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Ecological Footprint Inequality: A methodological review and some results.

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Abstract

Scarcities of environmental services are no longer merely a remote hypothesis. Consequently, analysis of their inequalities between nations becomes of paramount importance for the achievement of sustainability in terms either of international policy, or of Universalist ethical principles of equity. This paper aims, on the one hand, at revising methodological aspects of the inequality measurement of certain environmental data and, on the other, at extending the scarce empirical evidence relating to the international distribution of Ecological Footprint (EF), by using a longer EF time series. Most of the techniques currently important in the literature are revised and then tested on EF data with interesting results. We look in depth at Lorenz dominance analyses and consider the underlying properties of different inequality indices. Those indices which fit best with environmental inequality measurements are CV^2 and $GE(2)$ because of their neutrality property, however a trade-off may occur when subgroup decompositions are performed. A weighting factor decomposition method is proposed in order to isolate weighting factor changes in inequality growth rates. Finally, the only non-ambiguous way of decomposing inequality by source is the natural decomposition of CV^2, which additionally allows the interpretation of marginal term contributions. Empirically, this paper contributes to the environmental inequality measurement of EF: this inequality has been quite stable and its change over time is due to per capita vector changes rather than population changes. Almost the entirety of the EF inequality is explainable by differences in the means between the countries of the World Bank group. This finding suggests that international environmental agreements should be attempted on a regional basis in an attempt to achieve greater consensus between the parties involved. Additionally, source decomposition warns of the dangers of confining CO_2 emissions reduction to crop-based energies because of the implications for basic needs satisfaction.

Keywords: ecological footprint; ecological inequality measurement, inequality decomposition.

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1. Introduction

Ecological distribution refers to the social, spatial and temporal asymmetries or inequalities in the human use of environmental resources and services (whether trades or not). A typical example is the depletion of natural resources (Martinez-Alier and O'Connor, 1999). This paper deals with the empirical measurement of ecological distribution.

The aggravation of ecological crisis[1] brings distributional issues to the top of the agenda (Luks and Stewen, 1999). Since the scarcity of natural resources is now tangible, business-as-usual scenarios are feasible neither in a physical, nor in a social, sense. Standard economics has attempted to solve current distributional conflicts via growth, thus focussing on efficient allocation issues. Nevertheless, since ecological economics puts the *scale* goal on the table (Daly, 1992), fair ecological distribution becomes, not only a necessary condition, but also an ethical issue, for the achievement of sustainability. The core concern of sustainable development is that of working toward guaranteeing the rights and interests of future generations. However, such an approach cannot ignore the deprived people of today while trying to prevent deprivation in the future - this would be outrageous (Anand and Sen, 2000). Consequently, ceasing policies of unending growth to achieve sustainability will solve the distributional problem of future generations only at the expense of worsening the distributional problem within current generations (Aubauer, 2006; Daly and Farley, 2004).

Since allocation of resources is determined neither by ethical nor by ecological criteria, but by the dominance of market mechanisms (Røpke, 2001), distributional analysis of responsibilities for the depletion of ecological functions comes to the fore as an important tool for policy makers. Such responsibilities may not be equally distributed among countries, hence, neither are the commitments. The success of any international agreement depends highly on the perception of equitability by the parties (Duro and Padilla, 2006; Heil and Wodon, 2000; Padilla and Serrano, 2006). Greater responsibilities should involve greater efforts toward global sustainability. From Rio 1992 to Durban 2011, passing through Kyoto 1995, distributional issues have unquestionably determined the international agreements reached. Consequently, an in-depth understanding of ecological inequalities may be critical in achieving greater consensus.

As a result, papers focussed on the distribution analysis of ecological variables are becoming of greater interest in ecological economics: it is noticeable that empirical applications have risen significantly in recent years[2] (Alcantara and Duro, 2004; Aldy, 2006; Criado and Grether, 2010; Dongjing et al. 2010; Duro and Padilla, 2006; Duro and Padilla, 2008; Duro et al., 2010; Duro

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[1] Collapse of the three highly correlated ecological functions: resource supply, waste assimilation and environmental services, such as life support.

[2] Convergence or inequality approach; both approaches focus on disparities in environmental outcomes among countries.

and Padilla, 2011; Cantore, 2011; Ezcurra, 2007; Heil and Wodon, 1997; Heil and Wodon, 2000; List, 1999; Heil and Wodon, 1997; Miketa and Mulder, 2005; Nguyen Van, 2005; Padilla and Serrano, 2006; Steinberger et al., 2010; Strazicich and List, 2003; White, 2007; Wu and Xu, 2010). Additionally, as consequence of this literature proliferation, a burgeoning methodology discussion is growing around the adaptation of well-known income inequality tools to environmental issues (Maguire and Sheriff, 2011; Duro, 2012a).

This paper's aim is thus twofold: firstly, we summarize and order the empirical application of inequality approaches to ecological economics. In so doing, we revise the methodologies applied and propose the use of decompositions which are usually applied in the main literature. We consider the primary aspects which should be taken into account when these methodologies (already widely applied to *income* distributions) are applied to ecological issues; such translations are not always direct. Secondly, we analyse empirically the international inequality in Ecological Footprint (EF), showing both that it is a more comprehensive indicator than CO_2 emissions (on which analyses of this sort usually focus) and that there is less empirical evidence for its distribution (White 2007; Dongjing et al., 2010; Wu and Xu, 2010). Additionally, EF is a reliable proxy for critical natural capital, which makes its distributional analysis of deep interest.

