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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 emissions per capita in the European Union (EU-27) in the period 1990–2009 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. The policy implications of the results are discussed.

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

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) (European Council, 2007). 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. In this line, in the Durban climate conference in December 2011, the European Union and some vulnerable developing nations launched negotiations to develop a new international climate change agreement (European Council, 2013).

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, European Council, 2009), the target of the different member states to reduce their emissions to fulfill the 2020 objectives was finally determined.

The disparities in emissions per capita between the different countries of the European Union are very relevant for establishing the different mitigation policy targets and these disparities are due to factors that have evolved differently in different countries. Several studies have analyzed international differences in CO_2 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. We will analyze the evolution of the factors of the well-known Kaya identity (Kaya 1989), which decomposes emissions per capita into the contribution of the carbon intensity of energy (or carbonization index), the energy intensity of product and GDP per capita.

Differences in emissions per capita and in its driving forces might lead to different perceptions and interests about the criteria that should be used to distribute the burden of emission reduction and so may difficult the achievement of mitigation agreements. In addition, if there are important differences between groups of countries with similar characteristics, they may act as blocks with opposing interests about the criteria to follow, which may hinder agreements. It is then very relevant to determine both the evolution of inequalities and the importance of the different factors behind this evolution, as well as whether inequalities concentrate in the disparities between groups of countries or not. 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. The conclusions for policy design and feasibility of agreement would be quite different depending on the contribution of the different factors to emission inequality. It would, for instance, be easier to establish targets for the different countries tending to equalize their emissions per capita if differences were mainly caused by energy inefficiency in some countries than if differences were attributable to divergences in income per capita or to a different mix of energy sources as a result of different resource endowments. Moreover, the proper consideration of these differences is needed in order to increase the perceived fairness of mitigation proposals.

We present and apply a decomposition of a synthetic inequality index, the Theil index, which serves to show the contribution to total inequality of the different explanatory factors on a European level. Moreover, the Theil index has the advantage, with respect to other inequality measures, to be perfectly decomposable by population subgroups (Bourguignon, 1979). Therefore, 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. This would be particularly relevant as regards the possible formation of blocks with divergent interests in negotiations and so the feasibility to achieve agreements. Therefore, the analysis would: first, inform us on how the evolution of disparities leads or not to a situation in which countries would tend to share interests and perceptions about how to distribute mitigation burden; and second, show the factors behind this evolution that should be taken into account to facilitate agreement and a proper design of mitigation policies.

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) as well as the more recent analysis on polarization (Duro and Padilla, 2012).

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, 2012a, 2012b, 2012c). According to these, CO_2 emissions from fossil fuel combustion experienced an 11.7% reduction over the period 1990–2009 (although most of it in the last year of the period, in a context of economic crisis). However, there is a 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 the level of economic activity. However, there may be economic growth due to 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 factors (which, in turn, are determined by other factors): carbon intensity of energy or carbonization index (defined as the carbon dioxide emitted per unit of primary energy used, $\frac{CO_{2i}}{E_i}$), 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 depends on 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.

$$CO_{2i} = \frac{CO_{2i}}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{P_i} \cdot P_i \qquad (1)$$

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

$$\frac{CO_{2i}}{P_i} = \frac{CO_{2i}}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{P_i} \qquad (2)$$

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.

