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EXPLANATORY FACTORS OF CO_2 PER CAPITA EMISSION INEQUALITY IN THE EUROPEAN UNION

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Abstract

The design of European mitigation policies requires a detailed examination of the factors explaining the unequal emissions in the different countries. This research analyzes the evolution of inequality in CO_2 per capita emissions in the European Union (EU-27) in the 1990–2006 period and its explanatory factors. For this purpose, we decompose the Theil index of inequality into the contributions of the different Kaya factors. The decomposition is also applied to the inequality between and within groups of countries (North Europe, South Europe, and East Europe). The analysis shows an important reduction in inequality, to a large extent due to the smaller differences between groups and because of the lower contribution of the energy intensity factor. The importance of the GDP per capita factor increases and becomes the main explanatory factor. However, within the different groups of countries the carbonization index appears to be the most relevant factor in explaining inequalities.

Key words**:** CO_2 emissions, emission inequality, European Union, Kaya factors, Theil index.

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1. Introduction

The European Union has been the political community that, to date, has assumed the greatest commitments to the fight against climate change on a worldwide level. In March 2007, the European Council adopted a mitigation commitment of 20% of 1990 greenhouse gases by 2020 (extendable to 30% if the other developed countries assumed a similar objective). It was also committed to improving energy efficiency by 20% and increasing the percentage of energy consumption from renewable sources to 20%. The European Union has also played a very active role, though without the expected success to date, in the search for post Kyoto international agreements involving all countries in the fight against climate change.

However, the situations of the current member countries are very different—major differences in income, emissions per capita, energy provision structure, production structure and energy efficiency—and ambition with respect to objectives vary greatly among them. In spite of the disagreements, in April 2009 (decision n. 406/2009/CE of the European Parliament and the Council), the target of the different member states to reduce their emissions to fulfill the 2020 objectives was finally determined.

The differences in emissions per capita between the different countries of the European Union are very relevant for establishing the different mitigation policy targets and these differences are due to factors that have evolved in different ways in different countries. Several studies have analyzed international differences in emissions per capita by applying synthetic indicators of inequality, such as the Gini, Theil or Atkinson indexes (Heil and Wodon, 1997, 2000; Millimet and Slottje, 2002; Hedenus and Azar, 2005; Padilla and Serrano, 2006; Duro and Padilla, 2006, 2008; Cantore and Padilla, 2010a, 2010b; Groot, 2010). These studies have focused on international inequalities on a worldwide level or across OECD countries. In the present paper we will analyze the inequality in per capita emissions in the European Union—a political unit that is composed of 27 countries and whose mitigation objectives are jointly assumed—, as well as its different explanatory factors. As explanatory factors we will analyze the evolution of the well-known Kaya identity (Kaya 1989), which decomposes emissions per capita into the contribution of the energy intensity of carbon (or carbonisation index), the energy intensity of product and GDP per capita. A good knowledge of the factors behind the differences in emissions and their evolution in the different countries is essential guidance for better policy design. We present and apply a decomposition of a synthetic inequality index, the Theil index, which serves to show the contribution to global inequality of the different explanatory factors on a European level. The methodology also enables analysis of the inequalities between groups and within different groups of countries in the European Union, which will serve to check whether the greater differences, and the contribution of the different factors, are centered on the differences between or within the groups of countries that share some common characteristics. Duro and Padilla (2006) analyzed the factors behind emissions per capita inequality on a worldwide level. There have been no similar analyses for the European Union. In any case, the analysis of inequality and its major causes complements the existing literature on the convergence in emissions per capita and the different trends in the European Union countries (see Jobert et al., 2010).

In the next section we will analyze the emission data for the different countries of the European Union and will expose the methodology, which consists of a decomposition of the Theil index of inequality into the different Kaya factors and two interaction components. Section 3 presents the results. Section 4 gathers the main conclusions of the paper.

2. Data and methodology

2. 1. Data and Kaya factors

For the present paper we have used data from the International Energy Agency (IEA, 2009a, 2009b, 2009c). According to these, CO_2 emissions from fossil fuel combustion experienced a mild reduction over the 1990–2006 period (a 2% cutback). However, there is highly heterogeneous behavior among the different countries of the European Union, as well as important differences in the emissions per capita of the different countries.

One of the factors that determine the differences in the level of emissions and their evolution is economic activity. However, there may be economic growth due to there being more affluent inhabitants, or simply due to a greater population consuming the same. Moreover, the different technologies employed in production might cause more or less pollution depending on the energy requirements or the type of energy employed. Multiple factors affect CO_2 emissions, such as economic growth, demographic growth, technological change, resource endowment, institutional structures, modes of transport, lifestyles and international trade.

A frequently used analytical tool to explore the main driving forces of pollution is the Kaya identity (Kaya, 1989). According to this, a country's emissions can be decomposed into the product of four basic products (which, in turn, are determined by other factors): carbon intensity of energy or carbonization index (defined as the carbon dioxide emitted per unit of energy consumed, $\frac{CO_{2i}}{E_i}$), energy intensity (defined as the primary energy quantity consumed per unit of GDP, $\frac{E_i}{GDP_i}$), economic affluence (defined as GDP per capita, $\frac{GDP_i}{P_i}$) and population. The first component shows the mix of fuels of a given country; the second is associated both to energy efficiency and to the sectoral structure of the economy and the transport model; and the third is a measure of economic income.

$$CO_{2i} = \frac{CO_{2i}}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{P_i} \cdot P_i \tag{1}$$

The identity might also be used to analyze per capita emissions:

$$\frac{CO_{2i}}{P_i} = \frac{CO_{2i}}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{P_i} \tag{2}$$

This approach can be used to decompose the main driving forces of CO_2 emissions, which serves to make a first description of the important differences observed between countries [1]. Table 1 shows the values of the different factors for the different European countries.

