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Emilio Padilla

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Empirics of the international inequality in CO_2 emissions intensity: explanatory factors according to complementary decomposition methodologies

Juan Antonio Duro*, Jordi Teixidó-Figueras* and Emilio Padilla**
*Departament d'Economia and CREIP, Universitat Rovira i Virgili, Av. de la Universitat, 1, 43204 Reus, Spain.
** Department of Applied Economics, Univ. Autónoma de Barcelona, 08193 Cerdanyola del Vallès, Spain. E-mail: emilio.padilla@uab.es (corresponding author).

Abstract

This paper analyses the international inequalities in CO_2 emissions intensity for the period 1971–2009 and assesses explanatory factors. Multiplicative, group and additive methodologies of inequality decomposition are employed. The first allows us to clarify the separated role of the carbonisation index and the energy intensity in the pattern observed for inequalities in CO_2 intensities; the second allows us to understand the role of regional groups; and the third allows us to investigate the role of different fossil energy sources (coal, oil and gas). The results show that, first, the reduction in global emissions intensity has coincided with a significant reduction in international inequality. Second, the bulk of this inequality and its reduction are attributed to differences between the groups of countries considered. Third, coal is the main energy source explaining these inequalities, although the growth in the relative contribution of gas is also remarkable. Fourth, the bulk of inequalities between countries and its decline are explained by differences in energy intensities, although there are significant differences in the patterns demonstrated by different groups of countries.

JEL codes: D39; Q43; Q56.

Key words: CO_2 international distribution, inequality decomposition, CO_2 emissions intensity.

1. Introduction

The study of the international distribution of CO_2 emissions has received much attention in recent years. From the viewpoint of the analysis of inequality, as examples, we can cite the works of Heil and Wodon (1997, 2000), Millimet and Slottje (2002), Hedenus and Azar (2005), Padilla and Serrano (2006), Duro and Padilla (2006, 2011), Cantore and Padilla (2010), Groot (2010) and Duro (2012); from a convergence analysis approach, there are the papers by, for example, Strazicih and List (2003), Aldi (2006), Romero-Ávila (2008), Jobert et al. (2010) and Barassi et al. (2011). These analyses focus on the international distribution of emissions per capita and provide information on inequalities and their driving forces, leading to a better understating of the underlying imbalances and their trajectories. The greater the level of inequality in both emissions and their causes, the greater the differences that tend to appear in the criteria to be followed in the distribution of mitigation efforts and even the level of mitigation considered desirable. These studies are therefore needed to inform the design of policies so these can adequately consider these imbalances and be viewed as more fair and facilitate greater participation by countries. In particular, these analyses inform the debate on the distribution of emission limits among countries in global mitigation agreements.

A commonly suggested alternative to the goals based on absolute emission limits are targets based on emission intensities, that is, emissions per unit of output. These targets can also be seen as a preliminary goal to achieve the ultimate target in terms of absolute reductions. In the case of certainty about the trajectory of gross domestic product (GDP), both targets are equivalent. With a given trajectory of GDP, the level of emissions would be equivalent to a given emission intensity and vice versa. However, there is no such certainty. Thus, while an absolute limit would be more effective in controlling emissions, there is greater uncertainty about its economic costs, which could hamper the widespread participation of countries (and this has been argued by countries as important to global emissions such as the USA or China, which have proposed modest goals in terms of emission intensities). A goal in terms of emission intensity, however, generates fewer uncertainties with regard to the associated economic costs (Ellerman and Wing, 2003), although if economic growth is higher than expected, it would lead to an absolute reduction below that projected. Moreover, much of the increase in emissions in the last decades can be attributed to the scale effect associated with economic growth, which was territorially homogeneous. In this sense, and if measures to limit economic growth are not on the agenda, the reduction of global emissions necessarily requires a significant decrease in emission intensities.

Therefore, as was the case of emissions per capita, it is of great interest to analyse the evolution of emission intensities, as well as the differences between countries and their driving forces, in order to develop better understanding of the international imbalances and inform the debate on the design of mitigation policies. As far as we know, only Camarero et al. (2013) have examined the international disequilibria in the CO_2 emissions intensity using tools of distributive analysis and they have done so from the convergence clubs approach for 23 OECD countries.[1] In our case, we will address in detail this distribution with a different approach, but complementary in some aspects, such as the decomposition of inequality, by applying it to a large sample including most world countries.

The proposed approach allows us to examine the sources of these international inequalities on the basis of different decomposition methodologies. In short, the literature has addressed

[1] They identify various groups of countries that converge to different equilibriums and conclude that these differences are more due for differences in convergence in the carbonisation index than for differences in the dynamics of energy intensity.

three types of decomposition. First, and perhaps the best known, is group decomposition. This consists of decomposing additively the level of inequality into a first component that reflects the differences between groups of countries and another that reflects the differences within the groups. This analysis allows clarification of the analytical relevance of the groups as descriptive elements of the international inequality with clear connections, for example, to the regional design of environmental policy. Shorrocks (1984) highlighted the properties of the Theil (1967) indexes with regard to this type of decomposition and in particular, of the measure with an inequality sensibility parameter equal to 0 (see Section 2). Duro and Padilla (2006) and Padilla and Serrano (2006), for example, have employed this decomposition technique to analyse international inequalities in the levels of CO_2 per capita, while White (2007) has used it to analyse international inequality in the ecological footprint per capita. Second, the literature has addressed the decomposition of inequality when the variable analysed can be expressed as a sum of factors (source decomposition). Shorrocks (1982) showed that, under the imposition of certain rules, all inequality indexes—and in particular the Theil indexes—can be decomposed in a common way (the natural way) that coincides with the decomposition of the variance. Finally, it is interesting to address the decomposition of inequality through multiplicative factors. As Duro and Padilla (2006, 2011) showed, it is possible to decompose the Theil index perfectly as a sum of the partial contributions of each indicator plus some interaction factors; they applied this to the analysis of the international distribution of CO_2 emissions per capita. In turn, this multiplicative decomposition can be combined with the group decomposition reviewed above.

In this research we apply these decompositions to the analysis of international inequalities in CO_2 emissions intensity for the period 1971–2009. The decomposition by groups is based on the regional economic groups defined by the IEA. The additive decomposition is performed for the three fossil energy sources, that is, coal, oil and gas. Finally, the multiplicative decomposition addresses the roles of the carbonisation index and energy intensity as explanatory factors for the global inequality in emissions intensity and the inequalities between and within the different groups considered.

The paper is organised as follows. Section 2 reviews the main methodological issues associated with the decomposition of inequality and the different approaches proposed. Section 3 analyses the level and trajectory of international inequality in emissions intensity for the period 1971–2009 and its explanatory factors by means of the three proposed decompositions. The final section sets out the main conclusions.

