Cross-country polarisation in CO_2 emissions per capita in the European Union: changes and explanatory factors

Abstract

We analyse the degree of polarisation in the international distribution of CO_2 emissions per capita in the European Union. It is analytically relevant to examine the degree of instability inherent to a distribution and, in the analysed case, the likelihood that the distribution and its evolution will increase or decrease the chances of reaching an agreement on climate policy. Two approaches were used to measure polarisation: the endogenous approach, in which countries are grouped according to their similarity in terms of emissions, and the exogenous approach, in which countries are grouped geographically. Our findings indicate a clear decrease in polarisation since the mid-1990s, which can essentially be explained by the fact that the different groups have converged (i.e. antagonism among the CO_2 emitters has decreased) as the contribution of energy intensity to between-group differences has decreased. This lower degree of polarisation in CO_2 distribution suggests a situation more conducive to the possibility of reaching EU-wide agreements on the mitigation of CO_2 emissions.

Key words: CO_2 emissions, distribution of emissions, European Union, mitigation agreements, polarisation.

1. Introduction

The concept of polarisation is associated with the degree to which the distribution of a given variable tends to cluster around homogeneous poles which are distant from one another. A distribution is highly polarised when there are few poles, each large in size, and a high degree of antagonism between them. Interest in this phenomenon, and in measuring it, is due to its link to the potential for conflict. Moreover, as demonstrated by Esteban and Ray (1994), this concept is also fundamentally different from that of inequality (Cowell, 1995). Inequality indexes only measure the degree of dispersion of observations and so do not capture the degree of antagonism between groups as polarisation does. There may be a case in which overall inequality declined but the observations of a distribution—CO_2 emissions per capita of different countries in our case—formed more homogeneous groups around different poles. In these circumstances, this reduction in inequality within groups could be linked to more conflicts of interest and antagonism between different groups, which will be reflected in an increase in polarisation indexes.

Because polarisation is associated with the potential for conflict, it is an especially relevant concept for the analysis of scenarios in which agents must negotiate and reach agreements. This is the case for the agreements on how to distribute, among the various European Union countries, the necessary efforts to reduce CO_2 emissions in order to meet the mitigation objectives assumed by the European Union as a political unit. Specifically, it would seem reasonable to assume that, all other factors being equal, greater polarisation of the distribution

of CO_2 emissions among European Union countries would mean less cohesion around effort-sharing proposals and greater difficulty in reaching agreements. Conversely, lower polarisation would mean closer interests of the different countries, fewer conflicting views on the criteria that should be used to distribute emission reduction efforts among countries and thus more opportunities to reach agreements on how to share the burden of mitigation. Furthermore, it should be noticed that mitigation agreements can also influence the evolution of polarisation with consequences on the possibility to achieve new agreements.

The European Union has demonstrated greater commitment to the struggle against climate change than any other political community to date. In March 2007, the European Council committed to reducing greenhouse-gas emissions by at least 20% (compared to 1990 levels) by 2020, with the option of raising the target to 30% if the other high-income countries agreed to a comparable objective. Nevertheless, there is great inequality among the various EU countries in terms of emissions per capita, the ambition to meet the set goals, and stances with regard to the criteria to be applied in the distribution of efforts. The emission-reduction efforts required of the various member states in order to meet the 2020 target were not established until April 2009 (Decision no. 406/2009/EC of the European Parliament and of the Council). The effort-sharing discussions were complicated, and conflicts arose between the objectives of various groups of countries (as, for example, at the European summit of October 2008 in Brussels, where a group of eight Eastern European countries called into question whether the previously agreed objectives should be

maintained).[1] Similar processes of negotiation and conflict had already occurred in the Kyoto discussions among the then 15 EU member states leading up to the adoption of the 8% reduction target. Today, due to the larger number of member states and the diverse range of situations they bring to the table, as well as the need to reach increasingly ambitious goals in the future, it is more important than ever to analyse the various factors that can increase or decrease the likelihood of reaching agreements at an EU level.

Given the potential importance of the subject, it seems worthwhile to conduct a quantitative assessment of the evolution of the polarisation of emissions of the various European Union countries. The literature describes two main approaches for measuring polarisation. The first of these is the endogenous approach, in which groups (of countries, in our case) are formed on the basis of similarities, using mechanisms aimed at minimising intra-group differences. The polarisation indices developed by Esteban and Ray (1994) and Esteban et al. (2007) for multiple-pole cases and by Wolfson (1994, 1997) and Wang and Tsui (2000) for the specific bipolar case are commonly cited examples of this approach. The second is the exogenous approach, comprising methods in which groups are determined ex-ante, for instance on the basis of geographical criteria. One example is the method proposed by Zhang and Kanbur (2001), which is based on inequality decomposition by population subgroups (Shorrocks, 1984).

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[1] Specifically, Bulgaria, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia, with Italy later joining the group. The governments of these countries questioned whether the goals should be so ambitious and rejected the adoption of measures that did not adequately respect the various countries' differences in terms of economic potential.

This concept has previously been applied to the analysis of environmental distribution by Ezcurra (2007) and Duro and Padilla (2008), who analyse polarisation in the international distribution of CO_2 emissions using the indices proposed by Esteban et al. (2007), and by Duro (2010), in a paper analysing international polarisation by means of the exogenous approach, which also made it possible to carry out a factor decomposition analysis. Ezcurra (2007) also uses non-parametric tools for analyzing polarisation through Kernel density function estimates (based on Quah, 1997). In the present study, we carry out the first polarisation analysis for the European Union—a 27-country political unit that has adopted mitigation objectives—using both the exogenous and endogenous approaches, with a view to gaining a more complete understanding of the situation. Specifically, we analyse the polarisation of CO_2 emissions per capita in the European Union from 1990 to 2007.

The rest of the paper is structured as follows. In Section 2, we review the main methodological aspects associated with the measurement and decomposition of polarisation. In Section 3, we provide empirical evidence derived from the application of polarisation measures to the case of CO_2 emissions in European Union countries from 1990 to 2007. Finally, in Section 4, we present our main conclusions.

2. Methodological aspects

Esteban and Ray (1994) suggest defining distributive polarisation in terms of the degree to which the observations (in our case countries) concentrate around opposing groups. This notion, which approaches the fracture of a given distribution, seems highly related to the probability of emergence of conflicts. In this sense, it seems interesting to have statistical measures showing the degree of polarisation present in distributions and thereby offer a quantitative approach to distributive inherent instability[2]. In this regard, the literature has made several contributions, which can be grouped into two major categories. The first category comprises methods in which groups are formed optimally, with the aim of minimising within-group heterogeneity. In this case, the groups of observations are therefore not set ex ante, for example, with regional or geographical criteria, but are formed according to information on the characteristics of observations. This category includes the ER indices, proposed by Esteban and Ray (1994), and the EGR indices, proposed by Esteban et al. (2007), both designed for general cases of polarisation (i.e., for any number of pre-established groups), as well as the measures proposed by Wolfson (1994, 1997) and Wang and Tsui (2000), designed specifically for analysing strictly the bipolar case. The second category includes the Z-K index, proposed by Zhang and Kanbur (2001). In this case, the pre-defined groups and the related measures are calculated without discussing the relevance of these groupings. For example, if the country analysis clustering was related to immediate regional areas because of their possible internal homogeneity.

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[2] The non-parametric techniques for analysing the shape and dynamics of a distribution—in other words, density function estimation— are unable to obtain precise quantitative information about changes in polarisation over time (Ezcurra, 2007).

Whatever the case, all the methods for measuring polarisation, regardless of category, satisfy two basic propositions. First, the measured polarisation increases as within-group inequality decreases; in other words, greater internal cohesion strengthens group identification and therefore increases the potential for conflict ("identification effect"). Second, the measured polarisation increases as the distance (antagonism) between the groups increases ("alienation effect").