[1] One problem is that these factors might not be independent from each other (e.g., there might be a positive correlation between greater affluence, greater capital level and the development of certain technologies that reduce energy intensity). This question is reflected in the inequality decomposition methodology developed below, where the corresponding interrelation components are included.

Table 1. Decomposition of CO_2 emissions per capita in Kaya factors, year 2006

	Emissions per capita CO_2/P	Kaya factors		
		Carbonization index CO_2/EP	Energy intensity EP/GDP	GDP per capita GDP/P
Austria	8.80	2.13	132.10	31.29
Belgium	11.12	1.92	194.26	29.79
Denmark	10.14	2.64	123.08	31.26
Finland	12.68	1.79	236.87	29.99
France	5.97	1.38	160.87	26.82
Germany	10.00	2.36	154.59	27.37
Ireland	10.57	2.91	102.97	35.32
Luxembourg	23.79	2.37	158.26	63.36
Netherlands	10.91	2.23	156.58	31.31
Sweden	5.32	0.94	176.62	31.99
United Kingdom	8.86	2.32	132.18	28.89
North	*8.78*	*2.01*	*152.68*	*28.53*
Cyprus	9.14	2.69	162.28	20.94
Greece	8.43	3.02	120.14	23.23
Italy	7.61	2.43	119.98	26.08
Malta	6.10	2.86	123.94	17.22
Portugal	5.32	2.22	138.07	17.41
Spain	7.43	2.27	138.22	23.73
South	7.43	2.41	127.58	24.21
Bulgaria	6.18	2.30	307.08	8.76
Czech Republic	11.78	2.63	234.14	19.15
Estonia	11.30	3.10	229.48	15.90
Hungary	5.60	2.04	171.73	15.96
Latvia	3.51	1.74	147.04	13.70
Lithuania	4.02	1.60	179.34	14.01
Poland	8.02	3.13	195.89	13.08
Romania	4.39	2.36	213.69	8.70
Slovak Republic	6.95	2.00	232.25	14.92
Slovenia	7.71	2.13	174.00	20.76
East	*7.00*	*2.59*	*207.05*	*13.05*
EU-27	*8.07*	*2.19*	*152.35*	*24.23*
Variation coefficient x 100	45.69	22.38	27.34	45.83

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

Note: per capita emissions in metric tons; carbonization index in tons of CO_2 per ton of oil equivalent; energy intensity in tons of oil equivalent per million of PPP-adjusted 2000 US dollars; GDP per capita in thousands of PPP-adjusted 2000 US dollars. The variation coefficient is considered for the 27 countries and is computed without weighting.

Table 1 shows major differences between the European Union countries, both in their emissions per capita and in the different factors determining these emissions. GDP per capita is one of the most relevant factors explaining these differences, the variation coefficient of this factor being the most relevant. However, variability is also very important in the other factors, so we find high income countries, such as France or Sweden, with emissions per capita well below the global mean and even below the average for the countries from the east and south of Europe. The variation coefficient is mildly greater for the energy intensity than for the carbonization index (27.34 and 22.38 respectively). The different energy intensities, which are especially large between East Europe and the other groups of countries, show both the different efficiencies in the use of energy as well as the different production structures. The differences in the carbonization index show the important disparities in the energy mix in the different European countries: while in some countries the share of fossil fuels is high, including coal, in others, the presence of renewable and nuclear power leads to lower indexes.

The table shows the (unweighted) variation coefficient for each of the different factors. However, this does not report precisely on the importance of each factor, and their interaction, on the global inequalities and their evolution. Moreover, it seems interesting to explore the behavior of the factorial components for various groups of countries. In order to explore these issues, the next subsection develops a decomposition methodology of inequality that makes it possible to explore the weight of each factor in it.

2.2. Synthetic decomposition of inequality into explanatory factors: Methodology

Although there are many measures of inequality, the Theil index (1967) has many desirable properties. Bourguignon (1979) showed that this measure is the only population weighted inequality index that can be broken down into groups of observations, is differentiable, symmetric, invariant with scale and satisfies the Pigou-Dalton criterion. In order to compute the inequality in CO_2 per capita emissions among countries, this measure might be written as:

$$T(c,p)=\sum_i p_i \ln\left(\frac{\bar{c}}{c_i}\right) \qquad (3)$$

where c_i are the CO_2 per capita emissions of country $_i$, p_i is the share of population of country i of the total European population and $\bar{c}$ is the average European emissions per capita. The lower limit is zero, and the upper limit depends on the sample. A value close to 1 indicates high inequality levels[2].