Table 1. Decomposition of CO_2 emissions per capita into Kaya factors, year 2009

		Kaya factors		
	Emissions per capita CO_2/P	**Carbonization index CO_2/E**	**Energy intensity E/GDP**	**GDP per capita GDP/P**
Austria	7.58	2.00	120.269	31.47
Belgium	9.33	1.76	180.098	29.44
Denmark	8.47	2.51	115.415	29.19
Finland	10.30	1.66	215.417	28.84
France	5.49	1.38	150.536	26.39
Germany	9.16	2.36	141.999	27.40
Ireland	8.83	2.75	101.583	31.59
Luxembourg	20.10	2.53	129.277	61.47
Netherlands	10.66	2.25	148.668	31.82
Sweden	4.48	0.92	158.176	30.87
United Kingdom	7.54	2.37	112.912	28.20
North	*7.82*	*2.00*	*139.264*	*28.14*
Cyprus	9.26	2.98	142.501	21.82
Greece	8.00	3.06	110.724	23.56
Italy	6.47	2.36	111.605	24.51
Malta	5.89	3.06	103.388	18.64
Portugal	5.00	2.21	125.943	18.00
Spain	6.17	2.24	119.970	22.96
South	*6.39*	*2.37*	*115.526*	*23.30*
Bulgaria	5.56	2.41	233.558	9.87
Czech Republic	10.45	2.62	203.831	19.61
Estonia	10.94	3.09	247.945	14.29
Hungary	4.80	1.94	168.529	14.72
Latvia	2.99	1.60	155.810	12.01
Lithuania	3.71	1.48	182.379	13.77
Poland	7.52	3.05	164.778	14.95
Romania	3.65	2.28	172.106	9.31
Slovak Republic	6.12	1.98	183.688	16.81
Slovenia	7.42	2.17	155.224	21.99
East	*6.34*	*2.55*	*177.858*	*13.97*
EU-27	*7.15*	*2.16*	*137.895*	*24.00*
Variation coefficient x 100	43.42	24.33	25.20	43.45

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

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 of the east and south of Europe. The variation coefficient is mildly greater for the energy intensity than for the carbonization index (25.20 and 24.33 respectively). The differences in energy intensities, which are especially large between East Europe and the other groups of countries, show both different efficiencies in the use of energy as well as different production structures. The differences in the carbonization index show the important disparities in the energy mix between 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 last row of the table 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 allows us to analyze the weight of each factor.

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 between countries, this measure might be written as:

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

where c_i are the CO_2 per capita emissions of country i, p_i is the share of country i population in the total European population and $\bar{c}$ is the average European emissions per capita. For this index the lower bound is zero and, therefore, indicative of zero inequality. However, by construction its upper bound is not homogeneously established. In this case, the maximum value depends on the data sample. In any case, and given reasonable samples, values close to 1 indicate high inequality levels[2].

In order to investigate the sources of inequalities in CO_2 emissions per capita 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:

$$c_i = a_i * b_i * y_i \tag{4}$$

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 vector, only the values of one of the factors to diverge from the mean. We obtain the following result[3]:

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

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:

$$\begin{aligned} T^a &= \sum_i p_i \ln\left(\frac{\bar{c}^a}{c_i^a}\right) \\ T^b &= \sum_i p_i \ln\left(\frac{\bar{c}^b}{c_i^b}\right) \\ T^y &= \sum_i p_i \ln\left(\frac{\bar{c}^y}{c_i^y}\right) \end{aligned} \tag{6}$$

These indexes measure the partial contribution of each factor to global inequality. Notice that the importance attributable to each factor 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 $\ln\left(\frac{\bar{c}}{\bar{c}^a}\right)$ and $\ln\left(\frac{\bar{c}}{\bar{c}^b}\right)$, we obtain:

$$
\begin{aligned}
&\left(T^a + \ln\left(\frac{\bar{c}}{\bar{c}^a}\right)\right) + \left(T^b + \ln\left(\frac{\bar{c}}{\bar{c}^b}\right)\right) + T^y = \\
&= \sum_{i=1} p_i * \ln\left(\frac{\bar{c}}{c_i^a}\right) + \sum_{i=1} p_i * \ln\left(\frac{\bar{c}}{c_i^b}\right) + T^y = \\
&= \sum_{i=1} p_i * \ln\left(\frac{\bar{a}}{a_i}\right) + \sum_{i=1} p_i * \ln\left(\frac{\bar{b}}{b_i}\right) + \sum_{i=1} p_i * \ln\left(\frac{\bar{y}}{y_i}\right) = \\
&= \sum_{i} p_i * \ln\left(\frac{\bar{a} * \bar{b} * \bar{y}}{a_i * b_i * y_i}\right) = T(c, p)
\end{aligned}
\tag{7}
$$

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

$$
\begin{aligned}
\ln\left(\frac{\bar{c}}{\bar{c}^a}\right) &= \ln\left(1 + \frac{\sigma_{a,by}}{\bar{c}^a}\right) \\
\ln\left(\frac{\bar{c}}{\bar{c}^b}\right) &= \ln\left(1 + \frac{a * \sigma_{bt,y}}{\bar{c}^b}\right)
\end{aligned}
\tag{8}
$$

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 inequality in emissions per capita between European countries into the sum of the individual contributions of the Kaya factors—expressed with Theil indexes—and two interaction terms.