With the notation adapted to the analysis of CO_2 emissions, the EGR indices would formally be defined as:

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

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 European Union average (in our case); α is the parameter that measures the sensitivity of the index to polarisation, the value of which falls between 1 and 1.6; $\beta \geq 0$ is a parameter showing the measure's sensitivity to the groups' level of cohesion; G is the Gini coefficient of the original distribution; and G_s is the Gini coefficient of the grouped distribution (between-group inequality). The higher the value of α, the greater the conceptual difference between EGR and the Gini coefficient.

The measure has two addends. The first addend corresponds to the ER index, which is axiomatically derived using a behavioural model (Esteban and Ray, 1994). The second addend takes into account the error committed when the observations are grouped and the distribution is simplified by poles, thereby incorporating a statistical approach into the measurement of polarisation.

Specifically, this second addend is equal to the difference between the overall inequality and the between-group inequality, and therefore provides an intuitive estimate of the degree of within-group inequality (i.e., a proxy of the error associated to grouping). The parameter β weights this error component ($\varepsilon = G - G_s$) in the general value of the measure. Thus, following Duro (2005), it would be reasonable to set β at a value of 1, mainly because the EGR and Gini expressions are similar and, as we see, the EGR contains Gini indexes.

Before the aforementioned formula can be applied, we must define the cut-off points between the groups (which are exhaustive and mutually exclusive), thus obtaining a simplified representation of the original distribution. As an example, one reasonable option would be to establish these boundaries following the method proposed by Davies and Shorrocks (1989), in which the cut-off point between groups is defined by the average weighted emission (income in the original formulation) of the two adjacent groups.

The EGR measures seem, for various reasons, to be preferable to those proposed by Wolfson (1994, 1997) and Wang and Tsui (2000). First, they are theoretically derived from the establishment of conflict models. Second, they can be applied not only to the examination of bipolarisation, but also to the general analysis of polarisation.

It may also be of interest to analyse the degree of polarisation when groups are determined ex-ante according to some reasonable criterion, such as geographical location; for instance. Zhang and Kanbur (2001) suggested a

polarisation measure based on the inequality decomposition by groups (Shorrocks, 1980, 1984). Thus, they use the fact that the inter-group inequality (T_b) measures the degree of antagonism (positively related to the degree of polarisation and conflict) and that intra-group inequality (T_w) approximates the degree of internal cohesion and therefore the group identification (positively related to the degree of polarisation and conflict) to derive a summary measure such as the following:

$$Z - K = \frac{T_b}{T_w} \tag{2}$$

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.

Note that the numerator reflects the magnitude of the heterogeneity between the groups, like the alienation effect in the EGR approach, while the denominator reflects the magnitude of the internal heterogeneities, like the identification effect. Thus, growth in the between-groups component (i.e. groups becoming more antagonistic) consistently tends to increase the value of the measure, whereas an increase in internal heterogeneity (i.e. less identification) tends to reduce it.

This measure also behaves differently from conventional inequality measures such as the Gini or the Theil index (see Cowell, 1995). Specifically, the

discrepancy is associated with the different role attributed to intra-group inequality. There is a positive relationship between intra-group inequality and the global inequality approach, but it is negative in the polarisation approach. For practical purposes, therefore, a significant variation of the within-group component could lead to inconsistent patterns between inequality measures and the Z-K measure.[3]

An essential aspect, for analytical purposes, is that the between-group inequality component can in turn be decomposed by multiplicative factors, such as the factors of the Kaya identity (1989), according to the methodology proposed by Duro and Padilla (2006). The same procedure can also be performed in the within-groups component, given that it is simply a weighted average of inequality indices. Therefore, as Duro (2010) noted, we can evaluate the sources of change in the value of the Z-K index by decomposing its group components. The methodology proposed by Duro and Padilla (2006) first measures the partial contribution of each factor to overall inequality as the quantity of inequality that would persist if only the examined factor changed among countries, taking the other factors equal to the mean. Thus the perfect decomposition of inequality is achieved by adding two interaction components, showing the joint contribution of the factors to inequality.

3. Empirical evidence

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[3] Analyses of international distribution of emissions that use the inequality approach include Heil and Wodon (1997), Hedenus and Azar (2005), Padilla and Serrano (2006) and Duro and Padilla (2006).

3.1. Endogenous groups

Let us begin by analysing the changes in CO_2 emissions per capita in the European Union between 1990 and 2007. The data—provided by the International Energy Agency (IEA) (2010a)—refer to metric tons of CO_2 emissions from fossil-fuel combustion. Emissions per European Union inhabitant dropped by 7.8% over the period (Figure 1). The emissions dropped most sharply between 1990 and 1994 and, despite fluctuations, the trend since 1994 has been towards stabilisation at around 8 metric tons. Changes in emissions per capita from 1990 to 2007 were more positive in the European Union than in the world as a whole, with the latter registering a 10% increase during the same period.[4]

FIGURE 1 ABOUT HERE

Before offering the polarisation calculations, it might be useful to build the density function of the distribution of CO_2 per capita in EU countries through non-parametric techniques. This gives us a visual indication of the shape of the distribution and its evolution throughout the period[5]. Figure 2 reproduces the kernel estimates for four selected years of the period: 1990, 1995, 2000 and

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[4] Nevertheless, it should be noted that per capita emissions in the European Union were 80% higher than the world average in 2007.

[5] 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) and Ezcurra (2007). 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.

2007^6. We find, for example, that the distribution of CO_2 emissions per capita in the EU in 2007 is clearly unimodal, with the bulk of the population by countries around the average distribution. Whatever the case, the most interesting figure is the pattern of evolution in time. Visually, there are two characteristics: first, the mode has shifted toward higher relative levels since 1990, and, second, the distribution seems to have moved from a bimodal format to the aforementioned one-peak[7]. This evolution, with the tendency to compaction of two modes at a time, should be quantified in terms of a reduction of polarisation. In either case, we need to know the values of synthetic indexes associated with the measurement of this polarisation feature.

FIGURE 2 ABOUT HERE

Let us now analyse the evolution of polarisation that has accompanied the changes in emissions in the European Union. If, for example, the overall reduction in emissions per capita had coincided with an increase in polarisation, then tensions could be expected to arise among the countries, against a backdrop of the need to reach mitigation agreements.

First, we computed the values of the EGR family of indices (generalised polarisation measure) for the international distribution of CO_2 emissions per capita between 1990 and 2007. In order to test the robustness of the calculations, we considered three different values for the parameter α for the

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[6] The density functions were estimated for every year in the period. The results are available from the authors upon request.

[7] This can be formally confirmed through multimodality texts (see Bianchi, 1997)..

cases of two (Table 1), three (Table 3) and four groups (Table 5), respectively—the cases that, according to the literature, seemed most reasonable. The value of β was set at 1, according to Duro (2005). The appendix shows the composition of the groups of countries obtained endogenously by means of the optimisation procedure suggested by Davies and Shorrocks (1989)[8].

In all cases an increase in the value of EGR indexes is indicative of an increase in polarisation. Tables 1, 3 and 5 include the values of the ER index (the first term of the expression (1)) and the error term emerged by grouping. Thus, an increase in the ER index value tends to increase the value of the EGR. Moreover, an increase of the error (ε) tends, ceteris paribus, to reduce the value of the EGR, as it helps to reduce intra-group cohesion.

