This is the postprint version of the article:
Duro, J.A., Padilla, E. (2006) "International inequalities in per capita CO_2 emissions: a decomposition methodology by Kaya factors", *Energy Economics*, Vol. 28, pp. 170–187.
https://doi.org/10.1016/j.eneco.2005.12.004

International inequalities in per capita CO_2 emissions: a decomposition methodology by Kaya factors[*]

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Abstract
In this paper we provide a methodology for decomposing international inequalities in per capita CO_2 emissions into Kaya (multiplicative) factors and two interaction terms. We use the Theil index of inequality and show that this decomposition methodology can be extended for analyzing between and within-group inequality components. We can thus analyze the factors behind inequalities in per capita CO_2 emissions across countries, between groups of countries and within groups of countries. The empirical illustration for international data suggests some points. Firstly, international inequality in per capita CO_2 emissions is mainly attributable to inequalities in per capita income levels, which helps to explain its recent reduction, while differences in carbon intensity of energy and energy intensity have made a less significant contribution. This result is strongly influenced by the performance of China and India. Secondly, the between-group inequality component, which is the biggest component, is also largely explained by the income factor. Thirdly, the within-group inequality component increased slightly during the period, something mainly due to the change in the income factor and the interaction terms in a few regions.

JEL classifications: C19, D39, Q43.

Key words: CO_2 emissions inequality, inequalities across countries, Kaya factors, Theil index

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[*] The funding for this research was kindly provided by the Instituto de Estudios Fiscales, Ministerio de Economía y Hacienda. Support from projects BEC2003-1831 (Ministerio de Ciencia y Tecnología) and 2001SGR-160 (Direcció General de Recerca) is also acknowledged. We would like to thank Vicent Alcántara, two anonymous referees and the editor for their helpful comments.
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1. Introduction

The increase in CO_2 concentrations in the atmosphere caused by human activity – mainly as a result of the combustion of fossil fuels – is the main factor responsible for the intensification of the greenhouse effect and the resulting climate change. The study of the driving forces behind CO_2 emission levels and their evolution has therefore understandably been of considerable interest to researchers and policy-makers. Many factors influence these emissions, such as economic and demographic developments, technological change, resource endowments, institutional frameworks, lifestyles and international trade. An analytical tool that is conventionally used for exploring the main driving forces behind this pollutant behavior is the Kaya (1989) identity (see e.g. Yamaji et al., 1991). According to this identity, per capita emissions are decomposed into the product of three basic factors (which are in turn influenced by different forces): carbon intensity of energy, energy intensity and affluence. This is a specific application of a more general approach for discussing the driving forces behind environmental impacts, the so-called IPAT identity, which relates impacts (I) to population (P) multiplied by affluence (A) and technology (T). The Kaya factors approach allows the main driving forces of CO_2 emissions to be decomposed. However, one of its caveats is that these main driving forces may not be independent of each other (e.g. countries with greater economic growth might develop more efficient technologies thanks to high capital turnover, leading to lower energy intensities).

Examination of its international inequalities complements the analysis of the level of carbon emissions into the atmosphere. This inequality is of great relevance for designing of global climate policies. Once the Kyoto Protocol entered into force in February of 2005,[1] distributive problems appear as the most important issue in the negotiations for adopting new agreements for controlling greenhouse gases emissions. Taking appropriately into account these distributive issues in policy design and negotiations might facilitate widespread participation, as the parties will only participate if the actions are perceived as fair. Any feasible solution to the challenge of stabilizing global emissions concentrations needs to involve both richer countries (including the major emitter, which has not ratified the Kyoto Protocol) and developing economies (which were not compelled to control emissions under the Kyoto Protocol). The increase in emissions in some developing economies has been impressive. However, their per capita emissions are still quite far from the levels of developed economies.

Stabilization of greenhouse emissions concentrations, as mandated by the UN Framework Convention on Climate Change (UNFCCC), implies establishing limits to the level of global emissions and distributing this level among the different countries. Imposing limitations might involve economic sacrifices, as emissions are an undesired subproduct of economic activity which is strongly linked to production[2]. While rich countries fear that limiting their emissions will endanger their economic growth, poor countries use the great inequality in current and past emissions between poor and rich countries as an argument for not limiting their development opportunities by mitigation policies. There are several approaches on the distribution

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[1] As of 19 November 2005, 157 states and regional economic integration organizations have ratified the Kyoto Protocol, including 37 Annex I Parties which accounted for 61.6% of the total carbon dioxide emissions for 1990 from that group.

[2] The analysis on CO_2 emissions and the environmental Kuznets curve might inform about this relationship (see e.g. Shafik, 1994; Holtz-Eakin and Selden, 1995; Schmalensee, et al. 1998; Roca et al., 2001; Heil and Selden 2001a). The literature tends to show that economic growth by itself involves greater CO_2 emissions for the overwhelming majority of countries.

of future emissions "entitlements": the distribution of entitlements on per capita terms (see e.g., Grubb, 1990; Agarwal and Narain, 1991; Meyer, 1995), distribution based on current emission levels (see e.g. Pearce and Warford, 1993), distribution based on GNP shares (see e.g., Wirth and Lashof, 1990; Cline, 1992) and several combinations of these rules[3]. As for the proposals for distributing abatement costs, they are mainly based on different applications of the polluter pays principle and indices of ability to pay (see IPCC, 1996, pp. 103-112). E.g., Smith et al. (1993) propose a "natural debt" index, so each country should pay in proportion to total cumulative emissions since a specified date[4]. In line with this argument, the so-called Brazilian Proposal (see Den Elzen, 1999; Den Elzen and Schaeffer, 2002; UNFCCC, 2001, 2002), argues that relative responsibilities for climate change are to be ascribed to countries and groups of countries on a historic emissions basis. Then, the proposal defines targets for nations, set on the basis of the relative degree of responsibility for the anthropogenic greenhouse effect.