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

where $\text{inter}_{a,by}$ and $\text{inter}_{b,y}$ are the first and the second interaction terms of expression (8).

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:

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

$$T(c,p) = T^A + T^B + T^Y \quad (11)$$

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

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

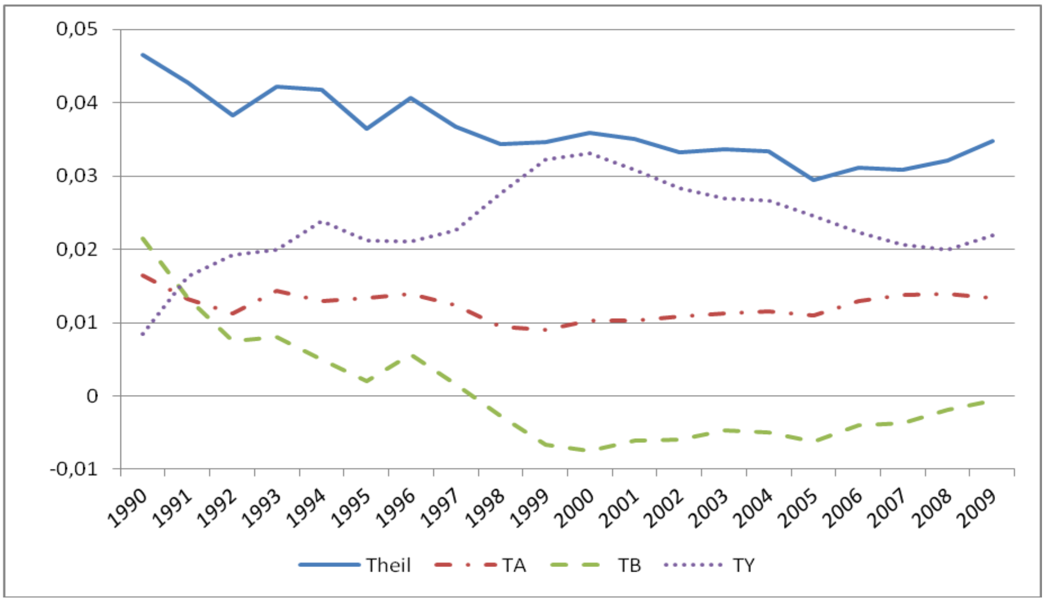
where p_g is the population share of group g, T_g denotes the internal inequality in group g, and c_g represents CO_2 emissions per capita in group g.

Notice that the first term—the within-group component—is a weighted mean of the internal Theil indexes for each group, and thus can be directly broken down into Kaya factors following our methodology. The second term—the between-group component—is simply a population weighted Theil index of the inequality between groups 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

Figure 1 shows the inequality in CO_2 emissions per capita and the contribution of each factor to this inequality over the period 1990–2009. For a simpler presentation and interpretation, figures show the results of the decomposition applying the Shorrocks rule (the results for interaction terms are shown in Annex I).

Figure 1. Inequality in CO_2 emissions per capita in the European Union and decomposition into explanatory factors



Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

Note: The Shorrocks rule is applied to distribute the interaction terms on an equalitarian basis among the different factors.