This empirical analysis consists of capturing, in the first place, the main trends in EF inequality over 47 years. Next, an additive decomposition is performed in order to distinguish between the underlying blocks of the observed inequality (Shorrocks, 1980, 1984). The main findings are that, although the observed inequality trend is quite stable and has a positive sign, the source decomposition analysis in contrast suggests diminishing inequalities in all EF components (carbon footprint, cropland, fishing ground, grazing land, forest, and built-up) - this may be caused by weighting issues. Meanwhile, subgroup decomposition shows that the bulk of the inequality (around 80%) is explained by the inequality *between* World Bank groups - this has strong policy implications in terms of commitments such as environmental taxation schemes.

The paper is organized as follows: Section 2 defines the meaning and significance of Ecological Footprint as an indicator of natural resource consumption. Section 3 revises the inequality approach methodology when the analysis is applied to environmental issues. Section 4 shows the empirical application of such methodologies by measuring EF inequality and its decompositions. Finally, Section 5 concludes the paper.

2. The Ecological Footprint indicator

A commonplace in ecological economics is the incommensurability problem which deals with the fact that is only possible to compare in nature once there is a common denominator available[3]. The EF, introduced by (Rees, 1992) and developed by (M. Wackernagel and Rees, 1996), proposes as common denominator a global bio-productive hectare, where each such hectare has the average biological productivity of the whole earth. So then, the question becomes how many global hectares a given population uses to maintain its consumption patterns; the answer is the Ecological Footprint.

The Ecological Footprint (EF) accounts for the biosphere regenerative capacity *occupied* by human activities via resource consumption (including household consumption as well as collective consumption such as schools, roads, fire brigades, etc.) and waste assimilation (see Ewing et al., 2010a, b; Kitzes and Wackernagel, 2009; Kitzes et al., 2009; Monfreda et al., 2004; Rees, 2000; Wackernagel and Rees, 1996; Wackernagel et al., 2004)[4]. Since both renewal and absorption depend on the health and integrity of ecosystems, regenerative capacity is a reliable proxy for the life-supporting capacity of natural capital (Monfreda et al., 2004). Therefore, this indicator aims to measure the amount of “critical natural capital” (Ekins, 2003; Victor, 1991) as it accounts for one of the key aspects of natural capital: the Earth’s ability to provide conditions conducive for life.

The EF framework has been widely used as an indicator of Sustainability as it is compared with a country’s bio-capacity. This approach has given rise to a considerable debate, resulting in several criticisms of the measure (Fiala, 2008; Van den Bergh and Verbruggen, 1999). Different (un)sustainability indicators are available, such as EF, Material Flow Accounts (MFA), human appropriation of Net Primary Production (HANPP), etc., each providing different critical information in an attempt to assess the complex concept of sustainability. Thus, sustainability assessment should accept its complexity and incommensurability and might best be carried out by multi-criteria decision making (Kitzes et al., 2009; Martinez-Alier and Roca, 2001). Nonetheless, such debates are beyond the scope of this paper since EF is merely used in resource consumption measurement as a proxy for critical natural capital. Indeed, any aggregate indicator (for example, measures of aggregate economic output) will have both strengths and weaknesses, and this also applies to EF. But EF has benefited from academic scrutiny of its properties and limitations and this has encouraged its continuous improvement. Its strengths and weaknesses are now well known, allowing the interpretation of EF analyses in a transparent and unequivocal manner (Caviglia-Harris et al. 2009; Kitzes and Wackernagel, 2009; White, 2007).

Different methods of country-level EF assessment have been developed for many nations (Aubauer, 2011; Bicknell et al., 1998; Ferng, 2001; Monfreda et al., 2004; Van Vuuren and

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[3] Money has been used to do so, however money is not a particularly objective instrument for evaluating what something is worth, especially for natural capital. See (Martinez-Alier & Roca, 2001; Røpke, 2001). Actually, Joan Robinson made the same criticism about capital (Victor, 1991).

[4] The concept stems from human ecology in the process of defining a suitable way of translating the carrying capacity concept to the human species (Rees, 2000).

Smeets, 2000; Wackernagel and Rees, 1996; Wiedmann et al., 2006). However the most widely used methodology for national footprint accounting is Global Footprint Network's standards (Global Footprint Network, 2010), where the accounts are based on a variety of international and national data sources, including databases from the United Nation Food and Agricultural Organization, the United Nations Statistics division and the International Energy Agency (FAOSTAT, UN Comtrade, IEA). Different analyses have been performed using country-EF to test different hypotheses such as the Environmental Kuznets curve or the IPAT/STRIPAT model (Bagliani et al., 2008; Caviglia-Harris et al., 2009; Dietz et al., 2007; York et al., 2003). Additionally, EF has been adopted by a growing number of government authorities, agencies, and policy makers as a measure of ecological performance. Notable examples are those international applications such as the European Environment Agency (EEA, 2010) and the European Parliament and the European Commission (Best et al., 2008), who consider EF to be a useful tool for measuring the environmental performance of the EU, or the United Nations Development Programme which considers that EF captures the environmental dimension of human development (UNDP, 2010).