In order to investigate the sources of CO_2 per capita emission inequalities in the European Union, we start from the Kaya identity defined in equation (2). To simplify notation, we denote the three factors of the identity (carbonization index, energy intensity of GDP, and GDP per capita) as a, b and y, respectively, for each country:

$$c_i = a_i * b_i * y_i \qquad (4)$$

We then measure the contribution of each individual Kaya factor to the global inequality index. To do this, we define three hypothetical vectors allowing, for each factor, only the values of one of the factors to diverge from the mean. We obtain the following result[3]:

$$\begin{aligned} c_i^a &= a_i * \bar{b} * \bar{y} \\ c_i^b &= \bar{a} * b_i * \bar{y} \\ c_i^y &= \bar{a} * \bar{b} * y_i \end{aligned} \qquad (5)$$

where $\bar{a}$, $\bar{b}$ and $\bar{y}$ are the European averages.

The degree of inequality of the individual factors is then computed using the Theil index:

$$T^a = \sum_i p_i \ln\left(\frac{\bar{c}^a}{c_i^a}\right)$$

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[2] Theil (1967) also offered an alternative inequality index, which might be obtained by interchanging the positions of $\bar{c}$ and c_i in the logarithm and substituting the population weighting scheme by a CO_2 weighting. However, the population weighted index—expression (1)—seems a better measure because: i) if CO_2 dispersion is analysed, the different observations should be weighted according to population; ii) there are various problems associated to the interpretation of results when the alternative index is decomposed by groups (see Shorroks, 1980).

[3] This decomposition technique was developed by Duro (2003) for the analysis of income spatial inequality.

$$T^b = \sum_i p_i \ln\left(\frac{\bar{c}^b}{c_i^b}\right) \qquad (6)$$

$$T^y = \sum_i p_i \ln\left(\frac{\bar{c}^y}{c_i^y}\right)$$

These indexes measure the partial contribution of each factor to global inequality. Notice that the importance attributable to each country might be understood as the quantity of inequality that would persist if only the examined factor was allowed to change among countries, while the other factors are equal to the mean.

If we add up these Theil indexes and the terms $\log\left(\frac{\bar{c}}{\bar{c}^a}\right)$ and $\log\left(\frac{\bar{c}}{\bar{c}^b}\right)$, we obtain:

$$\left(T^a + \log\left(\frac{\bar{c}}{\bar{c}^a}\right)\right) + \left(T^b + \log\left(\frac{\bar{c}}{\bar{c}^b}\right)\right) + T^y = \sum_{i=1} p_i * \log\left(\frac{\bar{c}}{c_i^a}\right) + \sum_{i=1} p_i * \log\left(\frac{\bar{c}}{c_i^b}\right) + T^y =$$

$$= \sum_{i=1} p_i * \log\left(\frac{\bar{a}}{a_i}\right) + \sum_{i=1} p_i * \log\left(\frac{\bar{b}}{b_i}\right) + \sum_{i=1} p_i * \log\left(\frac{\bar{y}}{y_i}\right) = \sum_i p_i * \log\left(\frac{\bar{a} * \bar{b} * \bar{y}}{a_i * b_i * y_i}\right) = T(c,p) \quad (7)$$

It can be shown that these terms may be interpreted as interaction components. We can then rewrite them[4]:

$$\log\left(\frac{\bar{c}}{\bar{c}^a}\right) = \log\left(1 + \frac{\sigma_{a,by}}{\bar{c}^a}\right)$$

$$\log\left(\frac{\bar{c}}{\bar{c}^b}\right) = \log\left(1 + \frac{a * \sigma_{bt,y}}{\bar{c}^b}\right) \qquad (8)$$

where $\sigma_{a,by}$ is the weighted covariance (using population shares) between carbon indexes and the per capita energy consumed, and $\sigma_{b,y}$ denotes the weighted covariance between energy intensities and GDP per capita.

Therefore, following Duro and Padilla (2006), we can decompose the emissions per capita inequality among European countries into the sum of the individual contributions of the Kaya factors—expressed with Theil indexes—and two interaction terms.

[4] These demonstrations are not included in the text. They are available from the authors on request.

$$T(e,p) = T^a + T^b + T^y + \text{inter}_{a,by} + \text{inter}_{b,y} \qquad (9)$$

where $\text{inter}_{a,by}$ and $\text{inter}_{b,y}$ are the first and the second interaction terms of expression (6).

Finally, to obtain a perfect decomposition of inequality into the three considered factors, we apply the Shorrocks (1990) methodology, according to which the interaction factors are divided on an equalitarian basis into the different factors that generate them:

$$T(e,p) = (T^a + \tfrac{1}{2}\text{inter}_{a,by}) + (T^b + \tfrac{1}{4}\text{inter}_{a,by} + \tfrac{1}{2}\text{inter}_{b,y}) + (T^y + \tfrac{1}{4}\text{inter}_{a,by} + \tfrac{1}{2}\text{inter}_{b,y}) \qquad (10)$$

$$T(e,p) = T^A + T^B + T^Y \qquad (11)$$

Moreover, this methodology might be extended to analyzing the components of between and within-group inequality. The Theil index might be decomposed by population subgroups in the following way (Theil, 1967; Shorrocks, 1980):

$$T(c) = \sum_{g=1}^{G} p_g T(c)_g + \sum_{g=1}^{G} p_g * \ln\left(\frac{\bar{c}}{c_g}\right) \qquad (12)$$

where p_g is the population share of group g, T_g denotes the internal inequality in group g, and c_g represents the emissions of CO_2 per capita in group g.

Notice that the first term—the within-group component—is a weighted mean of the internal Theil indexes, and thus can be directly broken down following our methodology. The second term—the between-group component—is simply a population weighted Theil index and thus can also be decomposed according to the methodology presented above.

