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

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Abstract

In this study, we analyse the degree of polarisation—a concept fundamentally different from that of inequality—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. 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 of countries 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).

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 EU 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 to address the problem and greater difficulty in reaching agreements.

The European Union has taken on greater commitments in 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 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 the EU level.

Given the potential relevance 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 major approaches to 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).

This concept has only previously been applied to the analysis of environmental distribution by Duro and Padilla (2008), in a study analysing polarisation in the international distribution of CO_2 emissions using the indices proposed by

[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.

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. In the present study, we carry out the first polarisation analysis of the European Union—a 27-country political unit that has jointly 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

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). We must therefore explore the various alternatives that have been proposed in the literature, which can be grouped in two major categories. The first category comprises methods in which groups are formed optimally, with the aim of minimising within-group heterogeneity. 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, as well as the measures proposed by Wolfson (1994, 1997) and by Wang and Tsui (2000), designed specifically for the bipolar case. The second category includes the Z-K index, proposed by Zhang and Kanbur (2001).

All methods for measuring polarisation, regardless of category, satisfy two basic properties. 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 worldwide average; α is the parameter that measures the sensitivity of the measure 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 comprises 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. 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 values are similar.

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 the 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 analysis of polarisation generally.

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. Zhang and Kanbur (2001) suggested a polarisation measure based on the inequality decomposition by groups (Shorrocks, 1980, 1984). One advantage of this measure is that it easily accommodates various decomposition formats. Specifically, the degree of polarisation of a distribution could be expressed as:

$$Z-K=\frac{T_b}{T_w} \qquad (2)$$

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, e_g is the average emissions per capita for group g, and Tg is the internal inequality of group g.

Notice 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 measurement, whereas an increase in internal heterogeneity (i.e. less identification) tends to reduce its value.

This measure also behaves differently from conventional inequality measures such as 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 turns negative depending on the polarisation approach. For practical purposes, then, a significant variation of the within-group component could lead to inconsistent patterns between inequality measures and the Z-K measure.[2]

An essential aspect, for analytical purposes, is that the between-group inequality component can in turn be decomposed by multiplicative factors, as with the Kaya identity (1989), according to the methodology proposed by Duro and Padilla (2006), and the same procedure can also be performed in the within-groups component, given that it is simply a weighted average of the 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.

3. Empirical evidence

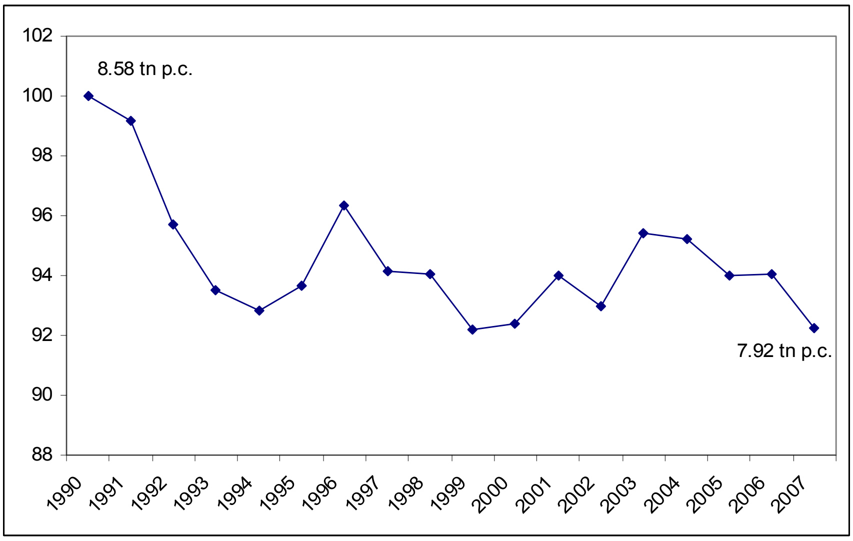
3.1. Endogeneous groups

Let us begin by analysing the changes in CO_2 emissions per capita in the European Union between 1990 and 2007. The data—which, like the other data cited below, were provided by the International Energy Agency (IEA) (2010a)—refer to metric tons of CO_2 emissions from fossil-fuel combustion. Emissions per

[2] 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).

inhabitant of the European Union dropped by 7.8% over the course of the study period. 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.[3]

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).

Let us now analyse the evolution of the polarisation that has accompanied these 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 the 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

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

calculations, we considered three different values for the parameter α for the cases of two, three and four groups, respectively—the cases that, according to the literature, seemed most reasonable. The value of β was set at 1, as in Esteban et al. (2007). Appendix 1 shows the composition of the groups of countries obtained endogenously by means of an optimisation procedure.