2. Inequality decomposition methodologies

The literature on inequality measurement has addressed the axiomatic characterisation of a series of measures. A battery of these have been considered satisfactory in terms of their compliance with a series of properties such as anonymity, homogeneity of degree 0 (relative measures) and the transfer principle (Cowell, 1995). Among the properties that are not basic but are appealing for analytical purposes to enable discrimination across measures, the capacity to be decomposed by parts is considered. That is, the capacity to decompose the value as a sum of factors. Among all the analytical measures, those with more advantages in this sense would probably be the Theil (1967) indexes. As is well known, this family of indexes corresponds to the following formulation (adapted to our analysis):

$$T(\beta)=\frac{1}{\beta(\beta-1)}\sum_i p_i\left[\left(\frac{e_i}{\mu(e)}\right)^{\beta}-1\right] \qquad (1)$$

where p_i is the share of each country (GDP share in our case); e_i is the emissions intensity of country i; $\mu(e)$ is the average world emissions intensity. The β parameter captures the sensitivity of the measure in relation to the place where distributional changes occur. In particular, the smaller this value is, the more sensitive the measure is to changes at the bottom of the ranking of observations; at the limit, when β tends to $-\infty$, the index only focuses on what happens at the lower end of the ranking.

One of the measures in this family that is commonly used is T(0), the algebraic expression of which is:

$$T(\beta = 0) = -\sum_i p_i \log\left(\frac{\mu(e)}{e_i}\right) \qquad (2)$$

This measure is the most attractive of all the indexes in terms of decomposition (Bourguignon, 1979). In particular, the literature has highlighted its capacity to be decomposed by population subgroups. The point is to group countries under an aggregation criterion, such as a geographical or economic one (as with the regions considered by the IEA) and decompose the inequality into between- and within-group components, where the groups are mutually exclusive. The first corresponds to the inequality, assuming that the groups are internally homogenous and there are only differences between group averages. The second consists of capturing the weighted average of internal inequalities. T(0) is the index with the best characteristics to be decomposed in this way (Shorrocks, 1984; Goerlich, 1998). In short, the decomposition can be expressed as follows:

$$T(e,p) = \sum_{g=1}^{G} p_g T(e)_g + \sum_{g=1}^{G} p_g * \ln\left(\frac{\mu(e)}{\mu(e)_g}\right) \qquad (3)$$

where p_g is the GDP share of group g, $T(e)_g$ denotes the internal inequality in group g, and $\mu(e)_g$ represents the average CO_2 emissions intensity in group g.

The results of this decomposition have two main implications. In analytical terms, the weight of the between-groups component shows the analytical relevance of the groups used and also informs on the internal homogeneity of these groups. In political terms, this relevance would indicate the opportunity to use these aggregations as reference units when establishing environmental policy goals.

Furthermore, the literature on inequality measurement has considered decomposition by sources (Shorrocks, 1982, 1984). This consists of assessing the role of the different factors that come together additively to form the variable analysed. Widely used in the field of income distribution, it has not been used in the analysis of environmental issues as far as we know. In particular, this contribution depends on three basic parameters: the individual inequality in each component; the relative weight of each component in global inequality; and, finally, the existence of correlations between the different factors. Thus, the higher the individual factor inequality and/or its relative weight and/or its positive correlation with other factors, then the higher would be the contribution of that factor to inequality. In short, in the context of our analysis in which the sources considered are the different fossil fuels, significant positive correlations are expected. The need to meet the energy demands of each country requires an adequate combination of sources and therefore a lower weight of some fossil sources in some countries in many cases would be compensated by the greater importance of others, except in the cases in which non-fossil sources of energy, such as nuclear and renewable sources, play a relevant role. Moreover, both the mix of energy sources and the substitution processes that have taken place over time are not homogeneous across countries.

However, the allocation of the correlations between factors complicates the methodologies of decomposition by sources for the different measures (Goerlich, 1998). In this sense, Shorrocks (1982, 1984) shows that, under certain plausible axioms, the inequality indexes can be allocated by sources in a non-arbitrary way through the natural decomposition of the variance, as a unique non-ambiguous rule, according to which the relative contributions of each source would be determined as their own variance and half of all their factorial covariances. That is to say, in the absence of additional information, the methodology recommends an equal allocation of variances by factors. In this way, the absolute contribution of factor k to inequality would be given by the following expression:

$$C_k = Var_\omega(e_{i,k}) + \sum_{k \# l} Cov_\omega(e_{i,k}, e_{i,l}) = Cov_w(e_{i,k}, e_i) \quad (4)$$

where the subindex ω indicates that variances and covariances are weighted according to the relative weight of each country (i.e. GDP share), $e_{i,k}$ and $e_{i,l}$ are the emissions intensity associated to the fossil sources k and l for country i and e_i is the aggregated emission intensity (of all fossil sources) of country i. Note that the contributions can be negative in the presence of significant compensating effects of factors, so that the relative contribution would be:

$$c_k = \frac{C_k}{Var_\omega(e_i)} \quad (5)$$

Finally, some works have established the utility of employing a multiplicative decomposition. This requires that the analysed factor can be expressed as the multiplication of a series of factors. In the case of energy intensity, as Camarero et al. (2013) consider in their analysis of convergence clubs, the following variables can be employed as reference factors: the carbonisation index (the ratio of CO_2 emissions to energy consumption), and the energy intensity (the ratio of energy consumption to GDP). The first factor is associated with the energy mix used by the country and, in short, the weight of the different fossil fuels with respect to all energy sources. The second is related to two elements: the sectoral structure (if it is biased to economic activities that are intensive in energy consumption) and energy efficiency. We have then:

$$\frac{CO_{2i}}{GDP_i} = \frac{CO_{2i}}{Energy_i} * \frac{Energy_i}{GDP_i} \quad (6)$$

or

$$e_i = c_i * b_i \quad (7)$$

where *Energy*$_i$ in the consumption of primary energy of country i, c_i is the carbonisation index, and b_i is the energy intensity.

Following the approach developed in Duro and Padilla (2006, 2011) the T(0) index can be decomposed as follows, with the notation adapted to the bi-factorial decomposition of emissions intensity:

$$T(e,p) = T(e^c, p) + T(e^b, p) + \log\left(1 + \frac{\sigma_{c,b}}{\mu(e^c)}\right) \quad (8)$$

where e^c is the vector of the CO_2 emission intensities of countries if energy intensity is constant across them (assuming that all countries have the average world energy intensity); e^b is the vector of the CO_2 emission intensities of countries if the carbonisation index is constant across them (assuming that all countries have the world average carbonisation index); $\sigma_{c,b}$ denotes the weighted (by GDP share) covariance between carbonisation indexes and energy intensities; and $\mu(e^c)$ is the world average of the fictitious vector of CO_2 emission intensities with the assumption that the energy intensities of all countries are equal to the world average.