3. Results of the decomposition of the inequality in CO_2 per capita emissions of the European Union into explanatory factors

Table 2 shows the inequality in CO_2 emissions per capita and the contribution of each of the factors to this inequality over the 1990–2006 period.

Table 2. Inequality in CO_2 emissions per capita in the European Union and decomposition into explanatory factors

	$T(c,p)$	T^A	T^B	T^Y
1990	0.0467	0.0171 (36.5%)	0.0186 (39.8%)	0.0112 (23.9%)
1991	0.0430	0.0135 (31.4%)	0.0108 (25.1%)	0.0187 (43.5%)
1992	0.0384	0.0115 (29.9%)	0.0055 (14.3%)	0.0213 (55.5%)
1993	0.0424	0.0143 (33.7%)	0.0065 (15.2%)	0.0217 (51.1%)
1994	0.0421	0.0129 (30.6%)	0.0035 (8.3%)	0.0257 (61.0%)
1995	0.0368	0.0133 (36.0%)	0.0005 (1.4%)	0.0230 (62.6%)
1996	0.0410	0.0137 (33.4%)	0.0043 (10.5%)	0.0230 (56.1%)
1997	0.0372	0.0123 (33.1%)	0.0006 (1.6%)	0.0243 (65.3%)
1998	0.0351	0.0094 (26.6%)	-0.0035 (-9.9%)	0.0293 (83.5%)
1999	0.0357	0.0090 (25.1%)	-0.0072 (-20.2%)	0.0339 (94.9%)
2000	0.0366	0.0101 (27.5%)	-0.0080 (-21.9%)	0.0346 (94.5%)
2001	0.0355	0.0101 (28.3%)	-0.0066 (-18.7%)	0.0320 (90.1%)
2002	0.0338	0.0103 (30.5%)	-0.0065 (-19.1%)	0.0299 (88.3%)
2003	0.0342	0.0110 (32.2%)	-0.0052 (-15.1%)	0.0285 (83.2%)
2004	0.0339	0.0113 (33.3%)	-0.0053 (-15.5%)	0.0280 (82.4%)
2005	0.0299	0.0105 (35.1%)	-0.0064 (-21.2%)	0.0259 (86.5%)
2006	0.0322	0.0127 (39.4%)	-0.0042 (-12.9%)	0.0237 (73.4%)

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

CO_2 emissions per capita inequality among European countries decreases over the period; the Theil index shows a 36.0% reduction. As for the factors responsible for these inequalities, the important inequalities of the base year were explained to a greater degree by energy intensity

(39.8%) and the carbonization index (36.5%), than by GDP per capita inequality, which made a lower contribution (23.9%). That is to say, the different production structures and energy efficiencies, as well as the differing importance of polluting fuels in the energy mix, were more relevant in explaining the different emissions than the different GDP per capita levels. However, over the period there is an uneven evolution in the responsibility of the different factors. Actually, while the carbonization index holds its relative importance in total inequality—therefore experiencing a similar evolution to the global index—both the energy intensity and the GDP per capita factors experience significant changes in opposite directions. The total contribution in absolute terms of the differences in GDP per capita experiences a noticeable increase: these differences increasingly explain the disparities in emissions per capita. However, inequality in energy intensities changes from being the main factor in the explanation of global differences to becoming a factor that reduces global inequality, as it works in the opposite way to the other inequalities. That is, while inequality in the carbon intensity of energy strengthens global inequality, inequality in energy intensity compensates for the other inequalities. This is explained by the important interaction components with a negative sign, especially the interaction between the energy intensity and GDP per capita factors[5] (see Annex I, Table 5).

Table 3 shows the results for the decomposition of total inequality into the inequality between groups and within the different groups considered in the previous section (North Europe, South Europe and East Europe). We have employed different classifications of countries according to geographical and socioeconomic and political criteria (such as EU-15 and others), the chosen grouping being the one explaining the greatest between-group component of inequality. This result reinforces our choice[6]. However, the between-group component would explain a third of the inequalities in the base year, but only 14.8% in 2006.

[5] That is to say, countries that tend to have greater GDP per capita would also tend to have lower energy intensity, so that this interaction compensates for the contribution to inequalities of the GDP per capita and energy intensity factors, in the latter case leading to a negative value.

[6] Computations for other groupings are available from the authors on request.

Table 3. Results for subgroups decomposition (North Europe, South Europe and East Europe)

	$T(c,p)$	T^A	T^B	T^Y
1990				
Between	0.0157 (33.6%)	-0.0024 *(-15.4%)*	0.0133 *(84.7%)*	0.0048 *(30.8%)*
Within	0.0310 (66.4%)	0.0195 *(62.9%)*	0.0034 *(11.1%)*	0.0081 *(26.1%)*
1995				
Between	0.0090 (24.5%)	-0.0056 *(-62.4%)*	-0.0028 *(-31.0%)*	0.0175 *(193.4%)*
Within	0.0278 (75.5%)	0.0192 *(69.3%)*	0.0020 *(7.1%)*	0.0066 *(23.6%)*
2000				
Between	0.0080 (21.8%)	-0.0070 *(-87.3%)*	-0.0122 *(-152.7%)*	0.0272 *(340.0%)*
Within	0.0286 (78.2%)	0.0175 *(61.2%)*	0.0029 *(10.1%)*	0.0082 *(28.8%)*
2006				
Between	0.0048 (14.8%)	-0.0050 (-105.1%)	-0.0081 (-170.6%)	0.0179 (375.6%)
Within	0.0274 (85.2%)	0.0181 (65.8%)	0.0035 (12.7%)	0.0059 (21.5%)

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c)

Note: First column shows (within brackets) the percentages with respect to global inequality, other columns show the percentages with respect to the between- and within-group components.