The distribution of emission entitlements is a normative issue, but the analysis of emissions inequality should be useful to inform the debate on the different proposals. The degree of inequality in per capita emissions across countries shows the different degree of responsibilities in the contribution to the climate change problem[5]. The different relative responsibilities of the inhabitants of different countries and regions,

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[3] It might be noted that most cost-benefit analyses applied to evaluate climate change mitigation policies do not establish any limit to global emissions and implicitly assume a distribution of rights where emitters have the right to pollute. This assumption may bias their results toward the recommendation of less aggressive mitigation policies (Padilla, 2004).

[4] With a threshold for "basic needs" emissions and taking into account an ability to pay element proportional to GNP (on a purchasing power parity basis) for all countries subject to a threshold value, so countries below the thresholds would be exempt. The payments would go to an international fund which would then be used to finance abatement at the lowest marginal cost.

[5] In order to compute the inequality in historical responsibilities for the climate change problem the inequalities in cumulative emissions should be analyzed, an issue developed in Heil and Wodon (1997).

the problems generated by this inequality, and the causes of these differences, are fundamental features to be considered by international climate change mitigation initiatives. In academic and policy terms, it is interesting to ascertain whether the apparent stability in global per capita emissions (around 4 –within 3.7 and 4.3– metric tons of CO_2 per world inhabitant over the period 1971-1999 according to IEA (2001) data on CO_2 emissions from fuel combustion) has coincided with an increasingly unequal distribution or not and which are the factors explaining it. This "distribution concern" requires the use of an inequality index, which synthesizes the degree of inequality in carbon emissions in a scalar number. We suggest that the appealing properties of the Theil index (Theil, 1967), and in particular, the fact that it can be decomposed into different components, make it suitable for this purpose.

Several studies have analyzed international inequality in CO_2 emissions, such as those in the IPCC report (1996, pp. 91-99). The works of Heil and Wodon (1997, 2000) and Padilla and Serrano (2006) introduce various indexes taken from income distribution analysis for measuring and studying the evolution of international inequality in CO_2 emissions[6]. Heil and Wodon (1997) employ a group decomposition of the Gini Index for analyzing inequality in per capita CO_2 emissions and the contribution of two income groups (poor and rich countries) to this inequality. Heil and Wodon (2000) employ this methodology for analyzing future inequality in per capita emissions using business-as-usual projections to the year 2100, as well as considering the impact on it of the Kyoto Protocol and other abatement proposals. Padilla and Serrano (2006)

[6] A complementary field of study is developed by Ravallion et al. (2000), who analyze the relationship between income distribution and the level of CO_2 emissions. They found that both economic growth and lower inequality (within and between countries) is associated with more emissions in the short term. However, they also found that economic growth improves the trade off with equity and that lower inequality improves the trade off with economic growth. Thus, economic growth with equity would lead to a better long term emissions trajectory.

employ concentration indexes to show that the inequality between rich and poor countries (inequality in emissions across countries ordered in the increasing value of income) has diminished less than the "simple" inequality in emissions and use a decomposition of the Theil index to show the contribution of 4 income groups to CO_2 inequality.

The main purpose of this paper is to use the capacities of these indexes to analyze the sources of international inequalities in per capita carbon emissions using the approach described by the Kaya factors. In short, the added value of the paper is twofold. Firstly, we show that when inequality is considered using the Theil index, it can be decomposed into multiplicative factors, such as the Kaya factors, and we also show that this methodology can be extended for exploring the sources of within- and between-group inequalities. Secondly, we carry out an empirical application of the methodology for international data on CO_2 emissions, energy consumption, population and GDP: we analyze the international inequality in per capita CO_2 emissions between countries, between groups of countries and within groups of countries for the period 1971-1999 and we decompose these inequalities into the inequalities in the main driving forces causing emissions (Kaya factors), so exploring which are the causes of the inequalities in per capita CO_2 emissions and their evolution.

The article is organized as follows. Section 2 shows an inequality decomposition methodology by Kaya factors. Section 3 performs an empirical illustration of this methodology by using international data. Finally, section 4 makes some concluding remarks.

2. Methodology: the decomposition of CO_2 inequality by Kaya factors

Let c_i be the per capita CO_2 emissions of country i, that is $c_i = \frac{CO_{2i}}{N_i}$ where N_i is population of country i. Although there are many measures of inequality, the Theil (1967) index has many desirable properties. Bourguignon (1979) has shown that this measure is the only population-weighted inequality index that is decomposable by groups of observations, is differentiable, symmetric, scale invariant and satisfies the Pigou-Dalton criterion[7]. For the purposes of computing inter-country CO_2 emissions inequality, this measure may be written as:

$$T(c,p) = \sum_i p_i \ln\left(\frac{\bar{c}}{c_i}\right) \tag{1}$$

where p_i is the share of country *i* in the total – world – population and $\bar{c}$ is the world average in per capita CO_2 emissions. Its lower boundary is zero, and the upper boundary depends on the sample. A value close to 1 indicates high inequality levels[8].

