, the density function approach was used based on Kernel's non-parametric estimation techniques[7]. Figure 1 represents the initial year, the final year and one intermediate year, 2000. The data demonstrate, for example, that the distribution has moved clearly towards bi-modality. Thus in 2010 a group emerges with relative emissions above the global average, with a per capita level of emissions approximately 40% higher than the average, and another group below this average, at around 50%. This means that strict bipolarization measures, this being the case of Wolfson's measure, might, *ceteris paribus*, tend to grow during this period. Meanwhile, this result denotes the high

[6]Indeed, this analysis constitutes an obvious advance step to computing the EGR or W family of indices.

[7]The estimates are based on Gaussian kernel functions (see Quah, 1997). These have been used previously for the analysis of the international distribution of emissions by Padilla and Serrano (2006), Ezcurra (2007) and Duro and Padilla (2013).The smoothing parameter is determined endogenously from the method of Silverman (1986). It should be noted that the results did not vary significantly with the use of other functions.

comparative explanatory capacity that endogenous structuring into two groups will have (EGR(2)) and, in the absence of subsequent evidence, certain reservations with respect to the level of instability inherent in this situation.

**Insert Figure 1 about here**

Table 1 shows the main results for the years selected in the period, approximately every five years, of the EGR polarization indices for two, three and four endogenous groups, plus Wolfson's index which, as mentioned earlier, is strictly an endogenous bipolarization index with a different formulation. This number of groups was chosen because they are typically found as relevant and put forward as such in the academic literature. In this context, an initial explanatory power indicator of the groups is proxied through the relative error committed by grouping, indicated from the ratio between G-Gs (that is, the magnitude of within-group differences) and the global inequality (G). As can be seen, the results highlight several points of interest[8].

Firstly, the EGR index (2) provides comparatively relevant results, which is consistent with the previous visualization of the estimated density function. Thus with just two groups, the relative error typically associated with grouping is lower than 25%. Indeed, if we compare the absolute level of the EGR measures for two, three and four (a better measure for comparing different EGRs), the EGR (2) shows the highest value, which is once again indicative, based on the literature, of a more attractive structure[9]. If the EGR index is taken as a

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[8] Please note that different countries are treated heterogeneously in the analysis. Thus, the importance of each country is approximated by its demographic weight.

[9] The basic idea is that for comparing different groupings with different number of groups the own value of EGR indexes would be a better (and complementary) measure, given that the ratio between G-Gs and G is a fully satisfactory measure but only when we are comparing

reference, therefore, global polarization would clearly have fallen during this period, especially in the last few years.

Graph 2 displays the main characteristics of the endogenous groups determined for computing the EGR (2), hence a simplified distribution, and its evolution between 1992 and 2010. Since in this case the distribution is synthesized in two endogenous groups we offer descriptive data on groups ‘means and their sizes. The world average is the weighted average according to the population size of countries. Thus, we can test the relevance of changes in the alienation component comparing with groups ‘weights. Indeed, as we shall see, a critical force behind the reduction in the EGR (2) is the convergence between groups and, consequently, a decrease in the alienation effect, especially with regard to the high-emission group. At the same time, a move towards bipolarization can be seen, in the sense of equalization in the weight of the two groups. Thus, the change in groups ‘weight would have promoted an increase in the bi-polarization, which would have been clearly offset by the reduction in the alienation effect in the case of EGR2.

Secondly, it results interesting to remark the fact that the two groups emerged from Davies and Shorrocks algorithm exhibit a high coincidence with income World Bank income groups; low $CO_2$ emitters happen to be low and lower middle income countries whereas the high $CO_2$ emitters group is mainly formed with high income countries: this is, all sub-Saharan countries (but South Africa

distributions with the same number of groups. Note, in particular, that when we increase the number of groups the error of grouping is reduced (increases the cohesion) and thus increases the value of EGR but, at the same time, it reduces the ER component, that is, the first factor of EGR expression (see expression (2), reducing, in turn, the EGR. Under such circumstances, the final value of the EGR itself provides an indication of the net explanatory relevance of aggregations. See Esteban, Gradin and Ray (2007).

and Seychelles), most of Asian and Latin American countries appear in the first group are in the low emitters group, where as in the high emitters group European countries, North America, Japan, Australia and China since 2005. Consequently, income group where a country belongs strongly determines the $CO_2$ endogenous group (see Annex).

Thirdly, the EGR for three and four groups do not record any very significant movement in that period.