EF accounts are made up of six types of land[5]: cropland, grazing land and fishing ground (to supply the food and clothes consumed), forest land (for timber and the fuel wood needed), energy land (accounting for the uptake of carbon emissions i.e. the carbon footprint)[6], and finally, built-up land (accounting for land covered by human infrastructure).

$EF = \sum_k C_k$ where k = Cropland, grazing land, fishing ground, forest land, carbon land, built-up land.

The basic equation necessary to develop an intuitive understanding of how EF is calculated is: Yield= Tonnes per year/Area – this may be rearranged as Area= Tonnes per year/Yield (Wackernagel et al., 2004). More formally: $EF_P = \frac{T_i}{Y_{W_i}} \cdot EQF_i$, where T_i is the annual amount harvested or waste emitted for of product I; Y_w is the world-average yield for the production of each product i, given by all the annual tonnes of product i produced globally, divided by all areas in the world on which this product is grown; EQF_i is the *equivalence* factor for the production of each product i which is used to translate the actual land area into a world-average biologically productive area (Ewing et al., 2010b; Galli et al., 2007).

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[5] For the underlying assumptions see (Ewing et al., 2010b).

[6] EF measures land appropriation by consumed products; some of them appropriate land directly (paper, food, housing, etc), while the use of fossil energy included in all products (carbon footprint) is appropriated by a fictive and indirect use of land. The idea is to calculate how great an area would be needed to replace the use of fossils or to soak up their emissions. In fact, a sustainable economy would not drain natural capital, but continuously would produce the energy which is used (Røpke, 2001).

In order to obtain a consumption based indicator of EF, it is necessary to add the EF of imports (EF_I) and subtract the EF of exports (EF_E). In this way, we obtain the EF of consumption (EF_C):

$$EF_C = EF_P + EF_I - EF_E$$

In summary, EF captures consumption in terms of land (and sea) regardless of *where* and *when* is located: a country may be consuming the land of other countries; indeed, the whole world may be consuming the land (and sea) of future generations. There is a clear distributional content to what is captured by the EF index (Martinez-Alier, 2002) - EF encapsulates in its definition unequal relations between countries and generations. Hence, its distributional analysis allows us to capture an additional dimension when applied to ecological distribution.

Data on Ecological Footprint have been taken from (Global Footprint Network, 2010) and they cover 119 countries over the period 1961 to 2007. The sample amounts to 90% of the world population, 91% of the 2007-GDP and 82% of the World Ecological Footprint[7]. The results presented must be read correctly: EF per capita is the EF of the whole country, divided by the country's population; no more, no less! We do not assume that every person within a country has the same EF - our focus is on analysing the inequality of resource consumption in a macro-political way.

3. Inequality and the environment: some basic methodological aspects.

The development of distributional analysis methods in economics has been tackled in the context of Social Welfare Theory (Atkinson, 1970; Theil, 1979; F. Cowell, 1980, 2011; Shorrocks, 1980). This focusses on the measurement of income inequality and its direct implication for social welfare. Therefore, the methodology applied to analyse environmental distribution issues may be borrowed from the income inequality literature. This inequality approach application to ecological economics has been applied increasingly in recent years.

3.1 Inequality measurement: partial ordering

At the root of inequality analysis, we will find that the key issue is the comparison between two states in order to decide which one is better off in terms of welfare. Ranking different distributions thus become a useful way of making this decision. The Lorenz criterion (second-order distributional dominance)[8] is surely the most popular tool for making such a ranking. For

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[7] See Appendix table A1 and figure A1 for some descriptive trends in EF per capita levels over the period analysed.

[8] First order dominance criteria are based on the quantiles of the distribution which are given by the (generalized) inverse of the distribution function (Pen's Parade) (Cowell, 2011). This, howver, is less restrictive than second order dominance, and the implications for environmental applications are similar to those described for GLC.

instance, if the Lorenz Curve of EF distribution for 1961 lay wholly inside the EF Lorenz curve for 2007, one could assert that 1961 Lorenz-dominates 2007, implying that 1961 has a more evenly-spread EF distribution than 2007. However, as can be seen in figure 1 (left), both curves intersect, leading to an ambiguous comparison. Yet, even if 1961 had Lorenz-dominated 2007, Lorenz curves ignore the average level of EF (or exposure levels of contamination). Hence, it may happen that, for instance, even though 80% of the population in 1961 had 57% of the whole EF, whereas in 2007 they had only 54%, the latter could involve higher EF level than the former (this in fact is what actually occurs. See Figure 1, right). Therefore, it may be undesirable to conclude that the 1961 situation is preferable to that of 2007 just because of there being more equity (Maguire and Sheriff, 2011).

Shorrocks (1983a) proved that, by multiplying the original Lorenz curve by its mean, some of those intersections could be solved, thus removing its ambiguity; this is the well-known Generalized Lorenz Curve (GLC)[9]. In the income literature, this implies that (holding inequality constant) the distribution with greater mean will necessary be GLC-dominant (better welfare). Unfortunately, the GLC can also yield intersections even when the means are different. Figure 1 (right) illustrates a situation of non-GLC-dominance. Nevertheless, greater mean income is desirable, although greater EF mean is not, since that involves more environmental impact (scale goal). Hence, focussing on the low part of the distribution (first and second quintiles), 2007 exhibits a more desirable situation. In contrast, in the higher parts of the distribution the more desirable situation is that of the 1961 distribution. So, using GLC complements significantly the information contained in Lorenz Curves.