In order to investigate the sources of international inequalities in CO_2 emissions, our starting point is the well-known Kaya (1989) identity. According to this, per capita emissions can be broken down into the product of three distinct components: carbon

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[7] The Pigou-Dalton principle of transfers postulates that if one distribution can be obtained from another by a sequence of regressive transfers from relatively poor to relatively rich, then the former should be deemed to be more unequal.

[8] Theil (1967) also offered an alternative inequality index, which can be obtained by interchanging the positions of $\bar{c}$ and c_i in the logarithm and substituting the population weight scheme by using CO_2 shares. However, the population-weighted index – expression (1) – seems a better measure because: i) in our opinion, if dispersion in CO_2 is to be analyzed, the different observations should be weighted according to the population importance; ii) there are some problems linked to the interpretation of results when the alternative index is decomposed by group (see Shorrocks, 1980).

intensity of energy (defined as the mass of carbon dioxide emitted per unit of energy consumed, $\frac{CO_{2i}}{E_i}$), energy intensity (defined as the amount of energy consumed per unit of GDP, $\frac{E_i}{GDP_i}$) and affluence (defined as per capita GDP, $\frac{GDP_i}{N_i}$). The first component reflects the fuel mix of a given country, the second is associated with both energy efficiency and the sectoral structure of the economy; and the third is a measure of economic production.

Thus, we can denote these three factors respectively as a, b and y, for each country:

$$c_i = a_i \cdot b_i \cdot y_i \qquad (2)$$

We will now measure the contribution of each individual Kaya factor to the global inequality index. In order to do so, we shall define three hypothetical vectors by letting factor values differ from the average by only one at time. As a consequence, we obtain the following[9]:

$$\begin{aligned} c_i^a &= a_i \cdot \bar{b} \cdot y \\ c_i^b &= a \cdot b_i \cdot y \\ c_i^y &= a \cdot \bar{b} \cdot y_i \end{aligned} \qquad (3)$$

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

[9] This methodology was initially used in Duro (2003) for the analysis of spatial income inequality.

The degree of individual factor inequality is now computed using the Theil index:

$$T^a = \sum_i p_i \ln\left(\frac{\bar{c}^a}{c_i^a}\right)$$
$$T^b = \sum_i p_i \ln\left(\frac{\bar{c}^b}{c_i^b}\right) \qquad (4)$$
$$T^y = \sum_i p_i \ln\left(\frac{\bar{c}^y}{c_i^y}\right)$$

Each of these indexes thus measures each factor's partial contribution to global inequalities. Note that the importance attributable to each factor can be perceived as the amount of inequality which would persist if only the factor examined was allowed to vary between countries, while the other factors are equalized to the mean.

Note that if we add these Theil indexes and add the terms $\log\left(\frac{\bar{c}}{\bar{c}^a}\right)$ and $\log\left(\frac{\bar{c}}{\bar{c}^b}\right)$, we would obtain the following:

$$\left(T^a + \log\left(\frac{\bar{c}}{\bar{c}^a}\right)\right) + \left(T^b + \log\left(\frac{\bar{c}}{\bar{c}^b}\right)\right) + T^y = \sum_{i=1} p_i \log\left(\frac{\bar{c}}{c_i^a}\right) + \sum_{i=1} p_i \log\left(\frac{\bar{c}}{c_i^b}\right) + T^y =$$
$$\sum_{i=1} p_i \log\left(\frac{\bar{a}}{a_i}\right) + \sum_{i=1} p_i \log\left(\frac{\bar{b}}{b_i}\right) + \sum_{i=1} p_i \log\left(\frac{\bar{y}}{y_i}\right) = \sum_i p_i \log\left(\frac{\bar{a} \cdot \bar{b} \cdot \bar{y}}{a_i \cdot b_i \cdot y_i}\right) = T(c, p) \qquad (5)$$

However, what do the two new terms added mean? It would be easy to demonstrate that these can be interpreted as interaction components. We might therefore rewrite them as[10]:

$$\log\left(\frac{c}{c^{a}}\right)=\log\left(1+\frac{\sigma_{a,by}}{c^{a}}\right)$$
$$\log\left(\frac{c}{c^{b}}\right)=\log\left(1+\frac{a\sigma_{b,y}}{c^{b}}\right) \quad (6)$$

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

We are therefore able to decompose inter-country inequality in per capita carbon emissions into a sum of the individual contributions of Kaya factors – which are expressed by Theil indexes – and two interaction terms. That is,

$$T(c,p)=T^{a}+T^{b}+T^{y}+\text{inter}_{a,by}+\text{inter}_{b,y} \quad (7)$$

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

Furthermore, this methodology may be extended for analysis of between- and within-group inequality components. It is well-known that the Theil index can also be

[10] These demonstrations are not included in the text. Nevertheless, details are available from the authors.

decomposed by population subgroup in the following way (Theil, 1967; and Shorrocks, 1980):

$$T(c) = \sum_{g=1}^{G} p_g T(c)_g + \sum_{g=1}^{G} p_g \ln\left(\frac{c}{c_g}\right) \qquad (8)$$

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

Note that the first term – the within-group component – is a weighted average of the internal Theil indexes, which can be immediately decomposed into the multiplicative Kaya factors defined above. The second term – the between-group component – is purely a Theil population-weighted index, and the application of our decomposition is also straightforward.