The inequality in CO_2 emissions per capita between European countries decreases until 2005 (a 36.8% reduction) and experiences a small increase thereafter; the Theil index shows a 25.4% reduction over the whole period. This reduction coincides with the trend shown by this inequality at worldwide level (Duro and Padilla, 2006; Padilla and Serrano, 2006). As for the factors responsible for these inequalities, the important inequalities of 1990—the base year of the Kyoto protocol—were explained to a greater degree by energy intensity (46.3% of total inequality) and the carbonization index (35.5%), than by GDP per capita inequality, which made a lower contribution (18.2%). That is to say, the different production structures and energy efficiencies, as well as the different weight 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. 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 contribution of the inequality in GDP per capita experiences a noticeable increase till the year 2000, and a reduction thereafter. As for the inequality in energy intensity, it changes from being the main factor in the explanation of global European differences in CO_2 emissions per capita to becoming a factor that reduces global inequality, as it works in the opposite way to the other inequalities[5]. That is, while inequalities in GDP per capita and in the carbon intensity of energy strengthen global inequality, inequality in energy intensity compensates for the other inequalities (although its negative contribution to inequality is very small in the last year of the period). The major relevance of GDP per capita inequalities is even more evident in the explanation of past and future international inequalities in CO_2 emissions at worldwide level than in our case; as shown by Duro and Padilla (2006) for the period 1971–2000 and Cantore (2012) for projections using MERGE and RICE models. Differences in GDP per capita should then be closely correlated to the stringency of the efforts required to the different countries in order to increase the perceived fairness of abatement agreements.

Table 2 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 explains a third of emission inequality in the base year, but only 15.0% in 2009[7].

Table 2. Results for subgroups decomposition (North Europe, South Europe and East Europe)

	$T(c,p)$	T^A	T^B	T^Y
1990				
Between	0.0155 (33.4%)	-0.0026 (-16.8%)	0.0155 (99.9%)	0.0026 (16.8%)
Within	0.0310 (66.6%)	0.0192 (62.0%)	0.0038 (12.1%)	0.0080 (25.9%)
1995				
Between	0.0089 (24.3%)	-0.0054 (-61.2%)	-0.0016 (-18.1%)	0.0159 (179.3%)
Within	0.0276 (75.7%)	0.0191 (69.2%)	0.0020 (7.1%)	0.0065 (23.7%)
2000				
Between	0.0078 (21.8%)	-0.0064 (-82.0%)	-0.0117 (-149.3%)	0.0259 (331.4%)
Within	0.0281 (78.2%)	0.0171 (61.1%)	0.0028 (10.1%)	0.0081 (28.8%)
2005				
Between	0.0046 (15.8%)	-0.0048 (-103.2%)	-0.0098 (-211.5%)	0.0192 (414.7%)
Within	0.0248 (84.2%)	0.0162 (65.3%)	0.0032 (13.1%)	0.0054 (21.7%)

2009				
Between	0.0052 (15.0%)	-0.0051 (-96.8%)	-0.0057 (-109.0%)	0.0160 (305.8%)
Within	0.0295 (85.0%)	0.0190 (64.3%)	0.0049 (16.5%)	0.0057 (19.2%)

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

Note: The first column shows (within brackets) the percentages with respect to global inequality, the other columns show the percentages with respect to the between- and within-group components. The Shorrocks rule is applied to distribute the interaction terms on an equalitarian basis among the different factors.

The reduction in global inequality is mainly explained by the reduction in inequality between the groups of countries considered. There was a continuous reduction in between-group inequality over the period, a reduction that was much greater than that experienced by inequality within the groups. Moreover, the results show a very different behavior of the different factors for 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. In fact, its contribution to global inequalities becomes highly negative. This change has to do, not so much with a decrease in energy intensity inequalities between groups, but above all with the increasing negative values of the interaction terms (see Annex I, Table 5), and would work in the same sense as that explained for this component in total inequality (that is, this inequality tends to compensate for the other inequalities). 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 (as the carbonization index is greater for groups with lower GDP per capita). This reduction in differences between groups may be seen as a process to a less conflicting emission distribution, in which perceptions and interests of the different groups about abatement criteria tend to be less divergent and so agreement more feasible.

Within-group inequality shows a more stable trajectory. It experiences a much lower reduction than between-group inequality, both in relative and absolute terms. The contribution of the different factors remains stable with low changes over the period. Contrary to between-group inequality, the main component of within-group inequality is that associated to the carbonization index, with a contribution of between 61.1% and 69.2% over the whole period. Much lower is the contribution of the affluence factor (between 19.2% and 28.8%) and that of energy intensity (between 7.1% and 16.5%). 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 between- and within-group inequalities. We next analyze the behavior of the different components within the different European regions.

Table 3. Decomposition of within-group inequality. Details by groups.