The results indicate a certain stability of values towards the mid-1990s, and a considerable non-monotonic decrease since then (Tables 1, 3 and 5). This pattern holds regardless of the parameterisation used for α and the number of groups. For example, the two-group EGR decreases by 38% when $\alpha = 1$, by 42% when $\alpha = 1.3$, and by 49% when $\alpha = 1.6$; the three-group EGR decreases

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[8] In particular, these authors suggest an algorithm to establish the groups so as to maximise inter-group inequality and, therefore, be as close as possible to the overall inequality. This procedure thus involves minimising the quantity of intra-group inequalities. The programme used to limit them was built using GaussView software. Obviously, other endogenous grouping criteria could have been used, such as the clustering procedure suggested in Phillips and Sul (2007). However, our understanding is that the mechanism established by Davies and Shorrocks is not only intuitive but more consistent with the approach of polarisation suggested by Esteban and Ray (1994).

by 27%, 31% and 35%; and the four-group EGR decreases by 22%, 23% and 25%, respectively.[9]

Let us now consider the role of changes in relative weights and relative emissions (between-groups distance) by groups in determining the evolution of the ER component. Thus, if the relative populations are equalised and/or the distances between groups increase, polarisation tends to grow. In the bipolar case (Table 2), we can clearly discern the role of the lower degree of alienation, given that the groups of countries with the lowest and highest levels of relative emissions are both close to the mean. In particular, the process of convergence to the mean associated with the low-emissions groups is mainly explained by the increase in relative emissions produced in Spain and Italy. Also, the convergence pattern made by the high-emissions group is mainly determined by the decrease in relative emissions experienced by Germany and, in second place, by the UK and Poland. In the three-group case (Table 4) we see a similar effect, with the middle and high groups approaching the mean (in the first case explained by the overall reduction of relative emissions and in the latter case by the approach to the mean made by Germany), but also a weighting effect due to the increased size of the middle group (due to the inclusion of Spain and Italy) [10].

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[9] The level of polarisation of emissions is considerably lower in the European Union than in the world as a whole (Duro and Padilla, 2008), regardless of the number of groups analysed and the value of the parameters. Moreover, the EGR value with parameters $\alpha = 1$ and $\beta = 1$ can be compared with the Gini coefficient, which moves in a range between 0 and 1. In this case, the polarisation values do not seem excessive. However, for example, the polarisation of emissions is higher than the regional polarization in Europe in terms of GDP per capita (Ezcurra et al., 2007).

[10] It is easy to understand that the role of countries depends on their relative weight (population-share) and their relative emissions per capita. In this case, the convergence to the mean process made by large countries such as Germany and

In addition, an analysis of the error term (ε) reveals that variations in this term over time have a limited impact on reducing the aforementioned polarisation. In the bipolar and four-group cases, the value of the error in 2007 is very similar to that obtained in 1990. In the three-group case, variations in the error term are somewhat greater, but their contribution to the decrease in polarisation is significantly smaller than the contribution of changes in the aforementioned relative weights and relative emissions. Thus, in global terms, the generalised evolution of polarisation can be attributed to the simplified polarisation component.

An interesting issue to analyse is whether the Kyoto agreement has influenced the evolution of polarisation. Mitigation agreements take into account emission distribution—involving greater reductions to greater polluters—and so may cause a polarisation reduction by inducing a reduction in between-group inequality that may, in turn, facilitate new agreements. If we analyse in detail Figure 3, it is not clear that this mechanism has worked in the observed reduction in polarisation. The decreasing trend in polarisation starts in 1994, before the Kyoto agreement. There is also an important reduction in polarisation between 1997 and 1999, and a stabilisation afterwards. However, we are not able to ascertain whether this second reduction in polarisation between 1997 and 1999 is directly related to the signing of the Kyoto protocol in December

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United Kingdom (which reduce their CO_2 relative emissions per capita from 1.40 to 1.23 in 1990 and 2007 and from 1.13 to 1.09, respectively) and Spain and Italy (which move from 0.61 to 0.97 and 0.82 to 0.93, respectively) largely explain the reduction in levels of polarization. More details about the role of the different countries are available from the authors on request.

1997. Our view is that the impact of the measures derived from the protocol on the distribution of emissions would be posterior, when the policy measures associated with the agreement were developed and could have impacted on the emissions of different countries[11].

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

TABLE 3 ABOUT HERE

TABLE 4 ABOUT HERE

TABLE 5 ABOUT HERE

Note that the different endogenous groupings have a high explanatory capacity. In the two-group case, inter-group differences account for 70% of the overall international inequalities (Table 6); this explanatory capacity reaches 89% in the three-group case and 94% in the four-group case. The limited increase in explanatory capacity as the number of groups increases beyond three leads us to prefer the three-group simplification. In any event, as Esteban et al. (2007) noted, the value of the generalised polarisation itself provides clues as to the most appropriate grouping. The analysis clearly indicates that the two- and

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[11] Whatever the case, we consider that agreements should be designed to take into account their potential impact on polarisation as, following our hypothesis, a reduction of polarisation would facilitate later agreements.

three-group cases are superior to the four-group case, but does not conclusively point to a general preference between the two- and three-group cases. Thus, with the exception of the past few years, the two-group simplification seems to be the most appropriate option. However, in the interest of maintaining explanatory capacity, the three-group option is the preferred form of analysis for the most recent years of the study period (Table 6).

TABLE 6 ABOUT HERE

As the groups are formed according to the differences in emissions per capita, which is also the main criterion explaining the differences in emission reduction targets, the group of lower emissions tends logically to include the countries with less stringent commitments, while the group of higher emissions is the one that contains most of the countries with more stringent commitments (see Table A.1)[12]. There are, however, various exceptions such as Austria, Ireland or Finland—and there is no clear divide, as the reduction targets are far from being proportional to the differences in emissions per capita[13].

An analysis of the evolution of inequality—a distribution concept that is, as mentioned above, fundamentally different from polarisation—reveals, in the

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[12] The two-group classification used by Duro and Padilla (2008) in their analysis of international polarisation was very similar to the classification between Annex B and others. There was a clear correlation between the industrialised countries conforming to Annex B—the ones committed to controlling their emissions—and the group of countries with greater emissions per capita.

[13] Moreover, it should be taken into account that the Kyoto protocol was signed in 1997 when the emissions of several countries were quite different from 1990, especially in some economies in transition.

same period, a noticeable downward trend that is nonetheless generally more monotonic than the trend revealed by the polarisation measures (Figure 3). While the EGR indexes of polarisation for two, three, and four groups decrease by 42.1%, 30.6% and 23.2% respectively over the course of the study period; the Gini coefficient decreases by 20.3% and the Theil indexes (T(0) and T(1)) and the Coefficient of Variation (CV) (other well-known inequality indexes[14]) show an even larger reduction (32.2%, 35.2% and 43.6% respectively). Therefore, both distributive indicators (polarisation and inequality) show a clear downward trend.

Table 7 shows the coefficients of correlation between selected polarisation and inequality indexes. Global correlation is positive and significant. However, these correlations do not invalidate the analysis for various reasons. First, as shown above, polarisation indexes measure a different concept than standard inequality indexes. Thus, in terms of the analysis of international distribution, it is of interest to know if both distributive dimensions, inequality and polarisation, change in the same direction (reinforcing each other) or not. Second, besides the general correlation found, there are some important specific differences.

TABLE 7 ABOUT HERE

Though the overall pattern is comparatively downward, significant disparities also emerge between the evolution of inequality and that of polarisation which are observed in more detail. In Table 8 some periods with significant

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[14] See Cowell (1995) for a survey on inequality index properties.

discrepancies between the rates of polarisation and some well-known inequality indices have been identified. For example, while in the periods 1990–1992, 1990–1993, 1999–2002 and 1990–1994 polarisation measures show a general increase, inequality indexes fell significantly.

FIGURE 3 ABOUT HERE

TABLE 8 ABOUT HERE

For instance, the different evolution of inequality and polarisation in the period 1990–1994 can be attributed to the changes in the within-group identification component. The reduction in within-group inequality would increase identification within a group and thus polarisation. Therefore, polarisation increases while inequality decreases for this period. In short, the increase in group cohesion is due to an increased cohesion in the group of higher emissions per capita, basically due to the convergence to the mean of Germany and Czech Republic. There is also an increase in group cohesion for the group of lower emissions, due to the process of convergence to the mean of Spain and Portugal.

The analysis of both concepts helps to a better interpretation of the international distribution and to its analysis in terms of policy. For example, in the cited period the reduction in inequality coincides with an increase in polarisation that could make the distribution more conflictive, even though emissions are more evenly distributed. Thus, the increase in polarisation would offset the improvements in equity for this period.