3. Empirical results: analysis of CO_2 inequality across countries

Data on all the variables –CO_2 emissions, energy consumption, population and GDP– have been taken from the International Energy Agency, IEA (2001)[11]. The emissions from the IEA do not include the emissions which do not derive from the combustion of fossil fuels, such as the generated by cement production and biomass burning. These data tend to underestimate the emissions from poor countries as biomass

[11] We employed the purchasing power parity (PPP)-adjusted measure of GDP, as it shows better what can be afforded by a given income level than exchange rate GDP measures. However, it should be noted that it also tends to give greater measures for GDPs of poor countries than the market exchange rate GDPs.

combustion is relatively important in these countries[12]. The analysis is carried out for the years 1971, 1980, 1990 and 1999. Two samples of countries have been considered. The full sample includes 114 countries and groups of countries (see Appendix A), which clearly reflects the international situation. This sample amounts for more than 99% of world population, GDP and emissions from fuel combustion[13]. Complementarily, the results have been recomputed when China and India are excluded from the sample. The restricted sample amounts for 61.9% of total population, 83.6% of total GDP and 82.4% of total emissions. Although it seems convenient to include all available countries in order to conduct a comprehensive analysis, it might also be interesting to test the impact of these countries on global inequality values. They have experienced impressive rates of economic growth and emissions, represent a large share of global population, and therefore might have significantly influenced the evolution of global inequality indexes. Table 1 shows summary statistics for the full sample employed and for the different regions considered in the analysis.

TABLE 1 ABOUT HERE

Table 2 presents the values of the inequality decomposition exercise for selected years. Some points can be made about these values.

TABLE 2 ABOUT HERE

[12] While fully sustainable biomass burning would result in zero net emissions, a good proportion of non-fossil fuel combustion related emissions are not compensated by replanting of biomass. As noted by a reviewer, if the complete picture of carbon emissions were available –including those related to biomass use, land-use change, agriculture, etc.– the global inequality would presumably be less than the one found in this analysis.

[13] We have not considered marine and aviation bunkers, as they are not assigned to any country.

Firstly, there is a substantial decrease in intercountry CO_2 emission inequality between 1971 and 1999. The decrease in the Theil index is 32%, which is fairly significant. This therefore shows that responsibility for CO_2 annual emissions, at least in per capita terms, have gradually become more diffused. Nevertheless, inequality levels are fairly high. These results agree with the results obtained by Heil and Wodon (1997) and Padilla and Serrano (2006).

Secondly, this declining path is mainly explained by the lesser role as an unequalizer played by the affluence factor (per capita income) over time. The contribution of the affluence factor to inequality, which is the most important, moves from 0.72 to 0.52, i.e. a decrease of 27%, although it did not decrease between 1971 and 1980. However, this factor is still the most influential component in explaining current global inequalities, with an individual contribution of 69%. Greater convergence in income across countries may thus be reasonably expected to bear a corresponding reduction in CO_2 inequalities due to a greater increase in developing economies. However, as the objective is not equality in emissions but their control and reduction, it is imperative that the measures and incentives for allowing economic growth in developing economies that do not involve a significant increase in global emissions in the future are in place. The great inequality between countries shows that a policy focused on reducing emissions in rich economies (the major emitters) might be quite effective in controlling emissions in the short term. However, the declining path of income inequality also shows that it would be quite ineffective in the long term, due to the strong economic growth of some developing economies[14].

Thirdly, the evolution of inequalities in carbon intensity of energy (carbonization index) and energy intensity has also influenced the recent declining path observed in inequalities of per capita carbon emissions[15]. These inequalities, and especially the inequality in energy intensities, which experienced a 40.3% reduction[16], also strongly declined during the period. However, the relative importance of both factors is clearly smaller than that estimated for the affluence factor.

Fourthly, a comment about the interaction terms seems in order. The interaction term referred to the correlation between energy intensity and level of development – $interact_{b,y}$– is negative, although it has clearly declined in importance in explaining global inequality since 1980. This negative correlation means that richer countries, which emit more emissions, tend to exhibit also lower emission intensities, which attenuates in turn emissions inequality. This negative correlation might be explained by the change in economic structure, as rich countries have strongly developed several activities in the tertiary sector that are less energy-demanding than industrial

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[14] Nevertheless, one might argue that focusing on rich countries will be enough as, thanks to economic growth, some developing economies will become "rich" and so would have to control their emissions. The problem would then be to establish the "wealth threshold" from which a country should have obligations under mitigation agreements.

[15] For an analysis of energy intensity evolution see Greening et al. (1997) who compare 6 different decomposition methods for analyzing energy intensity for manufacturing in 10 OECD countries. They found that most changes in energy intensity may be explained by changes in individual subsector energy intensity. Greening (2004) applies a decomposition analysis to carbon intensity of personal transportation, finding that while the reduction in fuel intensity has contributed to control the increase in CO_2 emissions, this has been offset by behavioral effects, such as declining load factors and modal shifts.

[16] Alcántara and Duro (2004) and Sun (2002) analyze the decrease in the inequality in energy intensities across OECD countries. Miketa and Mulder (2005) analyze the energy productivity convergence across developed and developing countries in 10 manufacturing sectors.

ones, while there is some stagnation in the demand for industrial activities[17]. International trade also helps to explain this correlation, as it might be used to displace energy consumption from rich to poor countries, without any reduction in the energy intensity content of the consumption of rich countries[18]. In any case, the reduction of the absolute value of this term shows that this correlation is now less clear than at the beginning of the period.