	$T(c,p)$	T^A	T^B	T^Y	p_g
1990					
North Europe	0.0355	0.0283 (79.6%)	0.0062 (17.4%)	0.0011 (3.1%)	52.9%
South Europe	0.0159	0.0073 (46.1%)	-0.0015 (-9.2%)	0.0100 (63.0%)	24.7%
East Europe	0.0368	0.0109 (29.6%)	0.0038 (10.3%)	0.0221 (60.1%)	22.4%
1995					
North Europe	0.0284	0.0246 (86.7%)	0.0047 (16.6%)	-0.0009 (-3.3%)	53.4%
South Europe	0.0080	0.0039 (48.8%)	-0.0033 (-41.2%)	0.0074 (92.4%)	24.6%
East Europe	0.0477	0.0227 (47.6%)	0.0012 (2.4%)	0.0238 (50.0%)	21.9%
2000					
North Europe	0.0226	0.0204 (90.1%)	0.0040 (17.5%)	-0.0017 (-7.5%)	53.8%
South Europe	0.0031	0.0020 (64.2%)	-0.0018 (-57.6%)	0.0029 (93.4%)	24.7%
East Europe	0.0705	0.0266 (37.7%)	0.0053 (7.6%)	0.0385 (54.7%)	21.5%
2005					
North Europe	0.0231	0.0221 (95.5%)	0.0039 (17.0%)	-0.0029 (-12.4%)	53.8%
South Europe	0.0033	0.0017 (49.5%)	-0.0005 (-15.6%)	0.0022 (66.1%)	25.4%
East Europe	0.0552	0.0185 (33.6%)	0.0061 (11.0%)	0.0306 (55.4%)	20.8%
2009					
North Europe	0.0281	0.0244 (86.7%)	0.0062 (22.0%)	-0.0025 (-8.7%)	53.8%
South Europe	0.0054	0.0040 (74.3%)	-0.0004 (-7.2%)	0.0018 (32.9%)	25.8%
East Europe	0.0636	0.0236 (37.1%)	0.0080 (12.6%)	0.0320 (50.3%)	20.4%

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

Note: The Shorrocks rule is applied to distribute the interaction terms on an equalitarian basis among the different factors. The last column shows the population weight of each group.

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 clearly lower in North Europe (except for 1990, in which it was only somewhat lower), 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 inequality and its components are also quite different in the different regions.

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 79.6% to 86.7%, 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 2.

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, being the most important for most part of the period, but the carbonization index factor is also very important and becomes the chief contributor at the end of the period. In this group, the contribution of energy intensity is negative and highly variable over the period.

Finally, the evolution is very different for the East Europe group. This group presents the greatest internal disparities and is the only one in which these increase. Inequality increases considerably between 1990 and 2000, experiencing a reduction between 2000 and 2005 and an increase thereafter. This is the group with greater carbonization and energy intensity indexes and lower GDP per capita (see Table 1). The greater disparity in this last factor is the main reason of the important inequalities within this group, although the contribution of differences in the carbonization index is also significant. Consequently, despite the countries included in this group tend to have lower GDP per capita and greater carbonization index than the European average, if internal differences within this group continue to increase in the future, these may difficult the formation of a cohesive group in European negotiations in the future. However, between groups differences in GDP per capita and in the other factors are still relevant.

4. Conclusions and policy implications

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 fairly controversial issue. It requires the maximum knowledge of the factors that determine the differences in emissions between countries and the changes in these. Differences in emissions per capita and in their driving forces have implications for the willingness to share the burden of emission mitigation within the EU and even for the negotiation strategy of the EU at global level. Greater inequality would increase the difficulty to share objectives—especially if the different factors explaining this inequality are not correctly taken into account in policy design. Moreover, if this inequality concentrates in the disparities between groups of countries, these may form blocks with divergent interests that may difficult agreements. Both greater differences in per capita emissions and greater differences in the determinants of these emissions would lead to different interests and perceptions about the criteria that should be used to distribute the burden; and even about how ambitious the goals should be, according to the difficulty to control the driving forces of emissions in each case.