Fourthly, Wolfson's index, in contrast to the pattern of the EGR index (2), clearly increases from 2000. The reason behind this apparently diverging result with the EGR (2) is due to methodological reasons. Wolfson's index, in particular, takes as reference for the calculation of groups the distributive median rather than the mean (as is the case in EGR (2)). This difference ultimately produces that W gives more weight to the group size equaiization pattern that to the reduction in between-group gap (Figure 2). This finding, in fact, underlines the convenience of handling different polarization indicators and, in this case, of bi-polarization for a complete observation of the patterns.

**Insert Table 1 about here**

**Insert Figure 2 about here**

In addition, given that they can be decomposed by alienation or identification factors, the DER indices allow the role of both factors in the evolution of polarization to be clarified precisely, as well as deriving from an individual analysis. Table 2 is attached for this purpose. Thus the DERs, which are synthesized here for average sensitivity parameters, confirm firstly the evolved results associated with the EGR measure (2), i.e. the reduction in polarization in this period. It should be remembered that this measure is not constructed based on the imposition of the number of groups and their endogenous determination, but rather emerges as the sum of the individual alienation-identification window which also introduces more continuity to the measure's evolution. Secondly, and what appears to be more interesting empirically, the DERs establish the role of explanatory factors in determining the polarization pattern. In particular, the downward evolution of the polarization of emissions, already corroborated with the EGR (2), coincided with the opposite evolution of the two factors that define it. Indeed, while the group alienation decreased, in accordance with the EGR 2, something that would be perceived as positive in terms of the potential conflict between countries, the group cohesion and feeling of identification also increased, though to a lesser extent, which would not be quite so positive. This evolution in identification, in itself, also would introduce certain reservations with regard to the future of this phenomenon, especially in the event that the alienation did not continue to decrease.

**Insert Table 2 about here**

Similarly, the exogenous polarization indices were calculated; i.e. with pre-defined groups. In this respect, the point is that it could seem reasonable for the groups to be organized according to these types of criteria. As well as comparing the evolution of the polarization of emissions, when delimited groups and measures are looked at in different ways it is interesting to compare whether, additionally, these kinds of structures are relevant in terms of their explanatory capacity of global distribution. The polarization index used is the Z-

K, which is delimited by the ratio of the group inequality components. In this way, which is conceptually consistent with the previous polarization measures, the polarization would increase either when the inter-group inequalities increased (i.e. the alienation component) or when the intra-group inequalities diminished (i.e. the identification component increases). In this context also an initial explanatory power indicator of the groups can be approximated through the ratio between the between-groups inequality component and the global inequality. On the other hand, we can also use EGR indexes as a better measure for comparing the different exogenous groups. Although these are intended for use with endogenous groups it can be useful to extend the analysis to the case of exogenous structuring.

In particular, a reasonable exogenous grouping criterion might consist of using an institutional definition of countries in terms of their level of development. In this respect, for example, the World Bank distinguishes the following categories: low-income, lower-mid, upper-mid and high income. Table 3 shows the results of polarization associated with distribution into two groups (low+lower-mid, upper-mid+high), three groups (low, lower-mid+upper-mid, high) and all four groups. The results obtained, in this case, allow the following observations to be made:

Firstly, it seems that the structure with just three exogenous groups, the low, middle and high income groups, produces quite satisfactory results. For example, it can be seen that this ad-hoc structure is able to approximate almost half of the international inequalities in per capita emissions. The structure of four income groups (decomposing middle income group in turn in two subgroups) does not yield significantly better results. Thus, with an additional group the relative error only reduces in two percentual points. In fact if we compute the EGRs associated with each exogenous income aggregation (as an indicator for compairing distributions with different number of groups) we will obtain values of -0.004, 0.010 and 0.003 for two, three and four groups cases at 2010, respectivaly. These results will strengthen, in fact, the explanatory appeal of structuring three groups of exogeneous income countries[10].

Secondly, in terms of evolution, while polarization measured in this way would have grown up to 2000, after 2000 the indices' patterns both decrease with the EGR (2) and the DER.

Thirdly, and having reached this point, it is interesting to evaluate the weight of the within-component (i.e. identification) and the between-component (i.e. alienation) in this drop in the exogenous polarization based on these groups since 2000. Following an exercise conducted by Duro (2010), for the case of the Z-K 3 it emerged that the drop in the index (37% in logarithmic terms) was mainly attributable to the alienation component (30%)[11].