To summarize, which year exhibits a more desirable situation depends on which part of the distribution is considered more relevant - this necessarily involves value judgements (Atkinson, 1970; Cowell, 2011; Shorrocks and Foster, 1987). Here, inequality indices show their true worth by ranking distributions unambiguously, based on the imposition of specific value judgements. Indeed, one of this paper’s aims is actually to argue that such unavoidable value judgements should be explicit and in line with the problem being analysed, rather than there being an arbitrary selection of index.

Figure 1: Second Order stochastic dominance between 1961 and 2007 using Lorenz Curves and Generalized Lorenz Curves (GLC).

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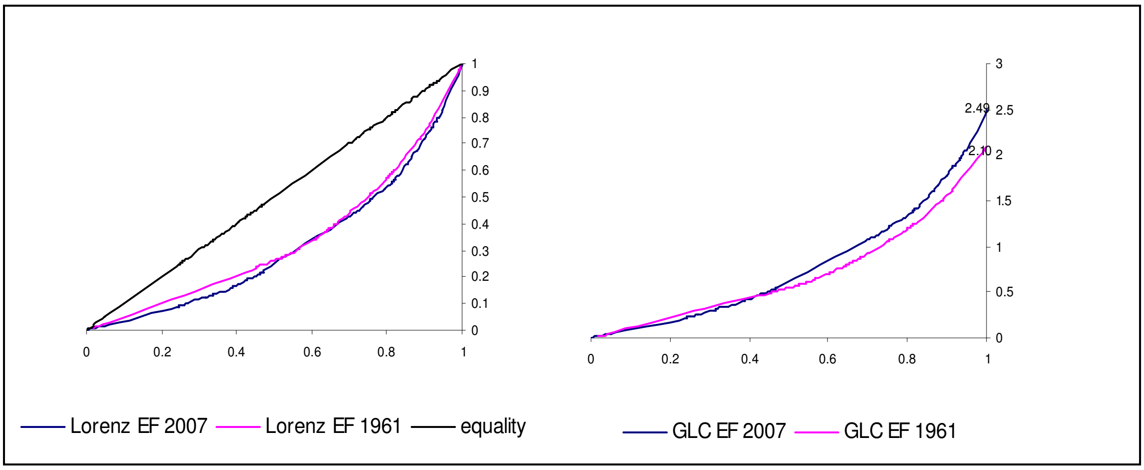
[9] While the Lorenz curve consists in ordering by accumulated EF share, the GLC orders by accumulated EF.



Note: The Lorenz Curves intersect at 0.581, 0.635, and 0.99. GLC intersect at 0.423.
Source: created by the present authors.

3.2 Inequality measurement: Indices

The literature on the measurement of inequality has identified three basic properties which any inequality index should satisfy: scale independence, the population principle and the Pigou-Dalton Principle of transfers[10]. Most of the more common inequality indices do satisfy such basic properties. Consequently, empirical analyses on ecological inequalities usually employ the inequality indices commonly used in the income literature; the Gini index (Heil and Wodon, 1997; Heil and Wodon, 2000; Wu and Xu, 2010; Steinberger et al., 2010), the Theil family index (Alcantara and Duro, 2004; Duro and Padilla, 2006; Duro et al., 2010) or the Atkinson index (White, 2007; Hedenus and Azar, 2005). In addition, it is also useful that the decomposability axiom be satisfied in order to disentangle the main contributions to the Total inequality (see Section 4). Authors take advantage of the properties of such indices in order to unambiguously analyse inequalities in environmental impact indicators.

Nonetheless, these indices were built axiomatically based on several assumptions which fit well for the measurement of income inequality, but which do not necessarily fit so well for ecological variables. In line with this, it is worth considering a remarkable property which usually is present in many inequality indices: the Diminishing Transfer Principle (Kolm, 1976). In the income framework, the society will value more "positively" a concrete increase of income for a poor individual than for a rich one[11] (i.e. inequality index will decrease more when there is a fixed transfer to a relatively poor individual than when the same transfer is made to a relatively richer person). This rationale does not make such sense when, for example, that

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[10] Three basic properties (Goerlich, 1998): scale-independence: the inequality measure remains unaltered by changes of the same proportion in all the observations. Population independence: the inequality index remains unchanged with replications of the population. Pigou-Dalton principle of transfers: any transfer from an observation (country) with a high level of a variable to an observation (country) at a lower level (which does not invert the relative rankings) should reduce the value of the inequality index.

[11] The reason will be found in the concavity of the implicit Social Welfare Function

transfer is in terms of pollution! Hence, the particular sensitivity of the different indices to the location where distributive changes take place must be taken into account when environmental outcomes are being analysed.