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 EU 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. These lower divergences would presumably tend to facilitate the rapprochement of positions on how to mitigate the problem at EU 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 to inequality 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. This reduction is especially relevant as regards the evolution towards a distributive situation where there is more feasibility to share positions on how to distribute mitigation burdens. However, despite these differences have decreased, recent effort-sharing discussions have been complicated. An example was the European summit of October 2008 in Brussels, where a group of eight Eastern European countries—which coincides to a great extent with the East Europe group employed in our analysis—called into question whether the objectives previously agreed in 2007 by the European Council on a 20% reduction (compared to 1990 levels) of green house emissions should be maintained. In short, 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. Despite the difficulties, an agreement on the emission reduction efforts required for the different member states was finally established in April 2009. More recently, since 2011 Poland has blocked the European proposals (known as "low carbon road map 2050", European Comission, 2011) to establish more stringent targets on emissions reductions (European Council, 2012). Similar processes of negotiation and conflicts already occurred in the Kyoto discussions among the then 15 EU member states to distribute the 8% reduction target. If the reduction of inequality between groups continues in the future the formation of blocks of countries with opposing interests would then be less likely.

Nowadays, the major factor explaining European inequalities in CO_2 per capita is the important inequality that still exists in GDP per capita. Consequently, it is logical that 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 CO_2 emissions 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/or renewable power (France and Sweden). These inequalities may be more difficult to be reduced in the short term due to the existence different resource endowments and energy facilities in different countries. If European policies were successful in encouraging the increase in the share of renewable energies and the reduction of fossil fuels, this inequality would tend to decrease.

As regards the important differences in energy intensities, these do not make a positive contribution to total inequality when the interaction terms are distributed among corresponding factors. 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. This is clear for the case of East Europe countries which is the group both with lower GDP per capita and greater energy intensity. Differences in energy intensity, quite substantial in the reference year 1990, would be a factor facilitating agreements as far as they would mean the capacity to assume some effort via efficiency policies by countries with lower GDP per capita and emissions than the European average. Therefore, greater energy intensity in lower income countries could reduce the difficulties imposed by emissions inequality on the possibility of reaching agreements, especially when these are due to lower efficiency. Consequently, one cannot conclude from the results that there is no need to make efforts to reduce inequalities in energy intensities when they 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. In a study for 16 OECD countries, Duro et al. (2010) found that while at 1995 the major part of inequalities in final energy intensity was explained by energy efficiency differences (71.0%), this factor showed a great decrease and the structure component increased its importance in explaining final consumption inequalities (47.3%); though energy efficiency differences remained important (42.2%). In case the EU inequalities showed a similar pattern, there would still be way for efficiency policies and technology transmission for reducing energy intensity differences between countries; though this reduction would already be happening.

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 primary energy sources 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/or renewable power in North Europe. In any case, results show that these groups are becoming less divergent as regards their CO_2 emissions per capita, which is also confirmed by recent evidence using polarization analysis (Duro and Padilla, 2012).

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. While differences arising from the different share of renewable energies might be reduced over time by adequate policies, different resource endowments and energy facilities will maintain important differences in this factor in the future, which could be a factor hampering consensus.

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 inequality 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 part of 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.

Notes

[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).

[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 analyzed, 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.

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

[5] If we check the decomposition without distributing interaction terms (equation (9); see Annex I, Table 4), we found that this is explained by the important interaction components with a negative sign, especially the interaction between the energy intensity and GDP per capita factors. 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.

[7] In contrast, the evidence at worldwide level shows a much greater importance of the between group component, as shown by Padilla and Serrano (2006) for the period 1970–1999 and Cantore (2012) for projections using RICE99 and MERGE models. Of course, these results are not contradictory, because our sample only includes European groups of countries that logically show less heterogeneity between them than the groups formed according to income in these studies.