The first term of expression (6) would then gather the partial contribution of the carbonisation index to the international inequality in CO_2 emission intensities. That is, it would inform on which would be the international inequalities if the unique factor varying between countries were the carbonisation index; the second component would bring together the partial contribution of the energy intensities and can be interpreted in terms of which would be the inequalities in the CO_2 emissions intensity if the energy intensities were the only ones that differed between countries. Finally, the third term is a component that depends on the correlation between the two factors, properly homogenised to take values consistent with the Theil index.

This is the only index of the Theil family that can be decomposed in this way and where the interaction component has a non-ambiguous interpretation in terms of factorial correlation.[2]

As suggested by Duro and Padilla (2006), the synthetic components of the decomposition by groups (expression 3) can be decomposed in a multiplicative way. This is so because the within-groups component (the first term of expression (3)) is a weighted average of Theils and, additionally, the component between is directly a Theil index.

3. Main Empirical Results

[2] The Theil (1) index can be decomposed, but the interaction element does not have a clear interpretation.

This section provides the main results obtained after applying the previous decompositions to the international distribution of CO_2 emissions intensity (CO_2/GDP) for the period 1971–2009. The data are provided by the IEA (2012), which includes data on CO_2 emissions from fuel combustion. The sample covers 116 countries, including some observations associated with groups of countries. To maintain a consistent sample for the entire period, the observations for the countries of the former USSR and Yugoslavia have been grouped together. The sample represents between 96% and 97% of world emissions (see the list of countries in the Appendix).[3]

Note that world CO_2 emissions intensity decreased in a continuous way over the period: from a value of 0.78 (tons per 1000 dollars of output) in 1971 to 0.44 in 2009, the minimum level of the time series. In this way, the global increase in total emissions, a noticeable 106% (from 13,560 million tons to 27,950 million tons), was lower than the 268% growth in GDP over the same period.

Table 1 shows CO_2 emission intensities by groups of countries, following the regional aggregations of the IEA. The reduction has been significant in all OECD groups, in the rest of Europe and particularly in China. In this last case, there has been an impressive reduction, from a ratio of 1.72 in 1971 to 0.55 in 2009. The CO_2 emissions intensity of China is however, still above the world average (although already significantly better than the average of non-OECD Europe). However, given the expected future economic growth, the intensity of emissions in China should be reduced at a rate of 7–10% in order to avoid a continuous growth in emissions. The regions with lower intensities are Latin America and OECD Europe.

[3] In short, as regards global IEA data, the analysis only excluded Botswana, Cambodia, Eritrea, Mongolia, Namibia and Netherlands Antilles, due to problems with the availability of data.

[Table 1]

We now examine international disparities in energy intensities to clarify the degree (and trajectory) of international heterogeneity in the relationship between CO_2 emissions and production. As an initial step to elaborate the synthetic indexes, we examine the changes in the shape of the distribution over these years, which can provide an indication of the evolution of inequality. Figure 1 shows the estimation of the density functions of the international distributions of this indicator for selected years in the period by means of the use of standard non-parametric techniques.[4] This figure shows, for example, very relevant changes in the shape of the distribution over the period. There is a transition from a fairly homogeneous density function in the early years to a bipolar function, and finally to a single peak in 2009. Obviously, the narrowing of the function from the ends toward the mean is the fundamental pattern behind a clear decrease in inequality. In addition, there is a displacement toward the left of the distribution, which shows the reduction in the world average emissions intensity.

[Figure 1]

Table 2 shows the international inequalities in emissions intensity, measured by the T(0) and their decomposition by group components, using the geographical–economic grouping of the IEA and following equation (3) in Section 2. The global value (first column), measured through the Theil index, shows that the international inequalities in emissions intensity halved, from 0.1973 in 1971 to 0.0959 in 2009. The reduction is more intense between 1990 and 2000, but since 2000 the inequalities have not changed significantly. Consequently, both

[4] The estimates are based on Gaussian kernel functions (see Quah, 1996) that have also, for example, been used in Ezcurra (2007) and Padilla and Serrano (2006) for the case of CO_2 emissions per capita. The smoothing parameter is determined endogenously through the Silverman method (1986). The results did not vary significantly using other functions. Estimates are available upon request.

the overall levels of emissions intensity and their international inequalities have decreased, a pattern that reinforces the positive dynamic of this indicator over the period.

[Table 2]

[Figure 2]

Table 3 details the main countries behind the Theil values for the years 1971 and 2009. The contribution of each country is approached through the absolute value that the expression of the index takes for each country and that depends on its GDP share and the distance between its emissions intensity and the world average. Two groups of countries are specified: those above the world average and those below it. Typically, those countries showing a greater contribution to the index do so because of their GDP share and of the gap in their intensity with respect to the world average. Among the contributors with an above average emissions intensity (i.e. a positive gap), the USA, the former USSR and China can be highlighted, both in 1971 and 2009. A clear reduction in the absolute contribution to inequality by the USA can be observed (a change from an emissions intensity of 42% above the world average in 1971 to 5% above in 2009 and a change in GDP share from 20% to 18%). This reduction explains to a great extent the trajectory of global inequality. In contrast, China increases its global contribution to inequality and would therefore increase global inequality (a pattern completely explained by the impressive increase in its GDP share, from 2.5% to 19%, as its emissions intensity has decreased approaching to the mean). It may be noticed that among the countries with an above average emissions intensity and that most contribute to inequality are two of the major emitters that have been most opposed to absolute emissions limits and have instead opted to propose moderate objectives for emissions intensity reduction (China and the USA). These countries had and still have a considerable margin in terms of approaching those countries with lower intensities and so would gain by setting goals in terms of percentage changes in emissions intensity with respect to the *status quo* (especially if they expect greater economic growth than do other countries, as may be the case for China). Among the countries with relatively lower emissions intensity, there are more changes in the ranking over the period. For example, the lower contribution to inequality by India is noticeable (due to an approximation to the mean), as is the greater absolute contribution of France in 2009 (due to the opposite, an increasing distance from the mean).

[Table 3]

Looking again at Table 2 and Figure 3 and focusing now on the decomposition by groups, these show that the between-groups component explains between 53% and 60% of global inequality. This is quite relevant given the exogenous formation of the groups according to geographical–economic criteria. Moreover, this weight has increased over time. The bulk of the reduction in inequality is explained by the between-groups component, although the reduction in inequality for the within-groups component is also relevant. Within-groups inequality explains 40% of global inequality, with a clear reduction over the period, a reduction that is proportionally greater than that for between-groups inequality. This reinforces the explanatory power of the groups employed. Table 4 provides more details related to this component. It shows the internal inequality of each group that, appropriately weighted by the GDP share, produces the global within-groups component of inequality (equation (3)). The area with the greatest internal inequality in emissions intensity is clearly Africa, followed by Latin America. The rest of the internal inequalities are clearly lower. Therefore, whether or not for the rest of the groups the regional structuring is a reasonable approximation of regional differences, in these two cases the application of the geographical criterion works less well, as those groups show more heterogeneous situations. In terms of absolute contribution—and although the GDP share is only 9.8%—these two regions concentrate 43.3% of the internal inequalities of all groups. Over time, internal inequalities decrease considerably in most cases (this is not the case for Latin America, which experiences a slight increase, or for OECD Asia Oceania or non-OECD Europe, where there is a significant increase). These lower internal differences show a greater degree of homogeneity with regard to CO_2 emission intensities, a degree of homogeneity that could result in a greater internal degree of agreement in interests and perceptions in each region in terms of the hypothetical approach of global goals for reductions in CO_2 emission intensities.