**Insert Table 3 about here**

On the other hand, and continuing with this exogenous approach, regional groupings were also used. In particular, the World Bank distinguishes two main possibilities, the most aggregate one considers seven regional groups: East Asia and the Pacific, Europe and Central Asia, industrial nations, Latin America

[10] More details about these calculations are available upon request

[11] Further details of these calculations can be requested directly from the authors.

and the Caribbean, Middle East and North Africa, South Africa and Sub-Saharan Africa. This institution then also uses a much more detailed group breakdown from which 22 groups emerge. In this particular case, we believe that the division into 22 groups is excessive for operating purposes and that an intermediate option of 14 groups would be a more reasonable choice[12]. The main results are given in Table 4. Looking at the results, certain interesting facts emerge: firstly, the structure of 14 groups explains 71% of global inequalities. This indicator is larger, for example, than the one obtained with four exogenous groups according to development level, which was 48%. Whatever the case, it should be noted that ten more groups were handled here. Secondly, using seven regional groups as the referential structuration approximates just over 50% of global inequalities. However, this structure improves only in a small way the indicator than the one produced by the breakdown into three or four groups by development level reviewed earlier. In fact, if we compute again the EGRs for these two groupings (as a better measure for comparing structurations with different number of groups), 7 and 14 groups, its value would be -0.0011 and 0.005, respectively (at 2010). These results would confirm, therefore, that the breakdown into 14 regional groups seems more attractive than 7, the which is the worst managed exogenous breakdowns (lower value of EGR). The data also indicate that, comparatively, the best comparative simplification by groups is the one that distinguishes three groups of exogeneous countries based on the level of income (remember EGR = 0.010).

[12] Division into 14 groups would be as follows: Central Asia, Eastern Africa, Eastern Asia, Europe, Latin America, Middle Africa, Northern Africa, Northern America, Oceania, South-Eastern Asia, Southern Africa, Southern Asia, Western Africa and Western Asia.

**Insert Table 4 about here**

## 4. Concluding Remarks and Policy Implications

International environmental negotiations typically involve the formation of groups of countries with common interests inside and conflicting among them: rich (developed) countries, poor (non-developed or developing) countries; regional groups; groups according to their total emissions or per capita, etc. The stronger, more equal and more different the groups formed are the negotiations can be more conflictive. These elements are precisely the notion of polarization measures. The study of the "theoretical" distributive polarization provides, thus, an indication of the inherent distributive conflicts and therefore the degree of complication of this type of processes. The scientific literature has generated notable contributions related to conflict models that include these elements (Esteban and Ray (1999), for instance). Obviously this is a “theoretical “approach and eventually countries may be organized on the basis of other criteria. In any case, we believe it is reasonable to assess the situation from a theoretical clustering based on emissions, income levels and geographic proximity as we do in this paper.

Also, it is not only interesting to understand how the theoretical polarization of emissions by country has evolved, but also to test whether different and *a priori* reasonable structures of these countries have the potential to explain the status quo, the final goal being not only to contribute to generating knowledge but also for this knowledge to help steer the design of environmental negotiations based on these theoretical groupings.

In order to carry out an analysis of polarization in these terms, it seems particularly appropriate to use a formal conflict model. In this respect, our belief is that the AI approach, a pioneering suggestion from Esteban and Ray (1994), is particularly attractive. According to this approach, polarization, and hence the level of predicted socio-political instability, would depend on two essential parameters: the level of separation of the groups and hence their divergence (i.e. the feeling of alienation) and secondly on the level of internal cohesion, which would strengthen the feeling of belonging (i.e. the feeling of identification). Polarization, and in particular the degree of potential conflict, would depend positively on both parameters. In this respect, it would be interesting to ascertain the role of both these factors in explaining the evolution of polarization.

In order to cardinalize this phenomenon, various suggestions have been put forward. In this respect, this paper has highlighted the usefulness of EGR indices, or the multi-polarization endogenous groups, the DER indices, which allow for a precise decomposition of polarization in the two previous parameters, Wolfson's bipolarization indices (also endogenous) and the Z-K indices, which allow polarization to be evaluated when the groups are predetermined, for example according to their membership of a regional group or according to development levels. Furthermore, the different ways of grouping that emerge for each of these measures (typically the EGR, W, and the Z-K) allow a comparative analysis to be made of the explanatory importance of these "theoretical" groups in terms of the international distribution of emissions observed.