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

Table 4. 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	$Interact_{a.by}$	$Interact_{b.y}$
1990	0.0465	0.0241 (51.8%)	0.0832 (179.1%)	0.0701 (150.9%)	-0.0152 (-32.6%)	-0.1158 (-249.1%)
1991	0.0427	0.0238 (55.6%)	0.0809 (189.2%)	0.0839 (196.2%)	-0.0212 (-49.6%)	-0.1245 (-291.3%)
1992	0.0382	0.0229 (60.0%)	0.0781 (204.5%)	0.0899 (235.4%)	-0.0231 (-60.5%)	-0.1295 (-339.4%)
1993	0.0422	0.0256 (60.8%)	0.0754 (178.7%)	0.0873 (207.0%)	-0.0227 (-53.9%)	-0.1234 (-292.6%)
1994	0.0417	0.0253 (60.7%)	0.0669 (160.2%)	0.0858 (205.6%)	-0.0247 (-59.2%)	-0.1116 (-267.2%)
1995	0.0365	0.0254 (69.7%)	0.0621 (170.2%)	0.0813 (222.9%)	-0.0242 (-66.3%)	-0.1081 (-296.5%)
1996	0.0406	0.0257 (63.2%)	0.0628 (154.8%)	0.0783 (192.8%)	-0.0236 (-58.1%)	-0.1026 (-252.6%)
1997	0.0367	0.0244 (66.7%)	0.0572 (156.2%)	0.0782 (213.3%)	-0.0240 (-65.5%)	-0.0992 (-270.6%)
1998	0.0344	0.0226 (65.7%)	0.0478 (139.0%)	0.0782 (227.3%)	-0.0263 (-76.5%)	-0.0879 (-255.5%)
1999	0.0346	0.0231 (66.9%)	0.0397 (114.6%)	0.0785 (227.0%)	-0.0282 (-81.6%)	-0.0785 (-227.0%)
2000	0.0359	0.0244 (68.0%)	0.0369 (102.8%)	0.0775 (216.0%)	-0.0282 (-78.7%)	-0.0746 (-208.1%)
2001	0.0350	0.0253 (72.2%)	0.0363 (103.6%)	0.0733 (209.3%)	-0.0299 (-85.5%)	-0.0699 (-199.6%)
2002	0.0332	0.0257 (77.5%)	0.0346 (104.1%)	0.0687 (207.0%)	-0.0298 (-89.9%)	-0.0659 (-198.7%)
2003	0.0336	0.0254 (75.5%)	0.0318 (94.6%)	0.0635 (189.1%)	-0.0281 (-83.6%)	-0.0590 (-175.5%)
2004	0.0333	0.0267 (80.2%)	0.0269 (80.7%)	0.0585 (175.5%)	-0.0302 (-90.7%)	-0.0486 (-145.8%)
2005	0.0294	0.0267 (90.7%)	0.0240 (81.4%)	0.0548 (186.1%)	-0.0314 (-106.7%)	-0.0446 (-151.6%)
2006	0.0312	0.0270 (86.8%)	0.0241 (77.3%)	0.0504 (161.6%)	-0.0283 (-90.9%)	-0.0420 (-134.9%)
2007	0.0308	0.0282 (86.8%)	0.0221 (77.3%)	0.0466 (161.6%)	-0.0288 (-90.9%)	-0.0372 (-134.9%)
2008	0.0321	0.0281 (87.5%)	0.0194 (60.6%)	0.0413 (128.8%)	-0.0283 (-88.4%)	-0.0284 (-88.6%)
2009	0.0347	0.0273 (78.6%)	0.0183 (52.6%)	0.0408 (117.5%)	-0.0278 (-80.2%)	-0.0238 (-68.5%)

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

Table 5. 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						
Between	0.0155 (33.4%)	0.0043 (27.6%)	0.0700 (451.0%)	0.0571 (367.9%)	-0.0138 (-88.7%)	-0.1021 (-658%)
Within	0.0310 (66.6%)	0.0200 (64.6%)	0.0088 (28.3%)	0.0130 (42.1%)	-0.0016 (-5.3%)	-0.0092 (-29.8%)
1995						
Between	0.0089 (24.3%)	0.0053 (60.1%)	0.0516 (582.0%)	0.0692 (779.3%)	-0.0215 (-242.5%)	-0.0957 (-1078.8%)
Within	0.0276 (75.7%)	0.0207 (75.2%)	0.0075 (27.3%)	0.0121 (43.9%)	-0.0033 (-12.0%)	-0.0095 (-34.3%)
2000						
Between	0.0078 (21.8%)	0.0060 (77.1%)	0.0263 (337.6%)	0.0639 (818.3%)	-0.0248 (-318.2%)	-0.0636 (-814.8%)
Within	0.0281 (78.2%)	0.0193 (68.8%)	0.0084 (29.8%)	0.0136 (48.5%)	-0.0043 (-15.4%)	-0.0089 (-31.7%)
2005						
Between	0.0046 (15.8%)	0.0061 (131.9%)	0.0156 (335.6%)	0.0446 (961.9%)	-0.0218 (-470.2%)	-0.0398 (-859.2%)
Within	0.0248 (84.2%)	0.0214 (86.2%)	0.0080 (32.4%)	0.0101 (40.9%)	-0.0104 (-41.9%)	-0.0044 (-17.6%)
2009						
Between	0.0052 (15.0%)	0.0056 (107.0%)	0.0108 (206.9%)	0.0325 (621.6%)	-0.0213 (-407.7%)	-0.0223 (-427.9%)
Within	0.0295 (85.0%)	0.0228 (77.3%)	0.0075 (25.5%)	0.0083 (28.3%)	-0.0076 (-25.9%)	-0.0015 (-5.1%)