The results show that the reduction in global inequality is mainly explained by the reduction in inequality between the groups of countries considered. The reduction experienced in the between-group inequality has been much greater than that experienced by the inequality within the groups. The latter only experienced a significant reduction in the first five years of the period, while the reduction of the between-group inequality is continuous over the period. Moreover, the results show a very different behavior of the different factors for the between- and within-group inequalities.

With respect to between-group inequality, while at first the main component was the energy intensity factor, it loses its explanatory capacity after the first years of the period. The reduction of this component is what contributes most to the reduction of between-group inequalities. Actually, after the first five years of the period its contribution to global inequalities becomes negative. This change has to do, not so much with a decrease in energy intensity inequalities between groups, but above all with the behavior of the interaction with the other components (see Annex I, Table 6), and would work in the same sense as that explained for this component in total inequality. At the same time, the GDP per capita factor happens to dominate the explanation of between-group inequalities. The between-group contribution of the carbonization index is increasingly negative.

Within-group inequality shows a more stable trajectory. It experiences a much lower reduction than between-group inequality, both in relative and absolute terms, and the reduction is centered on the first five years. The contribution of the different factors remains stable with low changes over the period. Contrary to between-group inequality, the main component of the within-group inequality is that associated to the carbonization index, with a contribution of between 60% and 70% over the whole period. Much lower is the contribution of the affluence factor (between 20% and 30%) and that of energy intensity (between 7% and 13%). All the factors make a net positive contribution to within-group inequality. The division of the considered groups has been relevant, not only in generating a greater between-group component than other groupings, but also in determining a quite different behavior for the components of the between- and within-group inequalities. We next analyze the behavior of the different components within the different European regions.

Table 4. Decomposition of within-group inequality. Details by groups.

	$T(c,p)$	T^A	T^B	T^Y	**Wi**
1990					
North Europe	0.0357	0.0285 (79.9%)	0.0058 (16.2%)	0.0014 (3.9%)	52.9%
South Europe	0.0160	0.0075 (47.2%)	-0.0017 (-10.4%)	0.0101 (63.2%)	24.7%
East Europe	0.0364	0.0113 (31.0%)	0.0035 (9.6%)	0.0216 (59.4%)	22.4%
1995					
North Europe	0.0290	0.0249 (85.9%)	0.0047 (16.4%)	-0.0006 (-2.2%)	53.4%
South Europe	0.0079	0.0039 (49.1%)	-0.0033 (-41.5%)	0.0073 (92.4%)	24.6%
East Europe	0.0472	0.0228 (48.2%)	0.0012 (2.5%)	0.0233 (49.3%)	21.9%
2000					
North Europe	0.0239	0.0208 (87.2%)	0.0041 (17.2%)	-0.0010 (-4.4%)	53.8%
South Europe	0.0030	0.0019 (65.0%)	-0.0017 (-58.2%)	0.0028 (93.2%)	24.7%
East Europe	0.0701	0.0272 (38.8%)	0.0051 (7.3%)	0.0377 (53.9)	21.5%
2006					
North Europe	0.0281	0.0251 (89.4%)	0.0043 (15.4%)	-0.0013 (-4.8%)	53.8%
South Europe	0.0053	0.0025 (47.0%)	-0.0002 (-3.8%)	0.0030 (56.7%)	25.5%
East Europe	0.0532	0.0190 (35.8%)	0.0058 (10.9)	0.0283 (53.3%)	20.7%

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

The data show a different level of inequality within the different groups of countries considered. East Europe is the group with the greatest level of internal inequality, it being somewhat lower in North Europe, and much lower in the case of South Europe, whose contribution to the within-group component of European inequality is of low significance. The evolution of the inequality and its components are also quite different.

The evolution of the inequality within the North Europe group shows a major reduction during the first ten years of the period and an increase at the end. In this case, the disparity in emissions per capita is mainly explained by the different carbonization indexes. The relative importance of this component increased from 79.9% to 89.4%, as its contribution decreased less than global inequality. It is these countries' share of population that determines the preponderance of the carbonization factor in the results in Table 3.

South Europe shows a very similar evolution of inequality to North Europe (a reduction between 1990 and 2000 and an increase afterwards). The contribution of the component associated to the GDP per capita factor might be highlighted, although the carbonisation index factor is also very important. The contribution of energy intensity is negative and highly variable over the period.

Finally, the evolution is very different for the East Europe group. In this case, inequality increases considerably between 1990 and 2000, experiencing a reduction over the last 6 years of the period. In this case, the GDP per capita factor explains the main differences, although the carbonization index is also significant. Of the three groups of countries considered, this one presents the greatest internal disparities and is the only one in which these increase, especially between 1990 and 2000.

4. Conclusions

The discussion within the European Union of the targets to achieve in the mitigation of greenhouse gases and the distribution of mitigation efforts between countries is a controversial issue that requires the maximum knowledge of the factors that influence the different member countries' emissions as well as the changes in inequality levels at communitarian level. The greater inequality, the more likely the difficulty to share objectives, especially if the different factors explaining this inequality are not taken into account in correct policy design.