3.2. Exogenous groups

As a complement to our analysis of endogenous groups, it is of interest to analyse the polarisation found using ex-ante groups of countries. We selected geographical location as a reasonable criterion for the grouping. Specifically, we chose an apparently reasonable three-group structure that provides better results than other exogenous segmentation options[15]. We named the groups Europe North (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom), Europe East (Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia) and Europe South (Cyprus, Greece, Italy, Malta, Portugal and Spain). Although this proposal is based on geographical, political and economic criteria rather than on an optimisation process as in the previous section, we find a degree of similarity between this analysis and that of the endogenous groups; note, for example, the degree of agreement with the other grouping for the year 2007[16] .

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[15] Obviously, other exogenous grouping criteria could have been used. The regional segmentation used in the paper was the one that provided better results in terms of the between-groups inequality component. We also checked the relevance of alternative exogenous groupings of EU countries using, for instance, as a benchmark indicator the average industrial structure (weight of manufacturing in GDP over the period 2004–2008). In all cases (groups) and years analysed the explanatory relevance of these groupings (estimated through the ratio Tbetween/Ttotal) was much lower than that associated with the regional groups finally considered in the text. For example, for the year 1990, the ratio associated with the chosen grouping was 33%, while it was only 10% for the best of cases using industrial structure as a reference indicator for forming the groups. Estimates are available from the authors upon request.

[16] There are, however, several countries that do not fit this trend. This is the case, for example, of France and Sweden which, despite belonging to Europe North and having high per capita incomes, have lower emission levels due to the

For this analysis we used the Z-K index, which has the advantage of being decomposable, a characteristic which enables us to investigate which sources explain the overall polarisation results. Table 9 shows the results of the Z-K index for the aforementioned groups of EU countries. As in the case of EGRs, an increase in the value of the Z-K index is interpreted in terms of an increase in polarisation. As in the endogenous polarisation analysis, we find a clear overall decrease over the course of the study period: the value of the polarisation measure dropped from 0.50 in 1990 to 0.12 in 2007. This amounts to a 77% decrease, which is larger than the reduction calculated for the endogenous indices mentioned above.

As previously stated, one of the advantages of these measures is that they can be decomposed immediately in order to understand the role of the identification component (proxied by within-group inequality) and the alienation component (proxied by between-group inequality). In this respect, an analysis of the group inequality components indicates that the bulk of the decrease can be attributed to the behaviour of the between-group component, which decreased by 79% during the study period, while the 9% decrease in within-group inequality helped to increase polarisation (by making the various groups somewhat more internally homogeneous). This result is in line with our intuitive interpretation of the endogenous polarisation analysis. Also, the rather low level reached by the between-group component indicates that any significant future reductions in polarisation would have to be based on an increase in the within-group

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importance of nuclear power and, in the case of Sweden, renewable energy sources. There are also various countries in the Europe East group which show very high emissions per capita, such as Estonia and Czech Republic.

component (in other words, a lower level of internal cohesion would prevent groups from forming around different interests).

TABLE 9 ABOUT HERE

Given the importance of the evolution of the between-group component in explaining the reduction in exogenous polarisation, it is of interest to investigate the factors behind this evolution. The Kaya identity (1989) enables us to decompose emissions per capita into three factors: carbon index (CO_2 emissions per unit of primary energy, CO_2/PE), energy intensity (primary energy per GDP unit, PE/GDP), and affluence (GDP per capita, GDP/P). The methodology proposed by Duro and Padilla (2006) makes it possible to decompose the value of the Theil index of inequality in emissions per capita into the inequality attributable to the three Kaya factors plus two interaction terms. We applied this methodology to decompose the between-group inequality.

The decomposition results shown in Table A.2 of the Appendix indicate that the partial contribution of energy intensity played an important role in the considerable decrease in inequality (81%). Nevertheless, the great importance of the interaction factors obliges us to consider their evolution as well, in order to account for the overall effect on the evolution of the components associated with the different Kaya factors. If we distribute the interaction components among the various factors that generate them following the criterion of Shorrocks (jointly generated, equally distributed), we obtain the results shown in Table 10. The lower contribution to inequality of energy intensity—which no longer plays anything like a leading role—largely explains the evolution of the

inequalities and offsets the greater contribution associated with the affluence factor.[17] The negative component can be explained by the fact that the region with the greatest energy intensity tends to be the one with the lowest GDP per capita (note the significantly negative interaction factor in Table A.2), which results in these two inequalities cancelling each other out and, in the case of energy intensity, leading to a negative net contribution. Table 11 shows the characteristics of the different exogenous groups.

TABLE 10 ABOUT HERE

TABLE 11 ABOUT HERE

Let us now examine the component associated with the energy intensity factor. The observed pattern can be explained by a relative reduction in energy intensity in the Europe East group in particular, paired with a relative increase for Europe South (this is in the context of reduced energy intensity for Europe as a whole: from 1990 to 2007, Europe went from 191 to 142 tonnes of oil equivalent per US$1 million for the year 2000 at purchasing power parity).[18]

The within-group component is less relevant to explaining the evolution of polarisation in the European Union. This polarisation—which, as mentioned above, has tended to increase—can essentially be attributed to the smaller contribution of GDP per capita to within-group inequality (Table 12). The groups

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[17] See Padilla and Duro (2011) for a more detailed analysis of the decomposition of inequality at the EU level into the various Kaya factors.

[18] In the Europe East zone, energy intensity dropped from 359 to 193 over the same period.

are therefore somewhat more homogeneous as a result of this factor's smaller contribution to within-group inequality.

TABLE 12 ABOUT HERE

4. Concluding remarks

In this study, we have made the first analysis of the polarisation of CO_2 emissions per capita for the countries of the European Union from 1990 to 2007. The study offers an in-depth examination of the measurement of a distributional characteristic closely related to the likelihood of reaching agreements on mitigation policy, a crucial aspect in the current context of EU policies and strategies to mitigate climate change.

In this analysis, we used the EGR indices (Esteban et al., 2007), which are designed for analysing polarisation in general (i.e. regardless of the number of groups) and take into account the error committed in the formation of groups. We also used the Z-K polarisation index (Zhang and Kanbur, 2001), which allows the analysis of polarisation with exogenous groups (in our case, three regional groups: Europe North, Europe South and Europe East) and the decomposition of the results by explanatory factors.

Our findings revealed a considerable non-linear decrease in polarisation concentrated between the mid-1990s and the present day. Most of this decrease can be attributed to the convergence of the various groups in terms of emissions per capita (i.e. antagonism between the groups has decreased). In

the endogenous analysis, segmentation of the countries into two or three poles was found to be very appropriate, with a low level of information loss associated with the grouping. In the analysis of the polarisation with exogenous groups—which showed an evolution qualitatively similar to that of the polarisation with endogenous groups—we confirmed that the decrease in polarisation can be attributed to the lower degree of antagonism between the groups, which can largely be explained by the lower contribution of the energy intensity factor. Indeed, energy intensity goes from being the main factor explaining the divergence among the groups to playing a role in reducing this divergence, a phenomenon explained by the strong negative between-group correlation between energy intensity and affluence. The internal coherence of the groups increased slightly, but this effect was easily offset by the decreased antagonism between the groups.

In short, we found that the overall reduction in emissions per capita in the European Union has coincided with a considerable reduction both in the polarisation of the distribution and in inequality. The overall evolution has thus been marked by a process of convergence among the countries, which tends to reduce tension in negotiations and increase the likelihood of reaching agreements on common mitigation policies at an EU level. Nevertheless, despite the reduced level of divergence in the distribution, the chances of reaching such an agreement are also heavily influenced by the degree of overall sacrifice required. If drastic levels of greenhouse-gas reduction are required—greater than 50% or 80%, as is recommended to help stabilise atmospheric gases at levels considered to be reasonable—then the persistence

and evolution of distributional differences will continue to be highly relevant factors in discussions about mitigation agreements.