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

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

Table 6. Decomposition of within-groups inequality into Kaya factors and interaction terms. Details by groups

	$T(c,p)$	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$	p_g
1990							
North Europe	0.0355	0.0305 (85.9%)	0.0066 (18.6%)	0.0015 (4.3%)	-0.0045 (-12.6%)	0.0014 (3.9%)	52.9%
South Europe	0.0159	0.0062 (38.7%)	0.0030 (18.7%)	0.0145 (91.0%)	0.0024 (14.8%)	-0.0101 (-63.3%)	24.7%
East Europe	0.0368	0.0105 (28.6%)	0.0203 (55.1%)	0.0386 (104.8%)	0.0007 (2.0%)	-0.0333 (-90.6%)	22.4%
1995							
North Europe	0.0284	0.0287 (101.3%)	0.0071 (25.1%)	0.0015 (5.2%)	-0.0083 (-29.2%)	-0.0007 (-2.3%)	53.4%
South Europe	0.0080	0.0055 (69.4%)	0.0035 (43.2%)	0.0141 (176.8%)	-0.0033 (-41.2%)	-0.0118 (-148.2%)	24.6%
East Europe	0.0477	0.0183 (38.4%)	0.0131 (27.5%)	0.0358 (75.0%)	0.0088 (18.4%)	-0.0283 (-59.3%)	21.9%
2000							
North Europe	0.0226	0.0258 (114.3%)	0.0072 (31.9%)	0.0016 (6.9%)	-0.0110 (-48.5%)	-0.0010 (-4.6%)	53.8%
South Europe	0.0031	0.0043 (141.2%)	0.0040 (131.1%)	0.0086 (282.1%)	-0.0047 (-154.2%)	-0.0092 (-300.3%)	24.7%
East Europe	0.0705	0.0202 (28.7%)	0.0163 (23.1%)	0.0495 (70.2%)	0.0128 (18.1%)	-0.0282 (-40.1%)	21.5%
2005							
North Europe	0.0231	0.0308 (132.9%)	0.0093 (40.4%)	0.0025 (11.0%)	-0.0173 (-74.9%)	-0.0022 (-9.4%)	53.8%
South Europe	0.0033	0.0032 (94.9%)	0.0028 (82.3%)	0.0055 (163.9%)	-0.0030 (-90.7%)	-0.0050 (-150.4%)	25.4%
East Europe	0.0552	0.0192 (34.8%)	0.0110 (20.0%)	0.0355 (64.3%)	-0.0013 (-2.4%)	-0.0092 (-16.7%)	20.8%
2009							
North Europe	0.0281	0.0330 (117.4%)	0.0110 (39.1%)	0.0024 (8.4%)	-0.0173 (-61.3%)	-0.0010 (-3.5%)	53.8%
South Europe	0.0054	0.0042 (77.7%)	0.0011 (20.1%)	0.0033 (60.3%)	-0.0004 (-6.9%)	-0.0028 (-51.2%)	25.8%
East Europe	0.0636	0.0194 (30.5%)	0.0066 (10.3%)	0.0305 (48.0%)	0.0084 (13.3%)	-0.0013 (-2.1%)	20.4%

Source: Prepared by the authors using IEA data (IEA, 2012a, 2012b, 2012c).

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