Table 1. Summary of inequality indices considered and their characteristics

Index	Formula	Basic axioms	Decomposability	Transfer-Sensitivity
Variance	$\sigma_\omega^2 = p_i \sum_{i=1} (y_i - \mu)^2$	No	Yes	Neutral
Gini	$G = \frac{1}{2\mu} \sum_i \sum_j p_i p_j \lvert y_i - y_j \rvert$	Yes	No	On the mode
CV^2	$CV_\omega^2 = \frac{\sigma_\omega^2}{\mu^2}$	Yes	Yes	Neutral.
A(ε)	$A(\varepsilon) = 1 - \left[\sum_i p_i \left(\frac{y_i}{\mu} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}$	Yes	No	Bottom of distribution (*ε>0)*
GE(0)	$GE(0) = \sum_i p_i \log\left(\frac{\mu}{y_i} \right)$	Yes	Yes	Bottom of distribution
GE(1)	$GE(1) = \sum_i p_i \left(\frac{y_i}{\mu} \right) \log\left(\frac{y_i}{\mu} \right)$	Yes	Yes	Bottom of distribution
GE(2)	$GE(2) = \frac{1}{2} \sum_i p_i \left[\left(\frac{y_i}{\mu} \right)^2 - 1 \right]$	Yes	Yes	Neutral

Notes: p_i is the population share of country *i*, y_i is the per capita variable of interest, μ is the mean of the variable of interest and ε is the inequality aversion parameter.

Source: Present authors.

The Gini Index, though not explicitly defined, has more sensitivity to transfers occurring close to the distribution mode. *GE* indices (when *β<2*) have more sensitivity to the low part of the distribution. The inequality aversion parameter, *ε*, in Atkinson indices also weights the low parts of the distributions more (as long as ε>0)[12]. On the other hand, weighting the top of the distribution more is not really suited to environmental analysis. Therefore, as Duro (2012a) proposes, neutral measures (i.e. a fixed transfer is weighted identically independently of where it occurs) become more appealing choices when there is no obligation to favour any particular part of the distribution. These are *GE(2)* and its cardinal equivalents such as *CV*^{2} [13].

Choosing neutral indices, however, is not free of empirical implications. Figure 2 shows the evolution of inequality in the course of the period analysed according to different well known indices[14]. Despite all them sharing a similar pattern, it is remarkable that the significant

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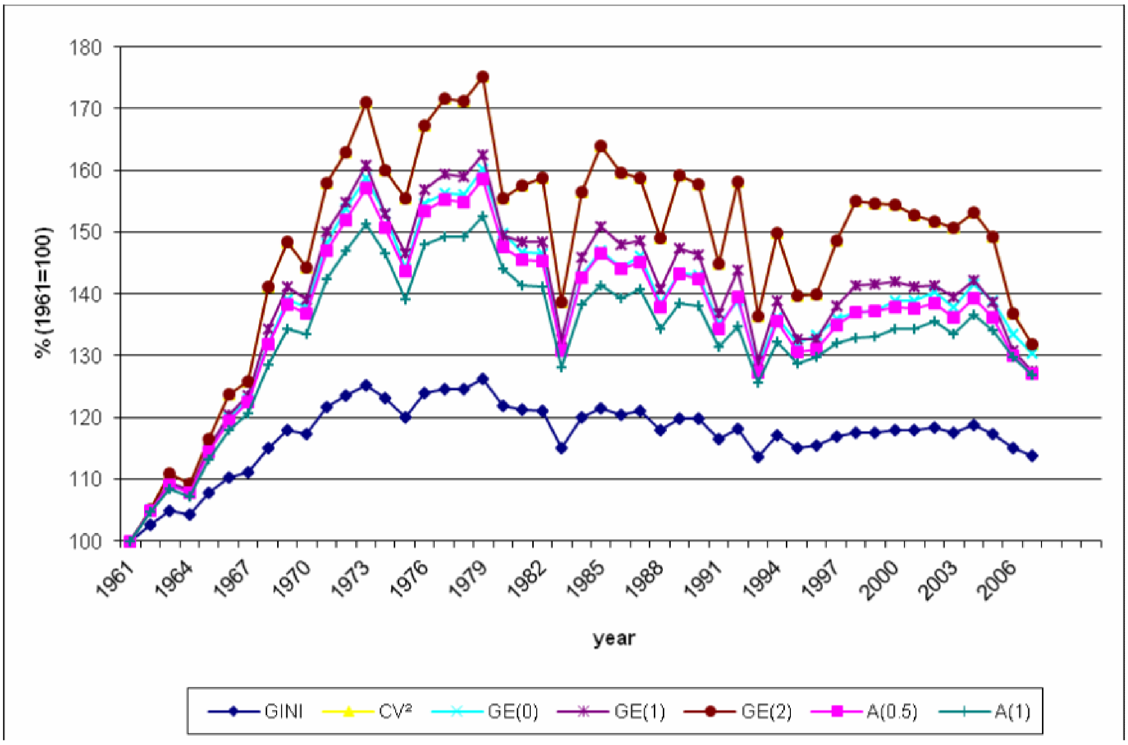
[12] When $\beta \to -\infty$ or $\varepsilon \to \infty$ the distribution tends to be assessed according to Rawls, only the lowest observation mattering

[13] $GE(2) = \frac{1}{2} CV^2$ (Goerlich, 1998)

[14] See Annex, Table A2, forthe inequality indices.

differences in growth rates observed depend on the index used. Firstly, the Gini index is considerably more stable than the other indices. The main reason for such behaviour must be attributed to the distribution mode preference of the Gini index. *GE(0)* favours the low part of the distribution - as does *GE(1)* - while *GE(2)* and CV^2 are neutral indices[15]. Moreover, a detailed observation of Figure 2 will show that, in some periods, the indices even indicate different signs for the inequality trend: in the period 1980-82 neutral indices (CV^2-*GE(2)*) show a clear increase in observed inequality whereas *GE(0)*, *GE(1)* and Gini show a slim decrease. In contrast, during the periods 1986-87 and 1998-2000, a reduction in inequality is shown by neutral indices whereas the Gini, Theil (i.e. GE(0) and GE(1)) and Atkinson indices indicate an increase in the observed inequality.