Acknowledgements

Appendix

TABLE A.1. ABOUT HERE

TABLE A.2. ABOUT HERE

TABLE A.3. ABOUT HERE

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Figure 1. Evolution of CO$_2$ emissions per capita in the European Union, 1990–2007
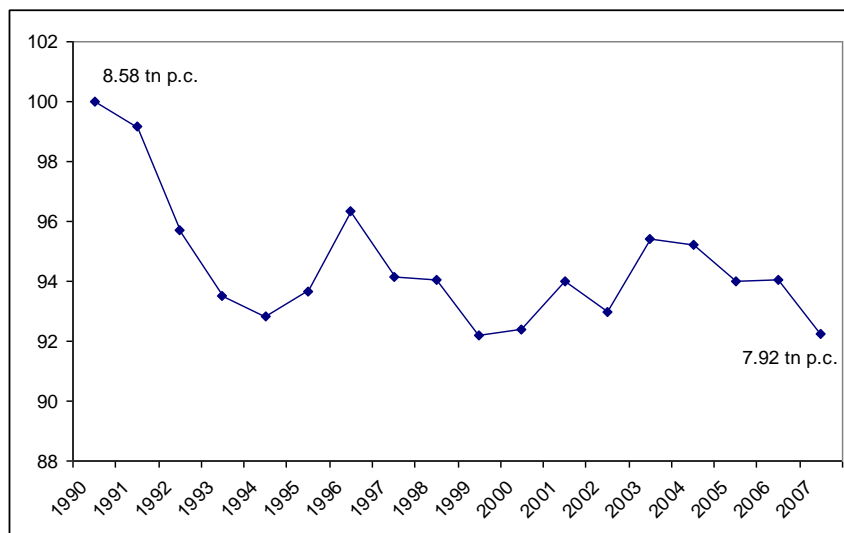
Note: 1990 = 100

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Figure 2. Evolution of density functions of the international distribution of CO$_2$ emissions per capita in the European Union, 1990–2007
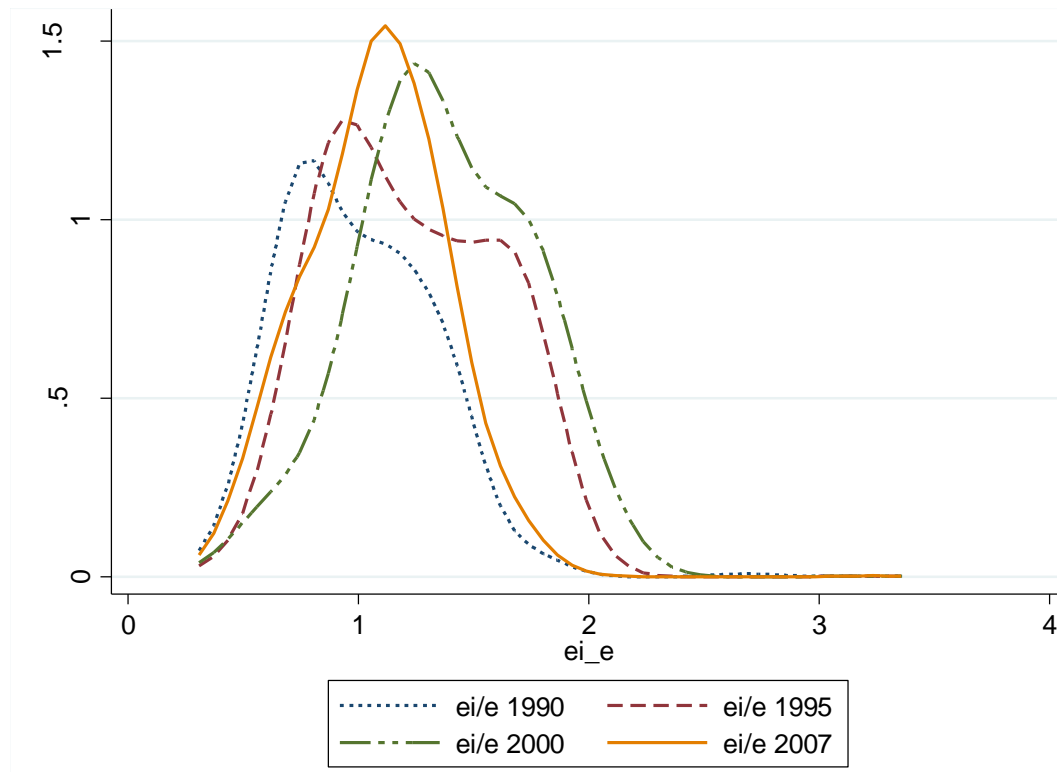
Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Figure 3. Evolution of cross-country European Union endogenous polarisation and comparison with well-known inequality measures, 1990–2007
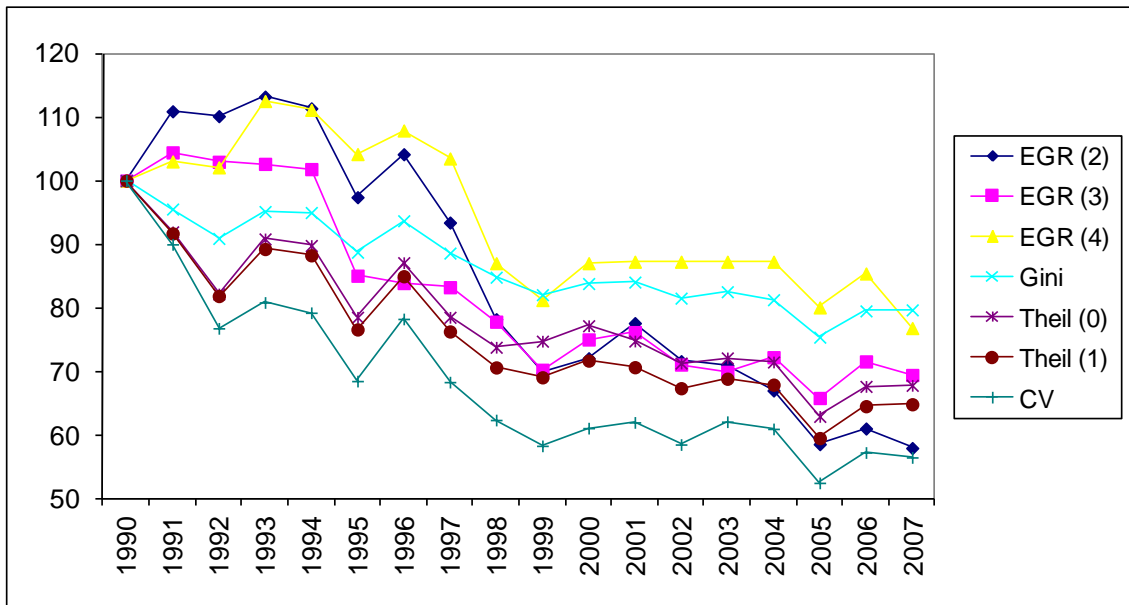
Note: 1990 = 100. EGRs are based on $\beta = 1$ and $\alpha = 1.3$.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 1. Two-group inter-country polarisation of CO_2 emissions per capita in the European Union, 1990–2007