In the present paper we have applied a decomposition of a synthetic indicator of inequality, the Theil index, which makes it possible to analyze the factors behind inequalities in CO_2 emissions per capita at communitarian level. The virtue of this decomposition is that it can be used to obtain the contribution of different factors—Kaya factors—to the global inequality and its trajectory. Moreover, it has the advantage of also being applicable to the analysis of inequality between and within the groups of countries considered—North Europe, South Europe, and East Europe—thanks to the fact that the Theil index enables a perfect decomposition of the between- and within-group components of this inequality.

The results indicate an important reduction in the inequality of CO_2 emissions per capita between European countries. Lower divergences would presumably tend to facilitate the rapprochement of positions on how to mitigate the problem at communitarian level. The reduction is explained to a large extent by the lower contribution of energy intensity, which was the most important factor at the beginning of the period but has a negative contribution at the end, now being much less relevant than the other factors. As for the between- and within-group components, the reduction in inequality is mostly explained by the reduction in inequality between the groups of countries considered.

Nowadays, the major factor explaining European inequalities in CO_2 per capita is the important inequality that still exists in GDP per capita. Therefore, different affluence levels tend to group the interests of the different countries and groups of countries in the discussions on efforts distribution. The carbonization index has also maintained a relevant role in the explanation of inequalities. This is explained by the persistence of important differences in the energy mix, with some countries having an important share of coal (Poland and Czech Republic) and others having a relevant share of nuclear and renewable power (France and Sweden).

However, the important differences in energy intensities do not make a positive contribution to total inequality. That is to say, the differences in energy efficiency and/or production structures that lead to a different level of energy consumption per product unit, do not contribute to global inequalities, as the countries with greater energy intensity tend to be those with lower GDP per capita levels. Of course, one cannot conclude from this that there is no need to make efforts to reduce inequalities in energy intensities that are due to an inefficient use of energy, although the present work does not make it possible to differentiate which part is due to this and which is due to a different specialization in more energy intensive sectors. The greater energy intensity in lower income countries could reduce the difficulties that income inequality imposes on the possibility of reaching agreements, especially when these are due to lower efficiency.

The major reduction in inequality between groups is to a large extent the result of the reduction in the contribution of the energy intensity component between groups (mainly in the first years of the period). At the end of the period, the differences between the groups are mainly explained by the component associated to the GDP per capita factor and to a lesser extent to the carbonization index. The differences between the groups of countries according to GDP per capita would mainly explain the differences in emissions per capita levels, the differences in carbonization indexes that respond to different energy source mixes in the primary energy used in the different groups also being relevant, with a greater relative importance of coal in East Europe, and of nuclear and renewable power in North Europe.

However, at the end of the period the differences are concentrated within the groups of countries considered, the carbonization index being the most relevant within-group component of inequality. Countries classified according to similar geographic and socio-economic characteristics have very different compositions of energy sources (energy mix)—which is very clear in the group of higher income countries, North Europe. It might then be expected that, within the groups of countries considered, the different interests when negotiating mitigation policies may be based on this different importance of the use of more polluting fossil fuels, the energy intensity factor being of lower—although still significant—importance.

The present research complements the information provided by the data with synthetic indicators that reveal changes in the contribution of different factors to inequality. Discussions within the European Union on the ambition of mitigation objectives will continue in the future and it is essential to analyze the roots of the divergence through disaggregated analysis of the situation in each country as well as with aggregated indicators such as that proposed, which show the main factors behind the magnitude and evolution of the observed European disparities. The ability to reach agreements on the distribution of the burden in order to achieve the common objectives will depend on the proposals being seen as fair and taking the differences in the European Union adequately into account. A continuous trend in the reduction of income inequality in the future would facilitate a common position. With respect to the other factors, a reduction in energy intensity inequalities would be desirable, with convergence towards the situation in the most energy-efficient countries, although this has its limits as these inequalities might be due to different sectoral specializations. Finally, one measure of the success of common climate policies in the long run could be a reduction in the contribution of the carbonization index to inequality accompanied by a general downward trend in the level of the carbonization index in Europe. Ultimately, only a shift towards a decarbonized economy will lead to long-term sustainable use of energy.

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References

Alcántara V., Duro J.A., (2004), Inequality of energy intensities across OECD countries, *Energy Policy*, **32**, 1257–1260.

Alcántara V., Padilla E., (2005), Analysis of CO_2 emissions and its explanatory factors in the different regions of the world, (in Spanish), *Revista de Economía Crítica*, **4,** 17–37.

Ang B.W., (1999), Is the energy intensity a less useful indicator than the carbon factor in the study of climate change?, *Energy Policy*, **27**, 943–946.

Bourguignon F., (1979), Decomposable income inequality measures, *Econometrica*, **47**, 901–920.

Cantore N., Padilla E., (2010a), Equality and CO_2 emissions distribution in climate change integrated assessment modeling, *Energy*, **35**, 298–313.

Cantore N., Padilla E., (2010b), *Emissions distribution in post – Kyoto international negotiations: a policy perspective,* In: *Nanotechnology and Microelectronics: Global Diffusion, Economics and Policy*, Ekekwe N. (Ed.), IGI Global, Hershey, USA, 243–260.