Figure 2. Inequality trends in EF according to the main inequality indices (1961 – 2007)



Note: 1961=100 for all indices

Source: Present Authors.

As a result, the inequality trend in EF displays a quite stable pattern of global growth in the long term when we consider the whole period (from 1961 to 2007). Nonetheless, it is worth noting some particular episodes: during the first twenty years of the analysed period, there was a significant increase in the EF inequality. Once the 80s had passed, the inequality shows a tendency toward a slight decrease, this being more noticeable from 2003 onwards. The heavy industrialization of super-populated China in the last decades has had an equalizing effect on the

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[15] The coincidence in rates is due to cardinality equivalence.

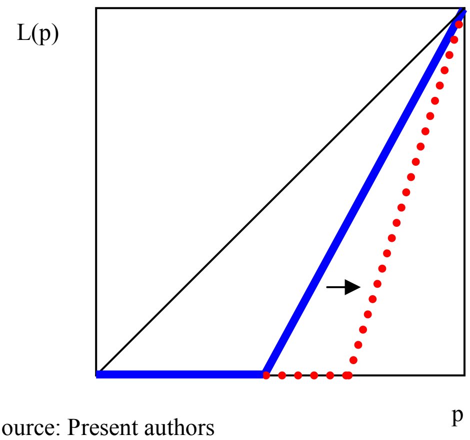
EF distribution[16], India has behaved similarly. However, apparent inequality stability can hide different underlying trends, as will be shown by decomposition techniques.

3.3 Weights and inequality changes

The scale impact of humankind on the environment, here measured by EF, is a function of both growing population and of growing *per capita* consumption. Sustainability is thus not only about accommodating more people, but also about accommodating "larger" people (Catton 1986, Rees, 2000). The analysis of EF inequality consists in measuring differences in *per capita* natural resource consumption weighted by (relative) populations.

Consider a world where there are only two countries, A and B. Country A is the only one responsible for environmental impact on the earth, country B having no environmental impact, since they live in a completely sustainable way. Subsequently, country A continues to have exactly the same environmental impact per capita with a lower relative population (either because of increasing population in country B or because of migration processes). Figure 3 shows that this two-country world has an increase in inequality due to weighting factors even with no change in the impact per capita vector. Similarly, an increase of relative population in country A would involve a reduction of inequality

Figure 3. **Lorenz curves of two-country world with change in relative population**.



Source: Present authors

Thus, although the per capita EF of the average Belgian and the average US citizen are equal, both countries are not weighted equally because of the large difference in their populations[17].

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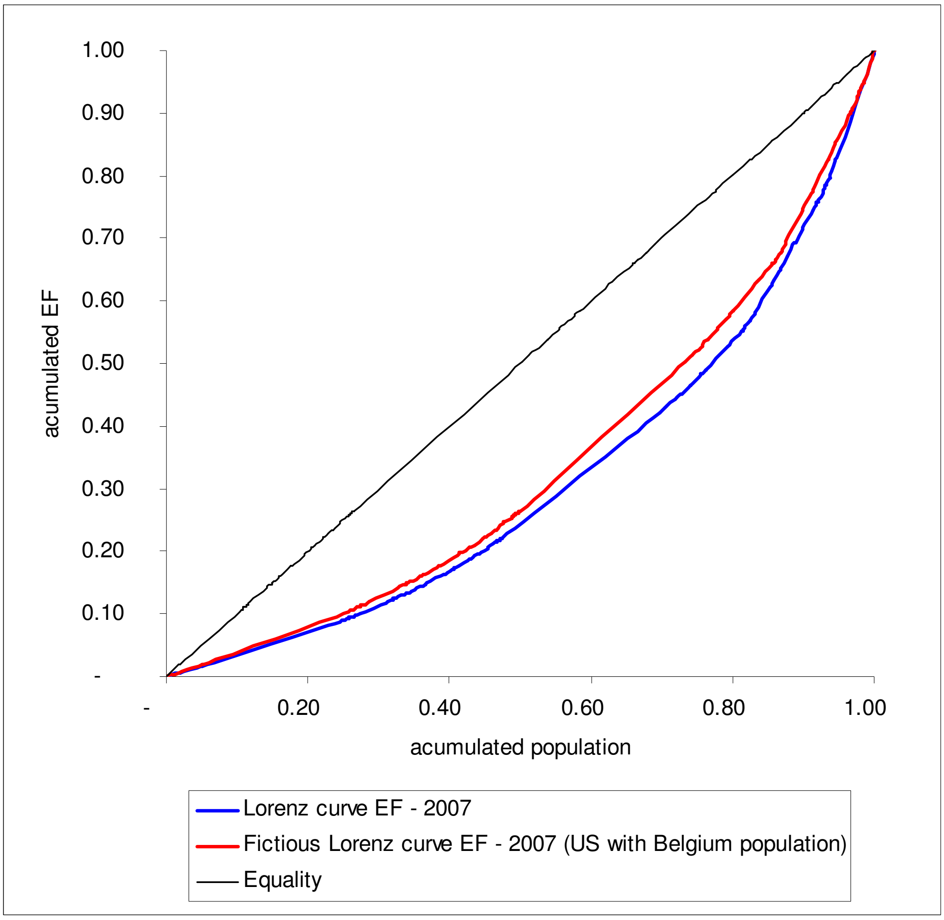
[16] The same analysis as shown in Figure 2 has been performed, excluding China from the sample. These results show an uninterrupted increase in the EF inequality. This is consistent with Duro and Padilla (2006), where the reducing trend in CO2 emissions inequality was found to be less evident without China and India in the sample.