The interaction term referring to the relationship between carbonization index and energy per capita –$interact_{a,by}$– shows a positive value, i.e., countries with greater per capita energy consumption also tend to emit more CO_2 per unit of energy. This correlation is mainly explained by the positive covariance between carbon intensity of energy and affluence (see Appendix A). This factor thus amplifies the inequalities between rich and poor countries in per capita CO_2 emissions. However, this correlation is much lower at the end of the period. At the beginning of the period, industrialized countries thus tended to show greater carbonization indexes than poorer ones. One explanation is that industrialized and industrializing economies tend to have more need to burn non-renewable fuels and emit carbon for generating energy than poorer countries, where the primary sector is predominant. Note that the IEA data do not include emissions from wood and other biomass combustion – which has an important share of global energy consumption in poorer countries. Therefore, as

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[17] However, not all the tertiary sector activities that have increased are less demanding of energy, as in the case of air transportation. Furthermore, even if this change in sectoral structure occurs and energy intensity for some rich countries decreases, this does not mean that total consumption of energy by these countries decreases, unless we assume that the most environmentally problematic sectors are those producing inferior goods, which is not at all probable (Torras and Boyce, 1998). There might be a "relative delinking" between economic growth and environmental pressure, but not an "absolute" one (see de Bruyn and Opschoor, 1997; Roca and Alcántara, 2002).

[18] Some authors have stressed this possibility to explain some inverted-U relationships – environmental Kuznets curves – observed between environmental pressures and economic growth (Arrow et al., 1995, Stern et al., 1996, Ekins, 1997; Suri and Chapman, 1998; Heil and Selden, 2001b).

poor countries develop and burn fuels other than wood, they increase their emissions –from fossil fuels burning– per unit of energy, while efficiency gains and changes in the fuel mix[19] in rich countries have contributed to heavily reducing the importance of this factor in emissions inequality[20].

Finally, although the interaction terms are significant when they are taken individually, mainly in the first years analyzed, when they are taken together they have a small overall impact on CO_2 inequality. This result indicates that global CO_2 inequalities might be broadly decomposable as the sum of the individual Kaya factor indexes.

The results have been recomputed after excluding China and India from the sample. The purpose of this exercise is to verify whether the results are qualitatively different from the ones obtained when the full sample is employed. In fact, the restricted sample depicts a fairly different scenario. The most striking aspect is the dramatic contrast observed in the role played by per capita income in explaining the recent reduction in CO_2 inequalities. The reduction in per capita CO_2 inequality is less important than when the whole sample is considered, and this reduction is mainly explained by the changes in carbon intensities and the interaction terms. Of particular interest is the role played by the term $\text{Interact}_{b,y}$, which plays an important role in the

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[19] Note that the possibility of switching to energies that do not emit CO_2, such as hydroelectrical and nuclear power plants – which has contributed to the reduction of carbon intensity in several rich countries – is not affordable for many poor countries.

[20] Roberts and Grimes (1997) observe that the carbon intensity of GDP – the product of carbon and energy intensities – has declined for a small number of wealthy countries since 1970, while the average for the rest of the world has worsened. They therefore argue that the different countries are not passing through stages of development; while wealthy countries specialize in services, production of intermediate semi-processed goods tends to concentrate in some middle-income countries (Hettige et al., 1992, Moomaw and Tullis, 1994). They stress that sociopolitical factors are increasingly important in determining which countries institute efficiency measures.

reduction, showing a growing correlation between the level of per capita income and energy efficiency, unlike what happens when the whole sample is considered. The effect of $Interact_{b,y}$ is less important in explaining the CO_2 inequality reduction of the restricted sample. Unlike what happens with the whole sample, the affluence difference across countries plays an increasingly important role in CO_2 inequality. Given this fact, and making a comparison with the full sample results, it should be pointed out that the observed convergence in per capita income in the full sample is basically explained by the (positive) differential growth experienced by India and China over the period, which involved a significant increase in their emissions[21]. The results therefore need to be interpreted with caution, taking the specific sample used into account. Nevertheless, it should be emphasized that the chief role played by different levels of income in explaining global CO_2 inequality levels is broadly confirmed in both samples.

We will next decompose the between and within-group inequality components by Kaya factors. We have used the seven major world regions suggested by Theil and Deepak (1994) in their analysis of international income inequalities (the list of countries by regions included in the study is shown in Appendix A). This choice is justified by various reasons. Firstly, groups are conformed basically according to geographical areas, which seems fairly appealing. Secondly, the different areas correspond roughly to different levels of economic development so given that we

[21] They have also experienced significant improvements in energy efficiency, which in the case of China are attributed much more to improving technical efficiency than to changes in economic structure (EIA, 2004). However, data on China are highly uncertain. As noted by a reviewer, according to official China National Bureau of Statistics, 2002-2004 witnessed a dramatic increase in energy consumption and rising energy intensity of GDP after experiencing a similarly dramatic *decrease* in energy intensity of GDP. Most analysts attribute this shift at least in part to data quality concerns (regarding both energy consumption and economic activity data).

have found that affluence inequality is the main determinant of carbon emission inequalities, it seems quite a reasonable choice[22].

TABLE 3 ABOUT HERE

TABLE 4 ABOUT HERE

The results are shown in Table 3 and Table 4. Several points should be noted. Firstly, the data reveal that between-group inequalities are the main factor behind overall inequalities (nearly 70% in both samples). This result confirms the relevance of the groups considered, as there are vast differences between them. Once again, difference in affluence appears as the main determinant of between-group inequalities.

Secondly, when we take the full sample, the decline in inequalities between groups is mainly explained by the reduction in per capita income disparities, but carbon and energy intensities and the first interaction term ($Interact_{a,by}$) have also helped the declining trajectory. All these factors experience a greater reduction than that when total per capita CO_2 inequality was considered. In the case of the restricted sample, the reduction is explained by the convergence of carbon intensities and $Interact_{a,by}$, while the other factors tended to increase the between-group component of per capita CO_2 inequality.