Cowell F., (1995), *Measuring Inequality*, Prentice Hall, London.

Duro J.A., Alcántara V., Padilla E., (2010), International inequality in energy intensity levels and the role of production composition and energy efficiency: an analysis of OECD countries, *Ecological Economics*, **69**, 2468–474.

Duro J.A., Padilla E., (2006), International inequalities in per capita CO_2 emissions: a decomposition methodology by Kaya factors, *Energy Economics*, **28,** 170–187.

Greening L.A., Davis W.B., Schipper L., Khrushch M., (1997), Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries, *Energy Economicsk*, **19**, 375–390.

Groot L., (2010), Carbon Lorenz curves, *Resource and Energy Economics*, **32**, 45–64.

Hedenus F., Azar C., (2005), Estimates of trends in global income and resource inequalities, *Ecological Economics*, **55**, 351–364.

Heil M.T., Wodon Q.T., (1997), Inequality in CO_2 emissions between poor and rich countries, *Journal of Environment and Development*, **6**, 426–452.

International Energy Agency (IEA), (2009a), *CO_2 Emissions from Fuel Combustion*, IEA, OECD, Paris.

International Energy Agency (IEA), (2009b), *Energy Balances of OECD Countries,* IEA, OECD, Paris.

International Energy Agency (IEA), (2009c), *Energy Balances of non OECD Countries*, IEA, OECD, Paris.

Jobert T., Karanfil F., Tykhonenko A., (2010), Convergence of per capita carbon dioxide emissions in the EU: Legend or reality?, *Energy Economics*, **21**, 1364–1373.

Kaya Y., (1989), *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*, paper presented to the Energy and Industry Subgroup, Response Strategies Working Group, Intergovernmental Panel on Climate Change, Paris, France.

Millimet D.L., Slottje D., (2002), An Environmental Paglin-Gini, *Applied Economics Letters*, **9**, 271–74.

Padilla E., Serrano A., (2006), Inequality in CO_2 emissions across countries and its relationship with income inequality: a distributive approach, *Energy Policy*, **34**, 1762–1772.

Shorrocks A., (1980), The class of additively decomposable inequality measures, *Econometrica*, **48**, 613–625.

Sun J.W., (2002), The decrease in the difference of energy intensities between OECD countries from 1971 to 1998, *Energy Policy*, **30**, 631–635.

Shorrocks A.F., (1980), The Class of Additively Decomposable Inequality Measures, *Econometrica*, **48**, 613–25.

Theil H, (1967), *Economics and Information Theory*, North Holland, Amsterdam.

Annex I. Decomposition of inequality into Kaya factors and interaction terms

Table 5. Decomposition of European inequality in CO_2 emissions per capita into the contributions of Kaya factors and interaction terms

	$T(c,p)$	T^a	T^b	T^y	$\text{Interact}_{a,by}$	$\text{Interact}_{b,y}$
1990	0.0467	0.0256 (54.8%)	0.0773 (165.5%)	0.0699 (149.7%)	-0.0171 (-36.7%)	-0.1089 (-233.3%)
1991	0.0430	0.0249 (57.9%)	0.0757 (176.2%)	0.0836 (194.6%)	-0.0228 (-53.1%)	-0.1184 (-275.6%)
1992	0.0384	0.0237 (61.8%)	0.0738 (192.3%)	0.0896 (233.5%)	-0.0244 (-63.5%)	-0.1244 (-324.5%)
1993	0.0424	0.0261 (61.7%)	0.0718 (169.3%)	0.0870 (205.4%)	-0.0236 (-55.8%)	-0.1189 (-280.6%)
1994	0.0421	0.0258 (61.3%)	0.0634 (150.4%)	0.0856 (203.2%)	-0.0258 (-61.3%)	-0.1069 (-253.7%)
1995	0.0368	0.0259 (70.3%)	0.0585 (158.9%)	0.0810 (220.0%)	-0.0253 (-68.6%)	-0.1033 (-280.7%)
1996	0.0410	0.0261 (63.7%)	0.0592 (144.3%)	0.0779 (190.0%)	-0.0248 (-60.5%)	-0.0974 (-237.5%)
1997	0.0372	0.0250 (67.2%)	0.0544 (146.4%)	0.0781 (210.2%)	-0.0254 (-68.4%)	-0.0949 (-255.4%)
1998	0.0351	0.0234 (66.6%)	0.0455 (129.7%)	0.0783 (223.2%)	-0.0281 (-80.2%)	-0.0839 (-239.2%)
1999	0.0357	0.0240 (67.3%)	0.0375 (105.3%)	0.0786 (220.4%)	-0.0301 (-84.3%)	-0.0744 (-208.7%)
2000	0.0366	0.0253 (69.1%)	0.0348 (95.1%)	0.0774 (211.4%)	-0.0305 (-83.3%)	-0.0704 (-192.3%)
2001	0.0355	0.0258 (72.7%)	0.0346 (97.5%)	0.0732 (206.3%)	-0.0315 (-88.7%)	-0.0667 (-187.8%)
2002	0.0338	0.0261 (77.3%)	0.0322 (95.4%)	0.0685 (203.0%)	-0.0316 (-93.5%)	-0.0615 (-182.2%)
2003	0.0342	0.0259 (75.6%)	0.0299 (87.2%)	0.0635 (185.4%)	-0.0298 (-87.0%)	-0.0552 (-161.2%)
2004	0.0339	0.0272 (80.0%)	0.0251 (74.1%)	0.0583 (171.8%)	-0.0318 (-93.8%)	-0.0448 (-132.1%)
2005	0.0299	0.0268 (89.6%)	0.0222 (74.0%)	0.0544 (181.6%)	-0.0326 (-108.8%)	-0.0408 (-136.4%)
2006	0.0322	0.0269 (83.4%)	0.0223 (69.1%)	0.0501 (155.7%)	-0.0284 (-88%)	-0.0387 (-120.2%)