[17] In 2007, the per capita EF of both Belgium and the USA was 8.00, whereas the world population share of each was of 1% and 17% respectively.

However, if the US population decreased until it represented the same share population share as Belgium, the per capita EF inequality would reduce in Lorenz terms[18]; less accumulated population would entail less accumulated EF. We would like to stress in this section that such inequality reduction has occurred without any change in per capita consumption habits of either US or Belgium citizens (see Figure 4).

Figure 4. Comparison of real EF Lorenz curve with a fictitious EF Lorenz curve which assumes the US has Belgium's population share.



Source: Present Authors.

For the Lorenz-based indices we are using, the weight of each country is the relative population[19]. Despite the role such weights may play on inequality measurement, they have not received enough attention in empirical analyses (Duro 2012b). An increase of EF inequality in

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[18] Any Lorenz consistent index will reduce.

[19] In the income literature, the comparisons are made over the so-called "equivalent income" concept, which takes into account different needs among households (such as different personal attributes or different household sizes, etc). So in analyses across countries, those different needs are typically weighted by population. In this sense, weighted measures are more realistic than non-weighted indexes, in so far as population weights avoid the impact on the inequality values attributable to very small observations.

the course of the whole period (as is actually the case), typically will be interpreted as a result of greater differences within the per capita EF vector. Nonetheless, such an increase in inequality may stem from changes in weighting vectors (i.e. the relative population vector).

Consequently, international inequalities on this basis may be attributable not only to changes in per capita environmental impact, but also to changes on the structure of relative weights[20]. In order to capture such a weighting factor role, the EF inequality change can be decomposed in the following way:

$$I(p_{t+1},EF_{t+1})-I(p_t,EF_t)=\{I(p_t,EF_{t+1})-I(p_t,EF_t)\}+\{I(p_{t+1},EF_{t+1})I(p_t,EF_{t+1})\} \qquad (1)$$

where *p* and *EF* are the relative population and per capita *EF* at time *t* and *t+1*, while *I(.)* is a Lorenz-consistent inequality index. The first term of the expression would reflect the change in inequality caused by changes in per capita EF vector, since relative population remains constant. The second term would correspond to the role played by changes in the relative populations, given that the per capita EF vector remains constant. Accordingly, the inequality change can be decomposed by per capita EF share and population share.

Table 2 shows the main results of such a decomposition made over different periods. In general, the main role in inequality change is played by changes in per capita EF vector. For instance, from 1961 to 1971 inequality grew by 58% according to neutral indices. This growth rate was 95% due to changes in per capita EF, while only 5% of it was due to weighting factor changes. Nevertheless, according to the remaining indices whose sensitivities are to specific parts of the distribution, the role played by changes in weights was negative, - this means that such changes (located in low EF countries) contribute significantly to equalizing the distribution. In contrast, when a reduction of EF inequality is observed (see 2001-2007), the changes in relative populations contribute to making the resulting distribution less equal, i.e. the per capita EF vector contributes highly to a more evenly spread distribution, whereas the weighting factor contributes marginally to a more unequal distribution.

Despite results suggesting that the main contributor to inequality changes is per capita EF, the weighting factor role must be taken into account since it makes its own contribution to the inequality trend, especially when the whole inequality change is of low magnitude (such as in short periods[21]). In such scenarios, the weighting factor role can drive the bulk of inequality change (for example, 1991-2001).

Table 2. Decomposing International EF inequality changes by population share changes and by per capita EF changes by sub-periods of 10 years

CV2	GE(2)	GINI	GE(0)	GE(1)	A(1)	A(0.5)

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[20] Duro 2012b shows that in in some cases, changes in relative population play a significant role in explaining the inequality change in per capita CO_2 emissions and energy intensities.