[22] Note that the choice of the groups has a direct bearing on the outcomes of the decomposition analysis. Alternative grouping rules would yield different decomposition results (but not overall inequality) outcomes.

Thirdly, and in clear contrast, within-group inequalities increased over time and as a result, their relative importance in global inequality in both samples increased. In the case of the restricted sample, this component is more important and the increase was double that of the sample as a whole. This greater increase is basically explained by the growing differences in per capita income levels when the restricted sample of countries is considered.

It is also instructive to show information on the different world regions. Table 5 shows the main data for the first and the last year of the period under consideration.

TABLE 5 ABOUT HERE

Interestingly, the increase in the global within-group inequality component is mainly caused by the increase in inter-country inequality in Tropical Africa, South-West Asia and South-East Asia. The large increase in inequality observed in Tropical Africa is based on the increased contribution of income disparities and also on the large variation in the sign of interaction term $interact_{a,by}$, which in turn depends on the large increase in the covariance between carbon intensities of energy and per capita energy consumed in this region[23]. The increase in per capita CO_2 inequality in South-East Asia is mainly explained by the increasing role of affluence inequality within this region, and the reduction in the absolute value of $Interact_{b,y}$. Unlike this pattern, inequality in per capita carbon emission across countries in the Temperate zone group clearly declined during the period. This behavior is attributable to the smaller contribution of energy intensities on inequalities, which in turn can be associated with

[23] These results are not included in the text, but are available from the authors on request.

equalization in sectoral structures among developed countries, and the decreasing role played by $Interact_{b,y}$, which shows the correlation between energy intensities and levels of per capita income[24].

4. Concluding remarks

This paper has focused on two main aspects, the first one being methodological and the second empirical. As regards the former, we have shown that CO_2 per capita emissions inequalities – when they are measured using the well-known Theil index – might be decomposed in terms of Kaya factors into a sum of the contribution of each factor and two interaction terms, which show the influence due to the joint variations in factors. We have also shown that this methodology can be extended to analyze the between- and within-group inequality components. As far as the empirical aspect is concerned, we have used this methodology to investigate the sources of cross-country per capita CO_2 inequalities using data provided by the IEA.

We can discern some basic points from the results obtained. Firstly, international inequalities in per capita CO_2 emissions are mainly explained by inequalities in affluence – measured by per capita income – across countries, and the decrease in these income inequalities helps to explain the CO_2 inequality reduction since 1971. However, the evolution of the inequalities in carbon intensity of energy and energy intensity has also contributed to global reduction in per capita emissions. These results are strongly influenced by the performance of China and India. When they are excluded from the sample, the contribution of income inequality increases, although it

[24] Note that the sign of this term is positive. Then, unlike what happens with the sample as a whole, richer countries within this group tend to use more energy per unit of GDP, so this term has a positive effect on CO_2 inequality, although, as mentioned above, this correlation diminished over time.

is more than compensated for by the reduced contribution to inequality of the carbonization index and the interaction between energy intensity and income. Secondly, the decomposition of the between-group inequality component, which constitutes the largest inequality component, shows that the income factor is similarly important. Thirdly, and despite the above, the within-group inequality component showed a slight increase over the period, which is mainly explained by the pattern followed by Tropical Africa, South-West Asia and South-East Asia, with a strong change in the interaction between carbon intensity of energy and per capita energy in the first case, and in income inequality and the interaction term between energy intensity and per capita income in the third.

The use of the Theil index has allowed us to analyze the evolution of international inequality in CO_2 emissions and of its main driving forces. This analysis sheds light on global distribution issues –such as the differences in the responsibility for the problem– and so provides helpful information for the debate on how to distribute the burden-sharing in climate change.

The high level of international inequality in per capita CO_2 emissions and the great importance played by the income inequality component give support to the idea that initiatives focusing emissions control on rich countries might be quite effective in the short term. However, the declining path of this component, due to the strong economic growth of some developing economies, shows that any effective mitigation policy in the long term needs the future participation of these developing economies in emissions control.

The results also show that the contribution of inequalities in carbon intensity of energy and energy intensity should not be ignored. There are important divergences in energy intensities. The reduction in energy intensities differences –thanks to the energy efficiency gains in some developing economies– shows that efficiency improvement is one of the most important ways in which emissions might be controlled. The reduction experienced in the absolute value of the interaction term referred to the negative correlation between energy intensity and level of development shows how the reduction in energy intensities inequality –achieving more similar levels of efficiency in countries with different income– has contributed to attenuate emissions growth.

There are also important inequalities in carbon intensities of energy across countries, even within regions with similar income[25], although its contribution to CO_2 inequality has declined over time. It is remarkable the case of the Temperate zone group, where there has been an increasing inequality in countries with similar income. This might be due to the fact that some countries have undertaken more aggressive policies in the change from fossil fuels to non-CO_2 emitting energy sources. This shows the strong potential that this substitution might have to control global emissions in the future. The differences and changes in the carbon intensity of energy basically show the mix of energy sources while there are many more factors that might influence in the differences and changes in energy efficiency (such as different productive specialization)[26]. However, there is a great potential for controlling emissions through

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[25] Padilla and Roca (2004) –employing the International Energy Agency data for 1999– showed that, in a relatively homogeneous territory like the 15 European Union countries, the variability in the carbonization index was very similar and even somewhat bigger than the variability in energy intensity.
[26] See Ang (1999), Mielnik and Goldemberg (1999), and Roca and Alcántara (2002) for a discussion on the relative importance of energy intensity and carbon intensity of energy in explaining differences over time in per capita emissions of different countries.

increasing the share of renewable energy sources and it is unavoidable that this change takes place in the future.