[Table 4]

Another informative tool is the decomposition by sources (additive decomposition). In particular, given the available data, an interesting possibility consists of reviewing the role of the different fossil energy sources (coal, oil and gas) in the pattern followed by the inequalities in emissions intensity over the period. Some previous descriptive data are informative. Currently, the greatest source of CO_2 emissions is coal, followed by oil and gas, with weights of 43.1%, 36.7% and 19.9% on global emissions. Coal has increased its share of emissions, surpassing oil as the major source responsible for the CO_2 emitted in the world, with an important weight in some emerging economies. Gas has experienced an important, but lower, increase, typically due to the extension of combined cycle power plants. In terms of the absolute increase in emissions associated with coal, China is clearly the leading country, with an increase of 5,042 million tons between 1971 and 2009 (a 744% increase); the increases are much lower in India with 938 million tons (658% more) and the USA with 753 million tons (a 70% increase). Among the countries with a greater reduction are Germany (264 million tons less), the UK (235 million tons less) and the former USSR (207 million tons less). As for the increase in oil as a source of CO_2, this can be attributed to China (833 million tons more), India (344 million tons more) and Saudi Arabia (267 million tons more), while the main reductions take place in the former USSR (220 million tons less) and Germany (115 million tons less). With respect to gas, the source for which the generation of

CO_2 has increased most, the increase is especially attributable to the former USSR (693 million tons more), which has abundant reserves of this resource.

[Table 5]

Table 6 shows the CO_2 emission intensities corresponding to each source and regional group in 1971 and 2009. In 2009, for example, the high intensity of the emissions generated by the use of coal in China is noticeable (although this intensity has undergone a great reduction since 1971). The emissions intensity from oil in the Middle East is also noticeable (although for this source there is less dispersion between groups in the CO_2 emission intensities), as is that for gas in OECD America and non-OECD Europe (with a great increase in both cases). These different intensities are mainly explained by the different mixes of energy sources that are partly determined by the different endowments of energy resources in the different regions and the different policies and strategies implemented to promote the different energy sources.

[Table 6]

Table 7 shows the international inequalities in the emissions intensity of each source, using the T(0) for each indicator. These indexes do not show the total contribution of each source to overall inequality as this requires taking two additional elements into account: the weight of each source and the factorial correlations. However, the assessment of the individual inequalities allows us to note two interesting issues. First, the inequalities are quite high in the case of coal and gas and much lower in the case of oil (as could be expected observing the data by groups in Table 6). Clearly, this phenomenon is associated with the different contributions of the different sources to the energy mix of each country, where oil has a more homogeneous weight than gas or coal, mainly because of its use in transport. Second, the inequality in the CO_2 intensity from the use of gas has decreased considerably in the period, which shows the extension of the use of gas over the period, a change that has resulted in this inequality coming close to the levels of the inequality in CO_2 emissions intensity from coal.

[Table 7]

Table 8 shows the role of the different energy sources in the explanation of the inequality in emissions intensity, that is, their relative contribution, according to the application of the natural decomposition *a la* Shorrocks (1982, 1984) of the variance. In 2009, the relative contributions of coal, gas and oil were 39.3%, 34.5% and 26.2%, respectively. There are relevant changes over the period in the role of the different sources. The process of reduction of international inequalities in emissions intensity has coincided with a clear reduction in the relative contribution of coal and a significant increase in the contribution of oil and especially of gas. In this change, it is important to consider not only the pattern followed by the inequalities in each source, but also the change in their weights and the effect of correlations. Table 8 shows the weight of the direct effects, measured through the individual variances, and of the indirect effects, measured through the different combinations of factorial covariances. It is worth noting that the reduction in the percentage contribution of the inequality in the emissions intensity associated with coal depends crucially on its increasing negative correlation with the inequality associated with the other factors. This follows the logic of an energy substitution process that has not been homogeneous and that has led to an increase in the contribution of the direct effects. As for the great increase in the weight of gas, this is mainly due to a direct effect. Finally, the increase in the weight of oil is also mainly attributable to a direct effect. In both cases we also observe an important reduction in the contribution of the indirect effect, which also becomes negative in the case of oil. Thus, even though the divergences in emissions intensity have substantially decreased, it can be highlighted that this has been partly due to an increasing negative correlation (or decreasing positive one) between the contribution of the different sources to this inequality. The inequalities in the different sources would cease to be mutually reinforcing and would partially offset each other.

[Table 8]

Finally, we address a multiplicative decomposition of overall inequalities with the aim of clarifying the role of the carbonisation indexes and the energy intensities in the observed pattern of reduction in inequality of emissions intensity. For this purpose, we follow the approach suggested by Duro and Padilla (2006, 2011). Table 9 shows descriptive data on both factors for the regional groups and an assessment of the role of both factors in the change in emissions intensity thanks to their multiplicative role. The last three columns show logarithmic differences, which can be understood as rates of growth. The logarithmic decomposition of the change in emission intensities shows the greater importance of energy intensities in the explanation of the trajectory of overall emissions intensity. In short, the contribution of the reduction in energy intensities to the reduction in emissions intensity has been very important in China, OECD America and OECD Europe. This reduction has been quite generalised (except for Africa and the Middle East) and it certainly shows important efficiency improvements in the use of energy, above the possible effects that changes in production composition (or even less energy transformation) could have in each case. In the case of the carbonisation index, there is a significant disparity in its role in the different groups. While in the OECD groups its reduction contributes to a reduction in emissions intensity (particularly in the OECD Europe group), in the case of Asia and China it has increased considerably, which could be associated with the increase in the use of coal in these regions. The increase in the use of natural gas, proportionally greater than the increases in other sources, is also one of the factors contributing to the reduction in the overall CO_2

emissions intensity by reducing the carbonisation index, given its lower level of emissions per equivalent unit of primary energy.

[Table 9]

The multiplicative decomposition of inequality yields the following basic results (Table 10). First, around two thirds of these inequalities are attributed to the individual role of energy intensity disparities and one third to carbonisation index differences. Such weights reinforce the use of these factors to explain emissions intensity inequalities. Second, the interaction component does not have high values, so the contribution of the two individual factors would fairly approximate overall inequalities. Third, the bulk of the reduction of the inequalities in emission intensities is attributable to energy intensities. Fourth, the lower intensity in the reduction of the contribution to inequality of the carbonisation component has increased its weight.