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

Table 6. Decomposition of inequality into Kaya factors and interaction terms for groups of European countries (North Europe, South Europe and East Europe)

	$T(c,p)$	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$
1990						
	0.0157	0.0054	0.0653	0.0569	-0.0156	-0.0962
Between	(33.6%)	(34.4%)	(416.2%)	(362.2%)	(-99.6%)	(-613.2%)
	0.0310	0.0203	0.0084	0.0130	-0.0016	-0.0091
Within	(66.4%)	(65.4%)	(27.1%)	(42.1%)	(-5.1%)	(-29.5%)
1995						
	0.0090	0.0061	0.0487	0.0690	-0.0234	-0.0913
Between	(24.5%)	(67.3%)	(539.3%)	(763.8%)	(-259.5%)	(-1011.0%)
	0.0278	0.0205	0.0074	0.0120	-0.0025	-0.0097
Within	(75.5%)	(73.8%)	(26.8%)	(43.3%)	(-9.1%)	(-34.8%)
2000						
	0.0080	0.0072	0.0241	0.0635	-0.0284	-0.0585
Between	(21.8%)	(90.0%)	(301.8%)	(794.5%)	(-354.7%)	(-731.6%)
	0.0286	0.0191	0.0086	0.0139	-0.0031	-0.0098
Within	(78.2%)	(66.6%)	(29.9%)	(48.6%)	(-10.9%)	(-34.3%)
2006						
	0.0048	0.0059	0.0140	0.0401	-0.0218	-0.0335
Between	(14.8%)	(123.0%)	(293.9%)	(840.2%)	(-456.1%)	(-701.0%)
	0.0274	0.0217	0.0076	0.0100	-0.0073	-0.0046
Within	(85.2%)	(79.1%)	(27.8%)	(36.6%)	(-26.5%)	(-16.9%)

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

Note: first column shows (within brackets) the percentages with respect to global inequality, other columns show the percentages with respect to the between- and within-group components.

Table 7. Decomposition of within-groups inequality into Kaya factors and interaction terms. Details by groups

	$T(c,p)$	T^a	T^b	T^y	**Interact$_{a,by}$**	**Interact$_{b,y}$**	**wi**
1990							
North Europe	0.0357	0.0303 (84.9%)	0.0060 (16.9%)	0.0016 (4.5%)	-0.0036 (-10.0%)	0.0013 (3.6%)	52.9%
South Europe	0.0160	0.0058 (36.2%)	0.0035 (21.9%)	0.0153 (95.5%)	0.0035 (22.1%)	-0.0121 (-75.7%)	24.7%
East Europe	0.0364	0.0125 (34.5%)	0.0193 (53.2%)	0.0375 (103.0%)	-0.0025 (-7.0%)	-0.0304 (-83.7%)	22.4%
1995							
North Europe	0.0290	0.0286 (98.9%)	0.0069 (24.0%)	0.0016 (5.4%)	-0.0076 (-26.1%)	-0.0006 (-2.2%)	53.4%
South Europe	0.0079	0.0050 (62.6%)	0.0042 (53.2%)	0.0149 (187.1%)	-0.0021 (-27.0%)	-0.0140 (-175.9%)	24.6%
East Europe	0.0472	0.0182 (38.5%)	0.0123 (26.0%)	0.0344 (72.8%)	0.0092 (19.6%)	-0.0268 (-56.8%)	21.9%
2000							
North Europe	0.0239	0.0255 (106.7%)	0.0068 (28.5%)	0.0016 (6.9%)	-0.0093 (-39.1%)	-0.0007 (-3.0%)	53.8%
South Europe	0.0030	0.0040 (135.2%)	0.0049 (166.5%)	0.0094 (317.9%)	-0.0042 (-140.5%)	-0.0112 (-379.1%)	24.7%
East Europe	0.0701	0.0204 (29.1%)	0.0172 (24.5%)	0.0498 (71.1%)	0.0136 (19.4%)	-0.0309 (-44.1%)	21.5%
2006							
North Europe	0.0281	0.0317 (113.0%)	0.0083 (29.7%)	0.0027 (9.5%)	-0.0132 (-47.1%)	-0.0014 (-5.0%)	53.8%
South Europe	0.0053	0.0035 (66.0%)	0.0026 (49.9%)	0.0058 (110.4%)	-0.0020 (-38.0%)	-0.0046 (-88.4%)	25.5%
East Europe	0.0532	0.0182 (34.2%)	0.0119 (22.4%)	0.0344 (64.7%)	0.0017 (3.2%)	-0.0130 (-24.5%)	20.7%

Source: Prepared by the authors using IEA data (IEA, 2009a, 2009b, 2009c).

Note: Within brackets the percentage with respect to within-group inequality of each group. Last column shows population weight of each group.

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