	$\alpha = 1$			$\alpha = 1.3$			$\alpha = 1.6$		
	ER	ε	EGR	ER	ε	EGR	ER	ε	EGR
1990	0.1296	0.0402	0.0894	0.1053	0.0402	0.0651	0.0855	0.0402	0.0453
1991	0.1293	0.0329	0.0965	0.1050	0.0329	0.0722	0.0853	0.0329	0.0525
1992	0.1247	0.0296	0.0951	0.1013	0.0296	0.0717	0.0823	0.0296	0.0527
1993	0.1298	0.0317	0.0981	0.1054	0.0317	0.0737	0.0857	0.0317	0.0539
1994	0.1289	0.0323	0.0966	0.1048	0.0323	0.0725	0.0851	0.0323	0.0528
1995	0.1181	0.0325	0.0856	0.0960	0.0325	0.0634	0.0780	0.0325	0.0455
1996	0.1251	0.0339	0.0912	0.1017	0.0339	0.0678	0.0826	0.0339	0.0487
1997	0.1165	0.0339	0.0827	0.0947	0.0339	0.0608	0.0769	0.0339	0.0431
1998	0.1075	0.0365	0.0710	0.0873	0.0365	0.0509	0.0710	0.0365	0.0345
1999	0.1019	0.0374	0.0645	0.0828	0.0374	0.0454	0.0673	0.0374	0.0299
2000	0.1042	0.0381	0.0661	0.0850	0.0381	0.0469	0.0695	0.0381	0.0314
2001	0.1064	0.0362	0.0702	0.0867	0.0362	0.0505	0.0707	0.0362	0.0345
2002	0.1019	0.0364	0.0655	0.0830	0.0364	0.0466	0.0677	0.0364	0.0313
2003	0.1027	0.0374	0.0653	0.0836	0.0374	0.0462	0.0682	0.0374	0.0308
2004	0.1001	0.0379	0.0622	0.0815	0.0379	0.0436	0.0665	0.0379	0.0286
2005	0.0915	0.0364	0.0551	0.0745	0.0364	0.0381	0.0608	0.0364	0.0244
2006	0.0963	0.0387	0.0576	0.0784	0.0387	0.0397	0.0640	0.0387	0.0253
2007	0.0954	0.0398	0.0557	0.0775	0.0398	0.0377	0.0630	0.0398	0.0232

Note: The table shows the results for ER (Esteban and Ray, 1994) and EGR (Esteban et al., 2007) measures of polarisation, and error terms (ε), for extreme and intermediate α parameters (sensitivity of the measures to polarisation).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 2. Description of two-group case: population share and relative emissions per capita of each group

	Group 1		Group 2	
	p_1	e_1/e	p_2	e_2/e
1990	0.49	0.73	0.51	1.25
1991	0.50	0.74	0.50	1.26
1992	0.51	0.76	0.49	1.25
1993	0.51	0.75	0.49	1.26
1994	0.52	0.75	0.48	1.27
1995	0.52	0.77	0.48	1.25
1996	0.52	0.76	0.48	1.26
1997	0.52	0.78	0.48	1.24
1998	0.52	0.79	0.48	1.22
1999	0.52	0.80	0.48	1.21
2000	0.57	0.82	0.43	1.25
2001	0.56	0.81	0.44	1.24
2002	0.56	0.82	0.44	1.23
2003	0.56	0.82	0.44	1.23
2004	0.56	0.82	0.44	1.23
2005	0.56	0.84	0.44	1.21
2006	0.56	0.83	0.44	1.22
2007	0.48	0.80	0.52	1.19

Note: The first column for each group shows population weight (p_i). The second column for each group shows the ratio between emissions per capita of the group (e_i) and the European average (e).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 3. Three-group inter-country polarisation of CO_2 emissions per capita in the European Union, 1990–2007

	$\alpha = 1$			$\alpha = 1.3$			$\alpha = 1.6$		
	ER	ε	EGR	ER	ε	EGR	ER	ε	EGR
1990	0.1065	0.0188	0.0877	0.0796	0.0188	0.0608	0.0600	0.0188	0.0412
1991	0.1052	0.0153	0.0899	0.0788	0.0153	0.0635	0.0595	0.0153	0.0442
1992	0.1023	0.0150	0.0873	0.0775	0.0150	0.0626	0.0594	0.0150	0.0444
1993	0.1048	0.0163	0.0884	0.0787	0.0163	0.0624	0.0596	0.0163	0.0433
1994	0.1043	0.0165	0.0878	0.0783	0.0165	0.0619	0.0593	0.0165	0.0428
1995	0.0909	0.0138	0.0770	0.0655	0.0138	0.0517	0.0473	0.0138	0.0335
1996	0.0939	0.0166	0.0773	0.0676	0.0166	0.0510	0.0487	0.0166	0.0321
1997	0.0899	0.0141	0.0758	0.0646	0.0141	0.0506	0.0465	0.0141	0.0324
1998	0.0856	0.0142	0.0714	0.0615	0.0142	0.0473	0.0443	0.0142	0.0301
1999	0.0815	0.0159	0.0656	0.0586	0.0159	0.0427	0.0422	0.0159	0.0263
2000	0.0853	0.0165	0.0688	0.0621	0.0165	0.0456	0.0453	0.0165	0.0288
2001	0.0859	0.0163	0.0697	0.0625	0.0163	0.0463	0.0456	0.0163	0.0294
2002	0.0810	0.0157	0.0653	0.0588	0.0157	0.0432	0.0430	0.0157	0.0273
2003	0.0814	0.0165	0.0649	0.0590	0.0165	0.0425	0.0429	0.0165	0.0264
2004	0.0811	0.0148	0.0663	0.0588	0.0148	0.0439	0.0428	0.0148	0.0280
2005	0.0748	0.0142	0.0607	0.0542	0.0142	0.0400	0.0394	0.0142	0.0252
2006	0.0796	0.0142	0.0654	0.0577	0.0142	0.0435	0.0421	0.0142	0.0279
2007	0.0791	0.0152	0.0639	0.0574	0.0152	0.0422	0.0418	0.0152	0.0267

Note: The table shows the results for ER (Esteban and Ray, 1994) and EGR (Esteban et al., 2007) measures of polarisation, and error terms (ε), for extreme and intermediate α parameters (sensitivity of the measures to polarisation).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 4. Description of three-group case: population share and relative emissions per capita of each group

	Group 1		Group 2		Group 3	
	p_1	e_1/e	p_2	e_2/e	p_3	e_3/e
1990	0.49	0.73	0.29	1.11	0.23	1.44
1991	0.49	0.74	0.25	1.10	0.27	1.39
1992	0.51	0.76	0.22	1.12	0.27	1.36
1993	0.49	0.74	0.24	1.11	0.27	1.38
1994	0.49	0.74	0.24	1.10	0.27	1.38
1995	0.37	0.72	0.36	1.02	0.27	1.36
1996	0.35	0.70	0.38	1.01	0.27	1.38
1997	0.35	0.71	0.38	1.01	0.28	1.35
1998	0.35	0.73	0.38	1.00	0.28	1.34
1999	0.35	0.73	0.38	1.01	0.28	1.31
2000	0.26	0.69	0.33	0.93	0.40	1.26
2001	0.26	0.69	0.34	0.92	0.40	1.26
2002	0.26	0.69	0.46	0.98	0.28	1.31
2003	0.27	0.70	0.45	0.99	0.28	1.32
2004	0.27	0.69	0.45	1.00	0.28	1.31
2005	0.27	0.70	0.44	1.01	0.28	1.27
2006	0.27	0.69	0.45	1.01	0.28	1.29
2007	0.27	0.69	0.45	1.01	0.28	1.29

Note: The first column for each group shows population weight (p_i). The second column for each group shows the ratio between emissions per capita of the group (e_i) and the European average (e).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 5. Four-group inter-country polarisation of CO_2 emissions per capita in the European Union, 1991–2007