[Table 10]

This important weight of energy intensity inequalities may in turn be due to different factors. There may be a limited role for efficiency differences in energy transformation, although previous studies using IEA data for a similar period showed that this role was limited and clearly below 10% of energy intensity inequality was explained by this factor (Duro and Padilla, 2011). There may also be differences attributable to differences in sectoral composition and in final use of energy.[5]

[5] In a study of OECD countries, Duro et al. (2011) showed for a similar period a significant trend towards the convergence of energy efficiency between countries sector by sector, which explained much of the general trend for decreasing differences in energy intensities, but also that sector specialisation was increasingly explaining inequality in the final use of energy. However, these results may not be extendable to our wider and more homogeneous sample, which includes both developed and developing countries.

From the decomposition by groups we have seen that most of the inequality occurred between the groups of countries considered and that both between- and within-group inequality components had importantly declined (proportionally more for the latter). We apply the factorial multiplicative decomposition to these two synthetic components of group decomposition. Tables 11 and 12 show very differentiated patterns in the trajectory of between- and within-groups inequalities. While the reduction in the contribution of the carbonisation index and energy intensity components are similar in the case of the inequalities between groups, the reduction in the contribution of the carbonisation index is much lower in the case of within-group inequalities, which leads it to have the same contribution as energy intensity to within-groups inequalities at the end of the period. This within-groups behaviour would explain the greater weight of the carbonisation index in the explanation of overall inequalities in Table 10. Table 13 shows the decomposition of within-group inequality for each group, which shows very heterogeneous behaviours across the different groups of countries. While in most cases the most important component within the groups is energy intensity, which even increases its relative contribution in most cases, this is not so in the case of Africa and especially in the case of OECD Europe, where the absolute contribution to inequality of this component increases. This is one of the regions that shows a lower emissions intensity and one of the main reasons behind this is the lower carbonisation indexes of some countries with high levels of participation in renewable and/or nuclear power and with great differences according to the different mix of energy sources for countries with similar levels of economic development.

[Table 11]

[Table 12]

[Table 13]

4. Concluding remarks

The literature on the distributive analysis applied to environmental issues has focused on the study of different indicators and especially on the international distribution of CO_2 emissions per capita. However, except for the research of Camarero et al. (2012), there are no extant studies using the tools of distributive analysis to study the international disparity in CO_2 emissions intensity. However, this indicator is of great relevance as it compares emissions with the associated economic output; it could also be interpreted as an apparent indicator of efficiency as it indicates the capacity to generate production per unit of pollution. The analysis is also relevant in view of the fact that goals in terms of emissions intensity have repeatedly been suggested as an alternative to absolute emissions targets. In any case, any attempt to control global emissions requires a substantial reduction of emissions intensity, which should be greater in correspondence with greater economic growth.

This paper has addressed the analysis of the international inequality in CO_2 emissions intensity for the period 1971–2009. This has been approached through inequality decomposition techniques that allow us to investigate the explanatory factors from different perspectives. In short, the advantages of three decomposition methodologies have been reviewed: group, additive and multiplicative decompositions. The first breaks down inequality into a part attributable to differences between groups of countries and another attributable to the internal differences in these groups. We have considered the groups defined by the IEA. The second, the additive decomposition, allows us to decompose inequality by factors that explain additively the analysed variable. We have examined the decomposition of emissions intensity by energy sources. The third methodology decomposes inequality in a multiplicative way. In short, we have addressed the role of the carbonisation index (CO_2/primary energy) and the energy intensity (primary energy/GDP).

We would highlight five main results. First, the reduction in overall emission intensities has coincided with a clear reduction in its international dispersion, which is good in distributive terms (lower mean and lower inequality), showing the approach of the different countries to a lower emissions intensity. Second, the main component of this inequality is the between-groups component when considering the IEA regions, this component also being that which explains the greatest part of the reduction. Third, the reduction of the inequalities in CO_2 emission intensities has been accompanied by an increase in the relative contribution of gas (basically due to its greater weight in the energy mix) and, in second place, of oil; this is related to a reduction in the contribution of coal, which is, however, the main explanatory source of these inequalities. Fourth, two thirds of inequalities are due to energy intensity differences and one third to carbonisation index disparities. In this latter component, there is an increase in its relative weight. The reduction of inequalities has primarily been caused by the trajectory of energy intensities, but carbonisation indexes have also contributed. Last, this evolution is much different for the between- and within-group components. We may also note the increasing relative weight of the carbonisation index in explaining the internal differences in the groups, especially in the case of OECD Europe.

These results have several policy implications. First, we understand that the trajectory of the distribution in emission intensities has been positive; countries are less unequal and also the mean world level has decreased. In this sense, in the future we should still be able to achieve both world reductions in this indicator and less inequality between countries, in other words, that the different countries continue to converge to lower values of emissions intensity. In a context of economic growth, particularly in emerging economies, it is necessary to progress in the reduction of emissions intensity to try to reduce overall emissions in absolute terms. This convergence could also tend to facilitate the acceptance of agreements in terms of common goals for the reduction of emissions intensity by different countries, as far as situations and perceptions would be closer. In any case, the agreements should find equilibrium between this criterion—that may favour those countries emitting more in per capita terms—and the consideration of an adequate distribution of the atmosphere absorptive capacity that could be seen as fairer by other countries with lower levels of emissions per capita. Second, the regional groups defined by the IEA appear to be good proxies of the international differences in CO_2 emissions intensity and could therefore be relevant units for the design of mitigation policies (except perhaps for the groups of Africa and Asia). Third, the process of substitution between fossil fuels could continue to contribute to reducing both the global level of emissions intensity as well as overall inequality; however, this is not a long term solution, which necessarily involves substitution by renewable sources. Fourth, the bulk of the inequality in emissions intensity is attributable to energy intensity disparities. Therefore, new reductions in overall disparities involve processes of convergence in such energy intensities that, in so far as it is not clear that sectoral convergence is taking place, would mainly require a convergence towards enhanced levels of energy efficiency. This also requires the intensification of the processes of diffusion of environmentally efficient technologies. However, the internal differences in some groups of countries are increasingly due to the differences in carbonisation indexes, as is clearly the case for a group of countries with similar levels of development, such as OECD Europe. This is a clear example of the wide regional margin that exists in relation to decarbonising economies through the progressive abandonment of fossil fuels, which is a process that should ultimately be followed by the different countries.

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Appendix

Groups of countries:

OECD-Europe: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom.
OECD-North America: Canada, Mexico, United States.
OECD-Pacific: Australia, Japan, Korea, New Zealand.
Non-OECD Europe countries: Albania, Bulgaria, Cyprus, Gibraltar, Malta, Romania, Former USSR, Former Yugoslavia
Africa: Algeria, Angola, Benin, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Nigeria, Senegal, South Africa, Sudan, United Republic of Tanzania, Togo, Tunisia, Zambia, Zimbabwe, Other Africa
Latin America: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, Other Latin America.
Middle East: Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
Asia: Bangladesh, Brunei Darussalam, Chinese Taipei, India, Indonesia, Dem. People's Rep. of Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Other Asia.
China: People's Republic of China, Hong Kong.