The need for economic growth in poor countries in order to improve their standards of living, which can initially promote a decreasing pattern on CO_2 per capita inequalities, might also involve a significant growth in global emissions in the future, unless the countries with means for taking mitigating action reduce their energy and carbon intensities and co-operate with the developing economies with initiatives – such as technological transfers and cooperation – that compensate for this. This is the challenge.

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APPENDIX A

a) Covariance Matrix

- Full-sample

	$\text{cov}(a,b)$	$\text{cov}(a,y)$	$\text{cov}(b,y)$
1971	-0.05	2.71	-0.44
1975	-0.04	2.63	-0.52
1980	-0.02	2.56	-0.55
1985	-0.02	2.14	-0.39
1990	-0.01	1.85	-0.35
1995	-0.03	1.43	-0.29
1999	-0.04	1.66	-0.24

- Excluding China and India

	$\text{cov}(a,b)$	$\text{cov}(a,y)$	$\text{cov}(b,y)$
1971	-0.02	3.83	-0.00
1975	-0.02	3.96	-0.03
1980	-0.03	4.12	-0.10
1985	-0.06	4.07	-0.24
1990	-0.06	4.06	-0.31
1995	-0.06	3.56	-0.50
1999	-0.07	3.77	-0.54

b) Groups

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

Table 1. Summary statistics for the full sample of countries, 1999

Group	Temperate Zone	Eastern European Countries	Tropical America	Tropical Africa	South West Asia	South-central Asia	South-East Asia	People's Republic of China	Total (full sample)
Population	986.97	411.91	451.49	727.46	227.99	1347.37	508.65	1253.6	5915.44
Population share	16.68%	6.96%	7.63%	12.30%	3.85%	22.78%	8.60%	21.19%	100%
GDP	22812.92	2419.81	2705.53	1111.68	1312.64	2839.96	2265.49	4357.82	39825.85
GDP share	57.28%	6.08%	6.79%	2.79%	3.30%	7.13%	5.69%	10.94%	100%
Energy	5039.4	1179.61	501.9	378.91	413.51	586.87	451.13	1088.35	9639.68
Energy share	52.28%	12.24%	5.21%	3.93%	4.29%	6.09%	4.68%	11.29%	100%
Emissions	11743.7	3021.97	1011.85	381.11	1068.68	1043.95	913.48	3006.76	22191.5
Emissions share	52.92%	13.62%	4.56%	1.72%	4.82%	4.70%	4.12%	13.55%	100%
Mean p.c. GDP	22812.92	2419.81	2705.53	1111.68	1312.64	2839.96	2265.49	4357.82	39825.85
Mean p.c. energy	5039.4	1179.61	501.9	378.91	413.51	586.87	451.13	1088.35	9639.68
Mean p.c. emissions	11.90	7.34	2.24	0.52	4.69	0.77	1.80	2.40	3.75
Carbon intensity of energy	2.33	2.56	2.02	1.01	2.58	1.78	2.02	2.76	2.30
Energy intensity of GDP	0.22	0.49	0.19	0.34	0.32	0.21	0.20	0.25	0.24

Note: prepared by the authors using IEA data. Population in millions. GDP in billions of PPP-adjusted 1995 US dollars. Energy in millions of tons of oil equivalent. Emissions in millions of metric tons. Per capita GDP in millions of PPP-adjusted 1995 US dollars. Per capita energy in tons of oil equivalent. Per capita emissions in metric tons. Carbon intensity in tons of CO_2 per ton of oil equivalent. Energy intensity in tons of oil equivalent per thousand of PPP-adjusted 1995 US dollars.

Table 2. Decomposition of international inequalities in per capita CO_2 by Kaya factors using the Theil index

	$T(c,p)$	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$
Full sample						
1971	1.1167	0.1792 (16%)	0.1919 (17%)	0.7218 (65%)	0.2887 (26%)	-0.2648 (-24%)
1980	0.9944	0.1420 (14%)	0.1827 (18%)	0.7257 (73%)	0.2371 (24%)	-0.2930 (-29%)
1990	0.8479	0.1365 (16%)	0.1202 (14%)	0.6196 (73%)	0.1636 (16%)	-0.1919 (-19%)
1999	0.7581	0.1348 (18%)	0.1145 (15%)	0.5247 (69%)	0.1200 (12%)	-0.1360 (-14%)
Excluding China & India						
1971	1.1488	0.2521 (22%)	0.1601 (14%)	0.4679 (41%)	0.2706 (24%)	-0.0020 (-0%)
1980	1.0547	0.1960 (19%)	0.1508 (14%)	0.4962 (47%)	0.2531 (24%)	-0.0414 (-4%)
1990	1.0177	0.1941 (19%)	0.1547 (15%)	0.5568 (55%)	0.2397 (24%)	-0.1276 (-13%)
1999	0.9691	0.1941 (20%)	0.1730 (18%)	0.6129 (63%)	0.2085 (22%)	-0.2195 (-23%)

Note: prepared by the authors using IEA data. The percentages show the weight on total inequality.