	$\alpha = 1$			$\alpha = 1.3$			$\alpha = 1.6$		
	ER	ε	EGR	ER	ε	EGR	ER	ε	EGR
1990	0.0796	0.0094	0.0702	0.0525	0.0094	0.0431	0.0347	0.0094	0.0253
1991	0.0785	0.0079	0.0706	0.0523	0.0079	0.0444	0.0349	0.0079	0.0270
1992	0.0758	0.0068	0.0690	0.0507	0.0068	0.0440	0.0341	0.0068	0.0273
1993	0.0814	0.0062	0.0751	0.0547	0.0062	0.0485	0.0369	0.0062	0.0306
1994	0.0810	0.0065	0.0745	0.0544	0.0065	0.0479	0.0367	0.0065	0.0302
1995	0.0759	0.0062	0.0697	0.0510	0.0062	0.0449	0.0344	0.0062	0.0282
1996	0.0797	0.0071	0.0726	0.0536	0.0071	0.0465	0.0361	0.0071	0.0290
1997	0.0765	0.0072	0.0692	0.0518	0.0072	0.0446	0.0352	0.0072	0.0280
1998	0.0694	0.0090	0.0604	0.0465	0.0090	0.0375	0.0312	0.0090	0.0222
1999	0.0665	0.0093	0.0572	0.0442	0.0093	0.0350	0.0295	0.0093	0.0202
2000	0.0696	0.0094	0.0603	0.0469	0.0094	0.0375	0.0316	0.0094	0.0223
2001	0.0693	0.0088	0.0605	0.0464	0.0088	0.0376	0.0311	0.0088	0.0223
2002	0.0676	0.0077	0.0600	0.0453	0.0077	0.0376	0.0304	0.0077	0.0227
2003	0.0688	0.0087	0.0601	0.0463	0.0087	0.0376	0.0312	0.0087	0.0225
2004	0.0675	0.0076	0.0599	0.0452	0.0076	0.0376	0.0303	0.0076	0.0227
2005	0.0624	0.0073	0.0551	0.0418	0.0073	0.0345	0.0280	0.0073	0.0207
2006	0.0665	0.0078	0.0586	0.0447	0.0078	0.0368	0.0301	0.0078	0.0222
2007	0.0635	0.0088	0.0547	0.0419	0.0088	0.0331	0.0277	0.0088	0.0189

Note: The table shows the results for ER (Esteban and Ray, 1994) and EGR (Esteban et al., 2007) measures of polarisation, and error terms (ε), for extreme and intermediate α parameters (sensitivity of the measures to polarisation).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 6. International inequality explained by simplified distributions, 1990–2007

	Two groups	Three groups	Four groups
1990	76.3%	88.9%	94.5%
1991	79.7%	90.6%	95.2%
1992	80.8%	90.3%	95.6%
1993	80.4%	89.9%	96.2%
1994	80.0%	89.8%	96.0%
1995	78.4%	90.8%	95.9%
1996	78.7%	89.6%	95.5%
1997	77.5%	90.6%	95.2%
1998	74.7%	90.1%	93.8%
1999	73.2%	88.6%	93.4%
2000	73.2%	88.4%	93.4%
2001	74.6%	88.6%	93.8%
2002	73.7%	88.7%	94.4%
2003	73.3%	88.2%	93.8%
2004	72.5%	89.2%	94.5%
2005	71.5%	88.9%	94.3%
2006	71.3%	89.5%	94.2%
2007	70.6%	88.8%	93.5%

Note: The figures show the ratio (Theil between/Theil total).

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 7. Coefficients of correlation between inequality and polarisation

indexes

	Gini	Theil (0)	Theil (1)	CV
EGR2 (1,1)	0.94	0.89	0.91	0.87
EGR2 (1.3,1)	0.93	0.88	0.90	0.86
EGR2 (1.6,1)	0.92	0.87	0.88	0.84
EGR3 (1,1)	0.95	0.92	0.94	0.92
EGR3 (1.3,1)	0.92	0.89	0.92	0.90
EGR3 (1.6,1)	0.89	0.86	0.89	0.88
EGR4 (1,1)	0.93	0.87	0.89	0.84
EGR4 (1.3,1)	0.88	0.81	0.83	0.78
EGR4 (1.6,1)	0.82	0.75	0.77	0.71

Note: Pearson correlations. The polarisation measures are the EGR (α, β) for 2, 3 and 4 groups.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 8: Examples of significant differences between polarisation and inequality measures in the context of EU international distribution of CO_2 emissions

Sub-periods	EGR (2)	EGR(3)	EGR(4)	G	T(0)	T(1)	CV
1990–1991	0.7%	1.4%	0.9%	5.1%	-10.6%	-10.7%	-14.7%
1991–1992	-2.7%	0.3%	-9.3%	-4.5%	10.5%	9.0%	5.3%
1993–1994	14.4%	19.7%	6.7%	7.0%	-12.6%	-13.2%	-13.6%
1994–1995	-6.5%	1.4%	-3.4%	-5.3%	10.9%	10.9%	14.3%
1995–1996	11.5%	0.8%	4.3%	5.7%	-9.9%	-10.2%	-12.7%
1996–1997	19.4%	7.0%	18.9%	4.5%	-6.0%	-7.4%	-8.7%
1997–1998	12.1%	10.8%	7.1%	3.4%	1.3%	-2.2%	-6.5%
1998–1999	-3.2%	-6.4%	-6.7%	-2.1%	3.3%	3.8%	4.8%
2000–2001	8.4%	7.2%	0.0%	3.1%	-4.6%	-4.7%	-5.6%
2003–2004	14.4%	9.7%	9.0%	7.8%	-12.0%	-12.4%	-13.9%
2004–2005	-4.0%	-8.0%	-6.2%	-5.2%	7.5%	8.4%	9.1%
1990–1992	10.1%	3.0%	2.1%	-9.1%	-17.8%	-18.2%	-23.2%
1998–2000	-7.9%	-3.6%	0.0%	-1.2%	4.6%	1.5%	-2.0%
2002–2004	-6.4%	1.6%	0.0%	-0.3%	0.2%	0.8%	4.2%
1990–1993	13.2%	2.6%	12.5%	-4.9%	-9.2%	-10.8%	-19.2%
1999–2002	2.6%	1.2%	7.4%	-0.7%	-4.6%	-2.5%	0.4%
1990–1994	11.4%	1.8%	11.1%	-5.0%	-10.2%	-11.8%	-20.8%
1992–1996	-5.4%	-18.5%	5.7%	3.1%	6.0%	3.8%	1.9%
1998–2002	-8.4%	-8.7%	0.3%	-3.9%	-3.4%	-4.6%	-6.2%
1999–2003	1.8%	-0.5%	7.4%	0.6%	-3.5%	-0.3%	6.5%
2000–2004	-7.0%	-3.7%	0.3%	-3.0%	-7.4%	-5.3%	-0.2%
2002–2006	-14.8%	0.7%	-2.1%	-2.5%	-5.2%	-4.2%	-2.1%
1990–1996	4.1%	-16.1%	7.9%	-6.3%	-12.9%	-15.1%	-21.8%

Note: EGR indexes are based on moderate parameters $\beta = 1$ and $\alpha = 1.3$.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 9. Exogenous polarisation in the European Union, 1990–2007

	Between inequality	Within inequality	Z-K index
1990	0.0156	0.0311	0.5026
1991	0.0153	0.0276	0.5540
1992	0.0121	0.0262	0.4624
1993	0.0126	0.0298	0.4250
1994	0.0122	0.0297	0.4119
1995	0.0090	0.0276	0.3280
1996	0.0122	0.0284	0.4311
1997	0.0085	0.0281	0.3028
1998	0.0091	0.0253	0.3604
1999	0.0083	0.0266	0.3104
2000	0.0079	0.0282	0.2788
2001	0.0082	0.0267	0.3077
2002	0.0075	0.0258	0.2902
2003	0.0069	0.0268	0.2572
2004	0.0062	0.0272	0.2280
2005	0.0047	0.0246	0.1914
2006	0.0044	0.0271	0.1633
2007	0.0033	0.0284	0.1162

Note: The groups are Europe North, Europe South and Europe East. The Z-K (Zhang and Kambur, 2001) index of polarisation is computed as the ratio T_b/T_w.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).

Table 10. Decomposition of between-group inequality component into Kaya factors by applying the Shorrocks rule, 1990–2007

	Between-group inequality	Carbon index CO_2/PE	Energy intensity PE/GDP	Affluence GDP/P
1990	0.0156	-0.0026	0.0150	0.0031
		(-16.3%)	*(96.3%)*	*(20.0%)*
1995	0.0090	-0.0055	-0.0019	0.0163
		(-60.6%)	*(-20.8%)*	*(181.4%)*
2000	0.0079	-0.0066	-0.0118	0.0261
		(-85.7%)	*(-153.2%)*	*(339.0%)*
2005	0.0047	-0.0049	-0.0097	0.0193
		(-104.3%)	*(-206.4%)*	*(410.6%)*
2007	0.0033	-0.0042	-0.0082	0.0157
		(-125.8%)	*(-249.2%)*	*(475.0%)*
% change	-78.8%	*62.8%*	*-154.7%*	*401.6%*

Note: The percentage with respect to between-group inequality is shown in brackets.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).