The main empirical results obtained point in the following directions:

Firstly, the most significant endogenous multi-polarization indices (i.e. the EGR), thus according to the optimal delimitation of groups, indicate that polarization would have decreased clearly between 1992 and 2010. This is, *a priori*, positive.

Secondly, the EGR indices also note that a breakdown into just two groups is highly explanatory of global distances, in a comparative way. In particular, just two groups – those with the most and least emissions – would explain three-quarters of the current international distribution of carbon emissions per capita. It should be remembered that in this case the borderline between the two groups coincides with the mean value. In fact, the two groups emerged exhibit a high coincidence with income World Bank income groups; low $CO_2$ emitters happen to be low and lower middle income countries whereas the high $CO_2$ emitters group is mainly formed with high income countries.

Thirdly, when looking at the form of the distribution, this would have moved towards a bipolar position, something that is also highlighted by Wolfson's measure. In fact, Wolfson`s the measure just placing greater emphasis to the effect of the sizes of the groups (ie the equalization in the sizes) that reduction of the groups'gap. This result, in fact, introduces certain reservations towards the previous results. It so happens that some conflict models establish that this would reach its apogee in the presence of symmetrical bipolar distribution (Esteban and Ray, 1999).

Fourthly, despite the foregoing, the EGR (2) and the DER indices drop during the period when the role of all the parameters is evaluated. The reason for this is the role played by the alienation factor, which dropped significantly. Therefore, it is true that two poles are forming, and this could prove problematic like the previous comment underlines, though it is also true that the mean distances between the groups have shortened.

Fifthly, the decomposition of the DER index corroborates the above and specifies the role of the two factors underlying the polarization movement. In particular, they indicate that the reduction in polarization would have occurred at the cost of the divergent evolution of the two factors that explain it; in other words, the alienation would have decreased but the identification would have increased.

Finally, the Z-K indices for different exogenous groupings confirm the reduction in polarization, typically since 2000. In this case a structure based on three development groups (according World Bank classification) provides the most attractive explanatory results. The indices based on regional groupings only provide good results if we use 14 groups, which would will less operationally feasible in political terms.

Above and beyond our understanding of the phenomenon, certain implications can be extracted from the above results which are interesting in policy terms:

Firstly, the world seems to have (multi) polarized less because the reduction in the inequalities between groups. In this sense, it is important to encourage the inter-group convergence of emissions, particularly from the group of the main emitters. In particular, we will need to focus in the main drivers that explain carbon emissions inequalities. On this regard, we have the reference of the STIRPAT models and the kaya identity (1989): affluence, carbonization and energy intensities, for instance

Secondly, however and despite the previous comment, there are some evolutionary elements of concern. For example, in the period of analysis there has been a process of equalization in sizes of groups (in the case of two groups) and a move towards greater cohesion (identification) intra-group. In this sense, a world stagnated around two homogeneous and symmetric poles can be a more unstable world where conflicts are more likely and, most importantly, more intense (Esteban and Ray, 2008). Once again it is necessary to promote inter-group convergence from the main pollution-emitting countries. The point of this paper is that this is not just important in global terms but, most particularly, in terms of the levels of potential world conflict.

Thirdly, the country distribution of emissions is clearly endogenous structured into two groups, those that emit less than the world average and those that emit more than the average. This is because this is the structure that best explains the real distribution of emissions between countries. In this sense, it might make sense, among other possibilities, detailing the emissions targets at this level of aggregation.

Fourthly, exogenous structures based on three groups of countries according to their development levels is also quite interesting. This grouping would explain nearly half the current inequalities, which is important given the predetermined aggregation criterion, compared to the previous endogenous groups based on similarities in their pollutant behaviour which could vary over time. The use of these exogenous groups as a reference for the negotiation process does, in fact, can be also relevant

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# TABLES

### Table 1. Polarization of carbon emissions per capita according to the EGR family of indices and Wolfson's measure

| | EGR (2) | ε | ε/Gini | EGR (3) | ε | ε/Gini | EGR (4) | ε | ε/Gini | W |
|---|---|---|---|---|---|---|---|---|---|---|
| **1992** | 0.204 | 0.119 | 19% | 0.127 | 0.053 | 9% | 0.106 | 0.026 | 4% | 0.294 |
| **1995** | 0.191 | 0.127 | 22% | 0.125 | 0.051 | 9% | 0.108 | 0.027 | 5% | 0.254 |
| **2000** | 0.189 | 0.128 | 22% | 0.122 | 0.054 | 10% | 0.103 | 0.027 | 5% | 0.249 |
| **2005** | 0.157 | 0.150 | 27% | 0.123 | 0.047 | 9% | 0.107 | 0.027 | 5% | 0.302 |
| **2010** | 0.156 | 0.119 | 24% | 0.122 | 0.047 | 9% | 0.108 | 0.036 | 7% | 0.401 |