Table 1. CO_2 emissions intensity by groups of countries, 1971 and 2009

	1971 CO_2 intensity	GDP share	2009 CO_2 intensity	GDP share
OECD America	1.037	26.3%	0.451	21.4%
OECD Asia Oceania	0.605	9.3%	0.379	8.6%
OECD Europe	0.681	30.6%	0.291	20.0%
Africa	0.343	4.4%	0.364	3.9%
Middle East	0.254	2.3%	1.053	2.2%
Non-OECD Europe	1.219	0.1054	0.872	4.5%
Latin America	0.295	6.5%	0.257	5.9%
Asia	0.341	7.3%	0.347	14.1%
China	1.718	2.7%	0.553	19.4%
World	**0.777**		**0.436**	

Source: Prepared by the authors based on International Energy Agency data (2012).
Note: CO_2 intensity in tons per dollar (GDP in PPP 2000 USD).

Table 2. International inequality in CO_2 emissions intensity according to the Theil index decomposed by group components, selected years, 1971–2009

	Emissions intensity inequality	Between-groups component	Within-groups component
1971	0.1973	0.1047 (53%)	0.0926 (47%)
1975	0.1873	0.1062 (57%)	0.0811 (43%)
1980	0.1713	0.0956 (56%)	0.0757 (44%)
1985	0.1565	0.0837 (53%)	0.0728 (47%)
1990	0.1711	0.1083 (63%)	0.0628 (37%)
1995	0.1401	0.0893 (64%)	0.0508 (36%)
2000	0.1038	0.0628 (61%)	0.0409 (39%)
2005	0.0961	0.0574 (60%)	0.0387 (40%)
2009	0.0959	0.0578 (60%)	0.0381 (40%)

Source: Prepared by the authors based on IEA (2012) data.
Note: Within brackets the relative weight of each component on the global inequality in emissions intensity.

Table 3. Main countries responsible for emissions intensity inequality, 1971 and 2009

1971	Value	2009	Value
Above world average		*Above world average*	
United States	0.0790	China	0.0478
Soviet Union	0.0413	Soviet Union	0.0293
China	0.0214	United States	0.0086
Germany	0.0101	Iran	0.0068
Poland	0.0068	Saudi Arabia	0.0054
Below world average		*Below world average*	
India	0.0314	France	0.0196
Brazil	0.0295	Brazil	0.0195
Italy	0.0237	India	0.0162
Mexico	0.0175	Japan	0.0160
Spain	0.0172	United Kingdom	0.0133

Source: Prepared by the authors based on International Energy Agency data (2012)
Note: The contribution of each country to inequality is approached through the absolute value of the expression of the index in each country and that depends on its GDP share and the distance between its intensity and the world average. The values of the countries with energy intensities above the average are taken as an absolute value.

Table 4. Details of internal inequalities within regional groups, 1971 and 2009

	1971			2009		
	Internal T(0)	**GDP share**	**Absolute contribution**	**Internal T(0)**	**GDP share**	**Absolute contribution**
OECD America	0.0415	26.3%	0.0109	0.0034	21.4%	0.0007
OECD Asia Oceania	0.0073	9.3%	0.0007	0.0229	8.6%	0.0020
OECD Europe	0.1011	30.6%	0.0310	0.0318	20.0%	0.0063
Africa	0.4859	4.4%	0.0216	0.2403	3.9%	0.0095
Middle East	0.0761	2.3%	0.0018	0.0361	2.2%	0.0008
Non-OECD Europe	0.0105	10.5%	0.0011	0.0360	4.5%	0.0016
Latin America	0.0990	6.5%	0.0064	0.1198	5.9%	0.0070
Asia	0.2458	7.3%	0.0179	0.0608	14.9%	0.0086
China	0.0473	2.7%	0.0013	0.0080	19.4%	0.0015
World	**0.0926**			**0.0381**		

Source: Prepared by the authors based on IEA (2012) data.

Table 5. CO_2 emissions from the different fossil fuel energy sources in the world, 1971 and 2009

	1971	Share 1971	2009	Share 2009	Change 1971–2009
Coal	5,199	36.9%	12,493	43.1%	140.3%
Oil	6,826	48.5%	10, 631	36.7%	55.7%
Gas	2,058	14.6%	5,762	19.9%	180.0%
World	**14,085**		**28,999**		

Source: Prepared by the authors based on IEA (2012) data.

Table 6. CO_2 intensity by regional groups and energy sources, 1971 and 2009

	Coal		Oil		Gas	
	1971	**2009**	**1971**	**2009**	**1971**	**2009**
OECD America	0.251	0.144	0.506	0.194	0.279	0.112
OECD Asia Oceania	0.180	0.163	0.417	0.150	0.008	0.064
OECD Europe	0.316	0.085	0.329	0.125	0.036	0.078
Africa	0.208	0.127	0.129	0.166	0.007	0.071
Middle East	0.001	0.003	0.189	0.599	0.063	0.451
Non-OECD Europe	0.531	0.271	0.424	0.191	0.264	0.401
Latin America	0.016	0.018	0.245	0.174	0.036	0.067
Asia	0.182	0.177	0.151	0.117	0.008	0.053
China	1.439	0.463	0.264	0.077	0.016	0.014
World	**0.298**	**0.195**	**0.361**	**0.150**	**0.118**	**0.090**

Source: Prepared by the author based on IEA (2012) data.

Table 7. Inequality of emissions intensity for the different energy sources, selected years, 1971–2009

	Theil global	Theil Coal	Theil Gas	Theil Oil
1971	0.1973	1.263	2.952	0.123
1975	0.1873	1.360	2.517	0.107
1980	0.1713	1.388	2.327	0.080
1985	0.1565	1.106	1.759	0.078
1990	0.1711	1.049	1.581	0.088
1995	0.1401	1.041	1.371	0.078
2000	0.1038	0.926	1.129	0.077
2005	0.0961	0.950	0.972	0.093
2009	0.0959	1.013	0.936	0.119

Source: Prepared by the author based on IEA (2012) data.