Table 11. Characteristics of exogenous groups in relation to the EU as regards the different Kaya factors, 1990–2007

	Carbon index (CO2/PE) (relative)	Energy intensity (PE/GDP) (relative)	Affluence (GDP/P) (relative)	Emissions (relative)	p_i
1990					
North	0.93	0.99	1.20	1.11	52.9%
South	1.05	0.66	1.04	0.72	24.7%
East	1.17	1.87	0.48	1.06	22.4%
2000					
North	0.92	1.00	1.20	1.11	53.8%
South	1.09	0.80	1.04	0.91	24.7%
East	1.20	1.53	0.45	0.83	21.5%
2007					
North	0.92	0.99	1.18	1.07	53.8%
South	1.11	0.86	0.99	0.94	25.6%
East	1.17	1.36	0.56	0.89	20.6%

Note: The value 1 corresponds to the world average for each year and factor. The last column shows the share of EU population of each group.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).

Table 12. Decomposition of within-group inequality component by Kaya factors by applying the Shorrocks rule, 1990–2007

	Within-group inequality	Carbon index CO_2/PE	Energy intensity PE/GDP	Affluence GDP/P
1990	0.0311	0.0196	0.0034	0.0081
		(63.1%)	(10.9%)	(26.0%)
1995	0.0276	0.0192	0.0018	0.0067
		(69.4%)	(6.4%)	(24.2%)
2000	0.0282	0.0176	0.0027	0.0079
		(62.6%)	(9.4%)	(27.9%)
2005	0.0246	0.0162	0.0032	0.0052
		(65.9%)	(13.0%)	(21.1%)
2007	0.0284	0.0187	0.0043	0.0053
		(65.9%)	(15.3%)	(18.8%)
% change	-8.7%	-4.6%	28.1%	-34.1%

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).

Note: The percentage with respect to within-group inequality is shown in brackets.

Table A.1. Groups of countries determined endogenously by polarisation analysis

	Two groups		Three groups			Four groups			
1990	Portugal, Spain, France, Sweden, Malta, Hungary, Slovenia, Cyprus, Greece, Latvia, Italy, Romania, Austria	Bulgaria, Ireland, Lithuania, Poland, United Kingdom, Denmark, Netherlands, Slovakia, Belgium, Finland, Germany, Czech Republic, Estonia, Luxembourg	Portugal, Spain, France, Sweden, Malta, Hungary, Slovenia, Cyprus, Greece, Latvia, Italy, Romania, Austria	Bulgaria, Ireland, Lithuania, Poland, United Kingdom, Denmark, Netherlands, Slovakia	Belgium, Finland, Germany, Czech Republic, Estonia, Luxembourg	Portugal, Spain, France, Sweden	Malta, Hungary, Slovenia, Cyprus, Greece, Latvia, Italy, Romania, Austria	Bulgaria, Ireland, Lithuania, Poland, United Kingdom, Denmark, Netherlands, Slovakia	Belgium, Finland, Germany, Czech Republic, Estonia, Luxembourg
2000	Latvia, Lithuania, Romania, Bulgaria, Hungary, Malta, Portugal, Sweden, France, Slovakia, Slovenia, Spain, Italy, Poland, Austria	Greece, United Kingdom, Cyprus, Denmark, Germany, Finland, Estonia, Ireland, Netherlands, Belgium, Czech Republic, Luxembourg	Latvia, Lithuania, Romania, Bulgaria, Hungary, Malta, Portugal, Sweden, France	Slovakia, Slovenia, Spain, Italy, Poland, Austria, Greece	United Kingdom, Cyprus, Denmark, Germany, Finland, Estonia, Ireland, Netherlands, Belgium, Czech Republic, Luxembourg	Latvia, Lithuania, Romania, Bulgaria, Hungary, Malta, Portugal, Sweden, France	Slovakia, Slovenia, Spain, Italy, Poland, Austria	Greece, United Kingdom, Cyprus, Denmark	Germany, Finland, Estonia, Ireland, Netherlands, Belgium, Czech Republic, Luxembourg
2007	Latvia, Romania, Lithuania, Sweden, Portugal, Hungary, France, Bulgaria, Malta, Slovakia, Italy, Spain, Slovenia	Poland, Austria, United Kingdom, Greece, Denmark, Cyprus, Germany, Belgium, Ireland, Netherlands, Czech Republic, Finland, Estonia, Luxembourg	Latvia, Romania, Lithuania, Sweden, Portugal, Hungary, France, Bulgaria, Malta, Slovakia	Italy, Spain, Slovenia, Poland, Austria, United Kingdom, Greece	Denmark, Cyprus, Germany, Belgium, Ireland, Netherlands, Czech Republic, Finland, Estonia, Luxembourg	Latvia, Romania, Lithuania, Sweden, Portugal, Hungary, France	Bulgaria, Malta, Slovakia, Italy, Spain, Slovenia	Poland, Austria, United Kingdom, Greece, Denmark, Cyprus	Germany, Belgium, Ireland, Netherlands, Czech Republic, Finland, Estonia, Luxembourg

Table A.2 Decomposition of between-group inequality component, 1990–2007

	Between-group inequality	CO_2/EP	EP/GDP	GDP/P	$Corr_{a,by}$	$Corr_{b,y}$
1990	0.0156	0.0045	0.0688	0.0569	-0.0141	-0.1005
		(28.8%)	(441.0%)	(364.7%)	(-90.4%)	(-644.2%)
1995	0.0090	0.0054	0.0508	0.0690	-0.0217	-0.0945
		(60.0%)	(564.4%)	(766.7%)	(-241.1%)	(-1050.0%)
2000	0.0079	0.0062	0.0259	0.0638	-0.0256	-0.0626
		(80.5%)	(336.4%)	(828.6%)	(-332.5%)	(-813.0%)
2005	0.0047	0.0060	0.0155	0.0445	-0.0218	-0.0395
		(127.7%)	(329.8%)	(946.8%)	(-463.8%)	(-840.4%)
2007	0.0033	0.0058	0.0129	0.0368	-0.0199	-0.0323
		(175.8%)	(390.9%)	(1115.2%)	(-603.0%)	(-978.8%)
% change	-78.8%	28. 9%	-81.3%	-35.3	41.1	-67.9

Note: The percentage with respect to between-group inequality is shown in brackets.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).

Table A.3 Decomposition of within-group inequality component by Kaya factors

	Within-group inequality	CO_2/EP	EP/GDP	GDP/P	$Corr_{a,by}$	$Corr_{b,y}$
1990	0.0311	0.0203	0.0084	0.0131	-0.0015	-0.0093
		(65.5%)	(27.1%)	(42.3%)	(-4.8%)	(-30.0%)
1995	0.0276	0.0207	0.0072	0.0121	-0.0031	-0.0093
		(75.0%)	(26.1%)	(43.8%)	(-11.2%)	(-33.7%)
2000	0.0282	0.0197	0.0087	0.0139	-0.0042	-0.0100
		(70.1%)	(31.0%)	(49.5%)	(-14.9%)	(-35.6%)
2005	0.0246	0.0215	0.0085	0.0105	-0.0106	-0.0053
		(87.4%)	(34.6%)	(42.7%)	(-43.1%)	(-21.5%)
2007	0.0284	0.0232	0.0090	0.0100	-0.0091	-0.0048
		(82.0%)	(31.8%)	(35.3%)	(-32.2%)	(-17.0%)
% change	-8.7%	14.3%	7.1%	-23.7%	506.7%	-48.4%

Note: The percentage with respect to within-group inequality is shown in brackets.

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).