Note: ε is the absolute error associated with the groupings and ε/Gini is the relative error, which can be considered as a proxy of the explanatory capacity of the groupings

Source: Drawn up by the authors using the World Bank data set

### Table 2. Polarization as measured by DER indices and Alienation-Identification decomposition

| | DER(0.5) | Alien. | Ident. | Corr. | DER (0.75) | Alien. | Ident. | Corr. |
|---|---|---|---|---|---|---|---|---|
| **1992** | 0.304 | 0.598 | 0.561 | -0.094 | 0.234 | 0.598 | 0.444 | -0.118 |
| **1995** | 0.299 | 0.577 | 0.564 | -0.082 | 0.229 | 0.577 | 0.445 | -0.100 |
| **2000** | 0.296 | 0.571 | 0.565 | -0.083 | 0.221 | 0.571 | 0.447 | -0.105 |
| **2005** | 0.282 | 0.537 | 0.571 | -0.082 | 0.215 | 0.537 | 0.449 | -0.109 |
| **2010** | 0.278 | 0.503 | 0.589 | -0.061 | 0.215 | 0.503 | 0.468 | -0.085 |

Source: Drawn up by the authors using the World Bank data set

## Table 3: Exogenous polarization according to WB income groups, 1992–2010

| | Z-K (2) | % | Z-K (3) | %. | Z-K (4) | %. |
|---|---|---|---|---|---|---|
| **1992** | 0.830 | 45% | 0.641 | 39% | 1.065 | 52% |
| **1995** | 0.762 | 43% | 0.773 | 44% | 1.105 | 52% |
| **2000** | 0.906 | 48% | 1.219 | 55% | 1.709 | 63% |
| **2005** | 0.515 | 34% | 1.018 | 50% | 1.194 | 54% |
| **2010** | 0.307 | 23% | 0.845 | 46% | 0.923 | 48% |

Source: Drawn up by the authors using the World Bank data set

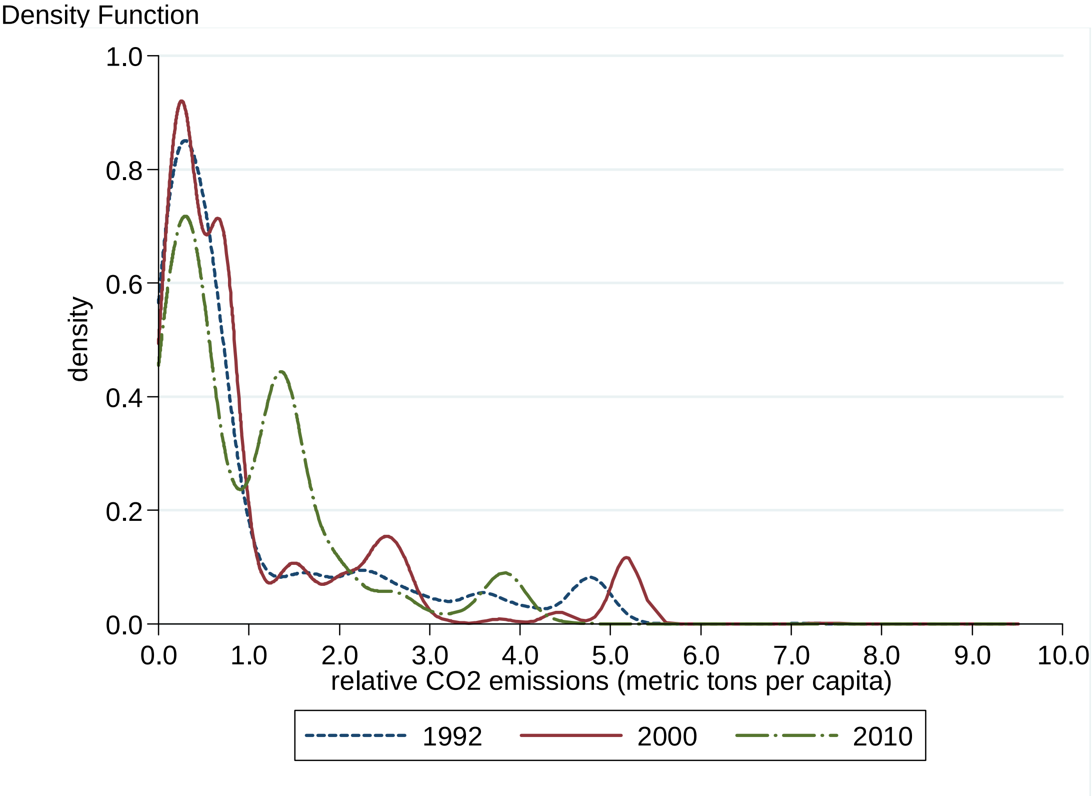
## Table 4: Exogenous polarization according to regional WB groups, 1992–2010