Table 8. Relative contribution of international inequality in emissions intensity by energy source, selected years, 1971–2009

	Coal			Gas			Oil		
	c_k	Direct	Indirect	**c_k**	Direct	Indirect	**c_k**	Direct	Indirect
1971	**62.4%**	95.8%	4.2%	**18.5%**	53.2%	46.8%	**19.1%**	61.3%	38.7%
1975	**63.6%**	89.5%	10.5%	**15.9%**	46.2%	53.8%	**20.5%**	53.6%	46.4%
1980	**68.2%**	90.9%	9.1%	**15.0%**	45.7%	54.3%	**16.8%**	50.2%	49.8%
1985	**66.4%**	99.9%	0.1%	**19.0%**	58.7%	41.3%	**14.6%**	60.9%	39.1%
1990	**54.5%**	90.6%	9.4%	**28.3%**	53.8%	46.2%	**17.2%**	50.7%	49.3%
1995	**49.1%**	98.6%	1.4%	**34.2%**	63.9%	36.1%	**16.7%**	76.3%	23.7%
2000	**38.6%**	108.9%	-8.9%	**42.0%**	72.1%	27.9%	**19.3%**	80.5%	19.5%
2005	**43.2%**	142.6%	-42.6%	**35.4%**	90.8%	9.2%	**21.4%**	104.5%	-4.5%
2009	**39.3%**	168.1%	-68.1%	**34.5%**	95.5%	4.5%	**26.2%**	109.8%	-9.8%

Source: Prepared by the author based on International Energy Agency data (2012).
Note: C_k refers to the relative contribution of each additive factor to overall inequality, based on expression (5). The other columns show the percentage explained by direct and indirect effects.

Table 9. Data for 2009 and bi-factorial logarithmic decomposition of the changes in emission intensities by regional groups 1971–2009

	2009			Logarithm differences 1971–2009		
	CO_2/PIB	**Carbonisation Index**	**Energy Intensity**	**CO_2 intensity**	**Carbonisation Index**	**Energy Intensity**
OECD America	0.451	2.36	0.191	-83.2%	-12.3%	-70.9%
OECD Asia Oceania	0.379	2.41	0.157	-46.6%	-15.7%	-30.9%
OECD Europe	0.291	2.15	0.135	-84.8%	-30.7%	-54.2%
Africa	0.364	1.37	0.265	6.1%	-0.6%	6.7%
Middle East	1.053	2.57	0.410	142.2%	7.1%	135.1%
Non-OECD Europe	0.872	2.38	0.366	-33.6%	-9.9%	-23.7%
Latin America	0.257	1.80	0.143	-13.7%	1.5%	-15.1%
Asia	0.347	2.16	0.161	1.7%	46.2%	-44.5%
China	0.553	3.03	0.183	-113.3%	38.9%	-152.2%
World	**0.436**	**2.37**	**0.184**	**-57.8%**	**-6.6%**	**-51.3%**

Source: Prepared by the authors based on IEA (2012) data.
Note: The variations in the three last columns show logarithm differences of the variables.

Table 10. International inequality in CO_2 emissions intensity according to the Theil index and multiplicative factorial decomposition, selected years, 1971–2009

	Emissions intensity inequality	Carbonisation component	Energy Intensity component	Interaction Component
1971	0.1973	0.0602 (30%)	0.1321 (67%)	0.0050 (3%)
1975	0.1873	0.0511 (27%)	0.1317 (70%)	0.0045 (3%)
1980	0.1713	0.0426 (25%)	0.1171 (68%)	0.0115 (7%)
1985	0.1565	0.0431 (28%)	0.0975 (62%)	0.0159 (10%)
1990	0.1711	0.0408 (24%)	0.1123 (66%)	0.0180 (10%)
1995	0.1401	0.0357 (25%)	0.0941 (67%)	0.0103 (7%)
2000	0.1038	0.0313 (30%)	0.0745 (72%)	-0.0020 (-2%)
2005	0.0961	0.0331 (34%)	0.0672 (70%)	-0.0042 (-4%)
2009	0.0959	0.0359 (37%)	0.0632 (66%)	-0.0031 (-3%)

Source: Prepared by the authors based on IEA (2012) data.
Note: Within brackets the percentage of each factor with respect to the global inequality in emissions intensity.

Table 11. Between-group inequality component decomposed by multiplicative factors, selected years, 1971–2009

	Emissions intensity inequality	Between-groups component	Carbonisation component	Energy Intensity component	Interaction Component
1971	0.1973	0.1047 (53%)	0.0268 (26%)	0.0760 (73%)	0.0019 (2%)
1975	0.1873	0.1062 (57%)	0.0214 (20%)	0.0828 (78%)	0.0020 (2%)
1980	0.1713	0.0956 (56%)	0.0179 (19%)	0.0700 (73%)	0.0077 (8%)
1985	0.1565	0.0837 (53%)	0.0159 (19%)	0.0572 (68%)	0.0106 (13%)
1990	0.1711	0.1083 (63%)	0.0124 (11%)	0.0783 (72%)	0.0176 (16%)
1995	0.1401	0.0893 (64%)	0.0115 (13%)	0.0632 (71%)	0.0146 (16%)
2000	0.1038	0.0628 (61%)	0.0096 (15%)	0.0489 (78%)	0.0043 (7%)
2005	0.0961	0.0574 (60%)	0.0123 (21%)	0.0416 (72%)	0.0035 (6%)
2009	0.0959	0.0578 (60%)	0.0148 (26%)	0.0389 (67%)	0.0041 (7%)

Source: Prepared by the authors based on IEA (2012) data.
Note: The percentages in the three columns of the factorial components show their relative weight in relation to the between-group overall component.

Table 12. Within-group inequality component decomposed by multiplicative factors, selected years, 1971–2009

	Emissions intensity inequality	Within-groups component	Carbonisation component	Energy Intensity component	Interaction Component
1971	0.1973	0.0926 (47%)	0.0381 (41%)	0.0562 (61%)	-0.0017 (-2%)
1975	0.1873	0.0811 (43%)	0.0330 (41%)	0.0489 (60%)	-0.0008 (-1%)
1980	0.1713	0.0757 (44%)	0.0268 (35%)	0.0471 (62%)	0.0018 (3%)
1985	0.1565	0.0728 (47%)	0.0282 (39%)	0.0404 (55%)	0.0043 (6%)
1990	0.1711	0.0628 (37%)	0.0299 (48%)	0.0340 (54%)	-0.0011 (-2%)
1995	0.1401	0.0508 (36%)	0.0266 (52%)	0.0309 (61%)	-0.0067 (-13%)
2000	0.1038	0.0409 (39%)	0.0244 (60%)	0.0256 (63%)	-0.0091 (-22%)
2005	0.0961	0.0387 (40%)	0.0234 (61%)	0.0256 (66%)	-0.0104 (-27%)
2009	0.0959	0.0381 (40%)	0.0240 (63%)	0.0242 (64%)	-0.0101 (-27%)