Table 3. Decomposition of between-group international inequalities in CO_2 per capita by Kaya factors using the Theil index

	$T_{between}$	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$
Full sample						
1971	0.9587 (86%)	0.1080 (11%)	0.1326 (14%)	0.6625 (69%)	0.2863 (30%)	-0.2308 (-24%)
1980	0.8306 (84%)	0.0747 (9%)	0.1319 (16%)	0.6565 (79%)	0.2202 (27%)	-0.2527 (-16%)
1990	0.6547 (77%)	0.0490 (7%)	0.0625 (10%)	0.5476 (84%)	0.1352 (21%)	-0.1396 (-21%)
1999	0.5509 (73%)	0.0416 (8%)	0.0373 (7%)	0.4411 (80%)	0.0875 (16%)	-0.0566 (-10%)
Excluding China&india						
1971	0.9144 (80%)	0.1464 (16%)	0.0522 (6%)	0.3731 (41%)	0.2714 (30%)	0.0713 (8%)
1980	0.8103 (77%)	0.0961 (12%)	0.0531 (7%)	0.3853 (48%)	0.2312 (29%)	0.0446 (6%)
1990	0.7279 (72%)	0.0638 (9%)	0.0551 (8%)	0.4406 (61%)	0.1984 (27%)	-0.0301 (-4%)
1999	0.6550 (68%)	0.0538 (8%)	0.0609 (9%)	0.4784 (73%)	0.1594 (24%)	-0.0974 (-15%)

Note: prepared by the authors using IEA data. The percentages in the first column show the weight on total inequality. The percentages in the other columns show the weight on between-group inequality.

Table 4. Decomposition of global within-group international inequalities in CO_2 per capita by Kaya factors using the Theil index

	T_{within}	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$
Full sample						
1971	0.1581 (14%)	0.0778 (49%)	0.0698 (44%)	0.0593 (38%)	-0.0043 (-3%)	-0.0446 (-28%)
1980	0.1638 (16%)	0.0596 (36%)	0.0597 (36%)	0.0692 (42%)	0.0246 (15%)	-0.0492 (-30%)
1990	0.1932 (23%)	0.0707 (37%)	0.0501 (26%)	0.0719 (37%)	0.0452 (23%)	-0.0447 (-23%)
1999	0.2072 (27%)	0.0738 (36%)	0.0527 (25%)	0.0836 (40%)	0.0520 (25%)	-0.0549 (-26%)
Excluding China&india						
1971	0.2343 (20%)	0.1188 (51%)	0.1046 (45%)	0.0948 (40%)	-0.0139 (-6%)	-0.0700 (-30%)
1980	0.2444 (23%)	0.0912 (37%)	0.0886 (36%)	0.1109 (45%)	0.0306 (13%)	-0.0769 (-31%)
1990	0.2898 (28%)	0.1077 (37%)	0.0756 (26%)	0.1162 (40%)	0.0638 (22%)	-0.0735 (-25%)
1999	0.3141 (32%)	0.1147 (37%)	0.0826 (26%)	0.1345 (43%)	0.0747 (24%)	-0.0925 (-29%)

Note: prepared by the authors using IEA data. The percentages in the first column show the weight on total inequality. The percentages in the other columns show the weight on within-group inequality.

Table 5. Decomposition of inequalities in CO_2 per capita emissions by major regions

	$T(c,p)$	T^a	T^b	T^y	$Interact_{a,by}$	$Interact_{b,y}$
Temperate zone						
1971	0.2092	0.0045 (2%)	0.0765 (37%)	0.0587 (28%)	-0.0119 (-6%)	0.0814 (39%)
1999	0.1208	0.0156 (13%)	0.0290 (24%)	0.0522 (43%)	0.0013 (1%)	0.0227 (19%)
Eastern Europe						
1971	0.0462	0.0029 (6%)	0.0214 (46%)	0.0243 (53%)	0.0044 (10%)	-0.0068 (-15%)
1999	0.0390	0.0058 (15%)	0.0614 (157%)	0.0335 (86%)	-0.0022 (-6%)	-0.0594 (-152%)
Tropical America						
1971	0.1853	0.0576 (31%)	0.0516 (28%)	0.0429 (23%)	0.0622 (34%)	-0.0290 (-16%)
1999	0.1684	0.0249 (15%)	0.0617 (37%)	0.0572 (34%)	0.0513 (30%)	-0.0268 (-16%)
Tropical Africa						
1971	0.4221	0.5860 (139%)	0.2843 (67%)	0.1941 (46%)	-0.2655 (-63%)	-0.3768 (-89%)
1999	0.8092	0.4842 (60%)	0.1654 (20%)	0.2520 (31%)	0.2424 (30%)	-0.3348 (-41%)
South-West Asia						
1971	0.1942	0.0046 (2%)	0.0982 (51%)	0.2552 (131%)	-0.0109 (-6%)	-0.1530 (-79%)
1999	0.2794	0.0010 (0%)	0.1556 (56%)	0.2480 (89%)	-0.0170 (-6%)	-0.1082 (-39%)
South-central Asia						
1971	0.1414	0.0468 (33%)	0.0562 (40%)	0.0145 (10%)	0.0391 (28%)	-0.0153 (-11%)
1999	0.1044	0.0286 (27%)	0.0391 (37%)	0.0181 (17%)	0.0259 (25%)	-0.0073 (-7%)
South-East Asia						
1971	0.3063	0.1174 (38%)	0.0994 (32%)	0.1750 (57%)	0.1379 (45%)	-0.2234 (-73%)
1999	0.4350	0.0321 (7%)	0.0424 (10%)	0.2738 (63%)	0.1504 (35%)	-0.0637 (-15%)

Note: prepared by the authors using IEA data. The percentages show the weight on each group inequality.