The results indicate, first of all, 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 α = 1, by 42% when α = 1.3, and by 49% when α = 1.6; the three-group EGR decreases by 27%, 31% and 35%; and the four-group EGR decreases by 22%, 23% and 25%, respectively.[4]

Let us now consider the role of changes in relative weights and relative emissions in determining the evolution of the ER component. 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 the three-group case (Table 4) we see a similar effect, with the middle and high groups approaching the mean, but also a weighting effect due to the increased size of the middle group.

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.

[4] 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.

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

	α = 1			α = 1.3			α = 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

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

Table 2. Two-group case: description of groups

	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

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

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

Table 4. Three-group case: description of groups

	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

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

	α = 1			α = 1.3			α = 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

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

Note that the various endogenous groupings have high explanatory capacity. In the two-group case, inter-group differences account for 70% of the overall international inequalities; 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, intuitively, 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 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.

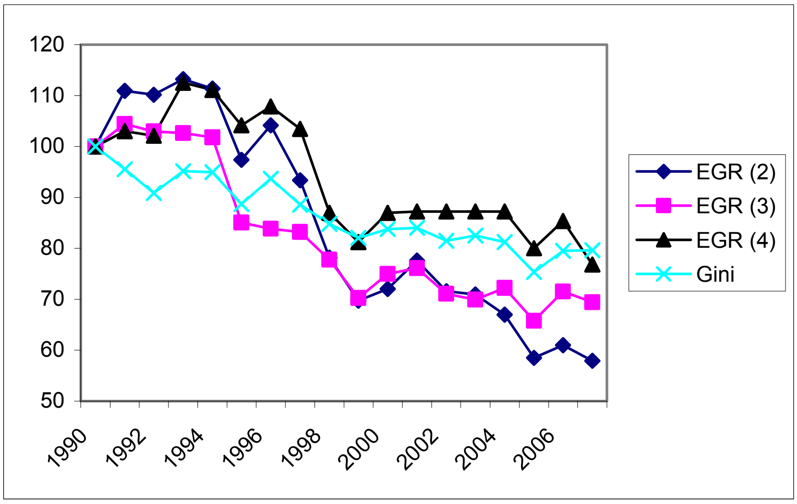
Table 6. International inequality (Gini) explained by simplified distributions, 1990–2007

	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%

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

An analysis of the evolution of inequality—a distribution concept that is, as mentioned above, fundamentally different from polarisation—reveals, in the same period, a noticeable downward trend that is nonetheless generally less intense and more monotonic than the trend revealed by the polarisation measures. The Gini coefficient decreases by 20% over the course of the study period.[5] In any event, this evolution reinforces the "goodness" of the distributional pattern followed by the emissions of the various EU countries.

Figure 2. Evolution of cross-country European Union endogenous polarisation and comparison with inequality, 1990–2007



Note: 1990 = 100. EGRs are based on β = 1 and α = 1.3.

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

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. 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,

[5] Although the overall pattern is analogously downward, significant disparities emerge between the evolution of inequality and that of polarisation. For example, if we compare the evolution of the three-group EGR index with parameters β = 1 and α = 1.3 to the Gini coefficient, we see that the former rose by 3% while the second dropped by 9.1% between 1990 and 1992. Another example of this sort of discrepancy occurred between 1992 and 1996, when the EGR index decreased by a significant 18.5% and the Gini coefficient, in contrast, increased by 3.1%.

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.[6]

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 7 shows the results of the Z-K index for the aforementioned groups of EU countries. 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. An analysis of the group inequality components that make up the index indicates that the bulk of this 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 component (in other words, a lower level of internal cohesion would prevent groups from forming around different interests).

[6] Sweden and France are two countries that do not fit this trend. Despite belonging to Europe North and having high per capita incomes, these two countries have lower emission levels due to the different range of energy sources they use, including nuclear power and, in the case of Sweden, renewable energy sources.

Table 7. 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

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a).
Note: The groups are Europe North, Europe South and Europe East.

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 emissions per unit of energy consumed, energy intensity, and GDP per capita. 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 8. 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.[7] 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 one another out and, in the case of energy intensity, leading to a negative net contribution.

Table 8. Decomposition of between-group inequality component by applying Shorrocks's rule, 1990–2007

	Between-group inequality	CO_2/PE	PE/GDP	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%*

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

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

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

Table 9. Characteristics of exogenous groups, 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%

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

Note: The value 1 corresponds to the world average for each year and factor.

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 Europe East 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.)[8]

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. The groups are

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

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

Table 10. Decomposition of within-group inequality component by Kaya factors

	Within-group inequality	CO_2/PE	PE/GDP	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.

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 among 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 among 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 the 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.

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Appendix .

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*

Source: Drawn up by the authors using International Energy Agency data (IEA, 2010a, 2010b, 2010c).
Note: The percentage with respect to between-group inequality is shown in brackets.

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%

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.

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