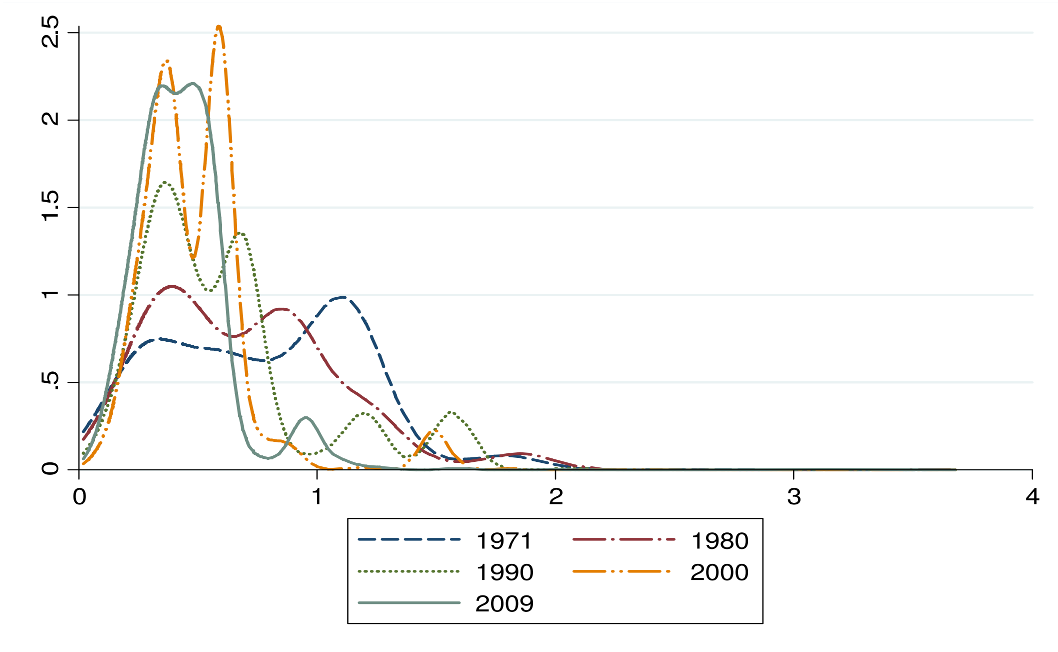
Source: Prepared by the authors based on IEA (2012) data.
Note: The percentages in the three columns of the factorial components show their relative weight in relation to the overall within-group component.

Table 13. Within-group inequality decomposed by multiplicative factors and groups, 1971 and 2009

	Emissions intensity inequality	Carbonisation component	Energy Intensity component	Interaction Component
OECD America				
1971	0.0415	0.0322 (3%)	0.0079 (78%)	0.0014 (19%)
2009	0.0034	0.0009 (26%)	0.0049 (144%)	-0.0024 (-71%)
OECD Asia Oceania				
1971	0.0073	0.0018 (25%)	0.0029 (39%)	0.0027 (36%)
2009	0.0229	0.0060 (26%)	0.0149 (65%)	0.0020 (9%)
OECD Europe				
1971	0.1011	0.0072 (7%)	0.0698 (69%)	0.0241 (24%)
2009	0.0318	0.0302 (95%)	0.0152 (48%)	-0.0136 (-43%)
Africa				
1971	0.4859	0.5368 (110%)	0.2608 (54%)	-0.3116 (-64%)
2009	0.2403	0.3162 (132%)	0.1155 (48%)	-0.1914 (-80%)
Middle East				
1971	0.0761	0.0165 (22%)	0.0712 (94%)	-0.0117 (-15%)
2009	0.0361	0.0012 (3%)	0.0310 (86%)	0.0039 (11%)
Non-OECD Europe				
1971	0.0105	0.0007 (7%)	0.0084 (80%)	0.0014 (13%)
2009	0.0360	0.0017 (5%)	0.0384 (106%)	-0.0040 (-11%)
Latin America				
1971	0.0990	0.0628 (63%)	0.0366 (37%)	-0.0004 (-0%)
2009	0.1198	0.0292 (24%)	0.0886 (74%)	0.0020 (2%)
Asia				
1971	0.2458	0.0946 (38%)	0.1063 (43%)	0.0449 (18%)
2009	0.0608	0.0211 (35%)	0.0363 (60%)	0.0033 (5%)
China				
1971	0.0473	0.0049 (10%)	0.0663 (140%)	-0.0240 (-51%)
2009	0.0080	0.0000 (0%)	0.0081 (101%)	-0.0001 (-1%)

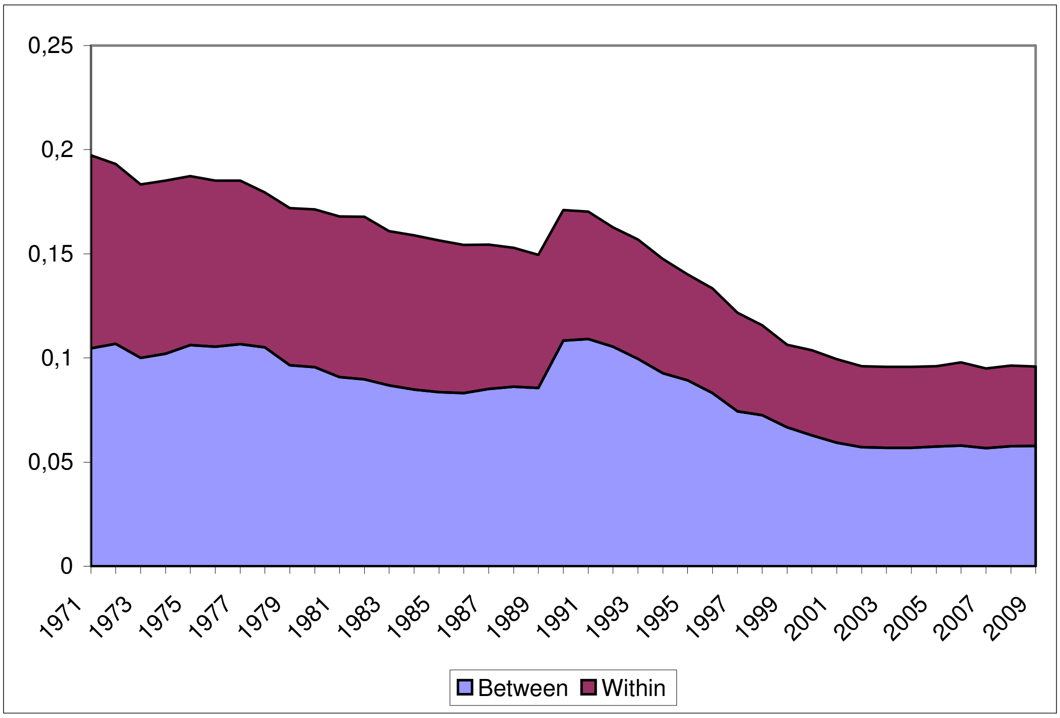
Source: Prepared by the authors based on IEA (2012) data.

Figure 1. Density functions of CO_2 emissions intensity, selected years, 1971–2009



Source: Prepared by the authors based on IEA (2012) data.

Figure 2. International inequality in CO_2 emissions intensity according to the Theil index and group components, 1971–2009



Source: Prepared by the authors based on IEA (2012) data.