| | Z-K (Geo7) | % | Z-K Geo 14) | %. |
|---|---|---|---|---|
| **1992** | 1.688 | 63% | 2.650 | 73% |
| **1995** | 1.473 | 60% | 2.526 | 72% |
| **2000** | 1.527 | 60% | 2.470 | 71% |
| **2005** | 1.347 | 57% | 2.513 | 72% |
| **2010** | 1.069 | 52% | 2.481 | 71% |

Source: Drawn up by the authors using the World Bank data set

## FIGURES

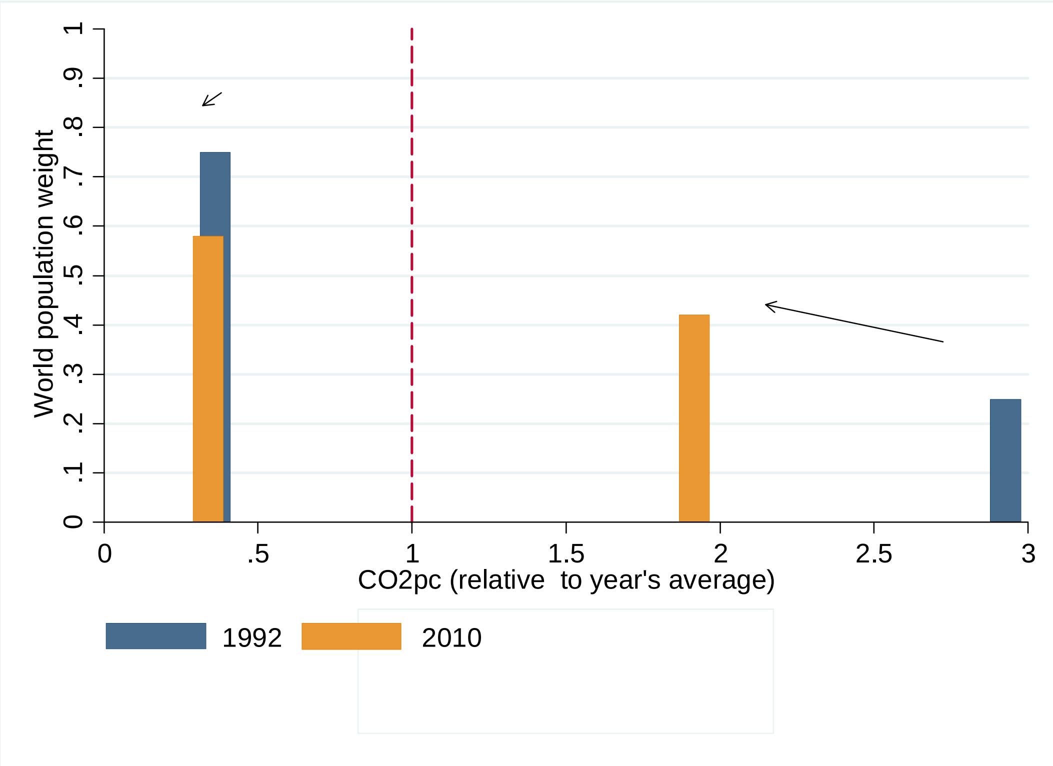
### Figure 1: Evolution of density functions of the international distribution of $CO_2$ emissions per capita, 1992–2010




Source: Drawn up by the authors using the World Bank data set

**Figure 2: Characteristics of the two groups, in 1992 and in 2010**

Relative Population




Note: the year's average is the weighted average according to the population size

Source : Drawn up by the authors using the World Bank data set