[21] See Table A3 in annex

Ineq. Index 1961	0.4436		0.2218		0.3319		0.1792		0.1890		0.1641		0.0888	
Total change 1961-1971	0.2572		0.1286		0.0717		0.0866		0.0945		0.0693		0.0415	
Growth rate	58%		58%		22%		48%		50%		42%		47%	
per c. EF share	0.2433	(95%)	0.1216	(95%)	0.0762	(106%)	0.0946	(109%)	0.0962	(102%)	0.0755	(109%)	0.0437	(105%)
rel.pop. share	0.0139	(5%)	0.0069	(5%)	-0.0045	(-6%)	-0.0080	(-9%)	-0.0016	(-2%)	-0.0061	(-9%)	-0.0022	(-5%)
Ineq. Index 1971	0.7007		0.3504		0.4036		0.2658		0.2836		0.2334		0.1303	
Total change 1971-1981	-0.0017		-0.0009		-0.0010		-0.0028		-0.0031		-0.0022		-0.0015	
Growth rate	0%		0%		0%		-1%		-1%		-1%		-1%	
per c. EF share	-0.0115	(667%)	-0.0058	(667%)	0.0037	(-376%)	0.0053	(-189%)	-0.0004	(12%)	0.0040	(-188%)	0.0010	(-68%)
rel.pop. share	0.0098	(-567%)	0.0049	(-567%)	-0.0046	(476%)	-0.0081	(289%)	-0.0028	(88%)	-0.0062	(288%)	-0.0025	(168%)
Ineq. Index 1981	0.6990		0.3495		0.4026		0.2630		0.2804		0.2313		0.1288	
Total change 1981-1991	-0.0559		-0.0279	(-8%)	-0.0157		-0.0207		-0.0217		-0.0161		-0.0098	
Growth rate	-8%		-8%		-4%		-8%		-8%		-7%		-8%	
per c. EF share	-0.0675	(121%)	-0.0337	(121%)	-0.0122	(78%)	-0.0149	(72%)	-0.0206	(95%)	-0.0115	(72%)	-0.0081	(83%)
rel.pop. share	0.0116	(-21%)	0.0058	(-21%)	-0.0035	(22%)	-0.0058	(28%)	-0.0011	(5%)	-0.0045	(28%)	-0.0017	(17%)
Ineq. index 1991	0.6431		0.3216		0.3869		0.2423		0.2588		0.2152		0.1191	
Total change 1991-2001	0.0344		0.0172		0.0045		0.0068		0.0081		0.0053		0.0032	
Growth rate	5%		5%		1%		3%		3%		2%		3%	
per c. EF share	0.0151	(44%)	0.0075	(44%)	0.0037	(82%)	0.0065	(96%)	0.0048	(59%)	0.0051	(96%)	0.0024	(75%)
rel.pop. share	0.0193	(56%)	0.0097	(56%)	0.0008	(18%)	0.0002	(4%)	0.0033	(41%)	0.0002	(4%)	0.0008	(25%)
Ineq. Index 2001	0.6775		0.3388		0.3914		0.2491		0.2669		0.2205		0.1223	
Total change 2001-2007	-0.0925		-0.0463		-0.0139		-0.0155		-0.0259		-0.0122		-0.0095	
Growth rate	-14%		-14%		-4%		-6%		-10%		-6%		-8%	
per c. EF share	-0.1038	(112%)	-0.0519	(112%)	-0.0157	(113%)	-0.0170	(109%)	-0.0289	(111%)	-0.0133	(109%)	-0.0105	(110%)
rel.pop. share	0.0113	(-12%)	0.0056	(-12%)	0.0018	(-13%)	0.0014	(-9%)	0.0029	(-11%)	0.0011	(-9%)	0.0010	(-10%)
Ineq. Index 2007	0.5850		0.2925		0.3775		0.2335		0.2410		0.2083		0.1128	

Source: Present Authors.

Consequently, the international inequality in per capita EF can be a consequence not only of changing (growing) per capita EF, but also of changing (growing) population. Nonetheless, the analysis indicates that the EF inequality trend observed is mainly attributable to the per capita EF vector rather than to the relative population vector. This means that the resulting EF inequality derives from differences in the “ecological size” of the average citizen in different countries, rather than from the world population structure.

4. Additive Decomposition analyses

Additive decomposition analysis turns to be a very useful in measuring and understanding the level, causes and development of observed inequalities – topics of considerable current interest. Decomposing an index consists of determining which part of the total inequality observed is attributable to each of its components - such information may be critical for policy making. However, a necessary condition for doing this is the satisfaction of an extra property: decomposability (Bourguignon, 1979; Cowell, 2000; 2011). This property implies that there should be a coherent relationship between the whole inequality observed and its constituent parts. Such a property additionally restricts the available inequality indices to a concrete family: Generalized Entropy indices or some cardinally-equivalent transformation. There are two classic ways of additively decomposing the global inequality: subgroup decomposition and source decomposition[22].

4.1 Subgroup decomposition

This consists in determining the contribution to the total inequality of each of the different mutually exclusive subgroups in the population. Here, the inequality can be expressed as the sum of the inequality *between* groups and the weighted inequality *within* those groups. The *between* component is the inequality which would exist if each member of the group had the average EF of that group. On the hand, the *within* component consists of the inequality which would be observed if the inequality between groups did not exist, so that the *within* inequality is the existing inequality in each group weighted by the population or pollution share. It takes the form

$$I = \sum_{g}^{G} \omega_g I_g + I_0 \tag{2}$$

where $\omega_g = \omega_g(p_g, y_g)$, $g=1,G$, are the weights for each *within* inequality, p_g and y_g being the relative population and the relative EF, respectively. Translating that expression to GE indices, we obtain (Shorrocks, 1980, 1984):

$$GE(\beta) = \sum_{g}^{G} \omega_g GE_g(\beta) + GE_0(\beta) \tag{3}$$

where $\omega_g = p_g^{1-\beta} y_g^{\beta}$. So, only for $\beta = 1$ or $\beta = 0$ (Theil indices) may the weights be read as population proportions ($\beta = 0$) or EF proportions ($\beta = 1$). The case for $\beta \neq 0, 1$ leads to a problem of interpretation since the weights are a non-linear combination of population and pollution shares, and those weights do not add to one. Furthermore, given that the decomposition for $\beta = 1$ corresponds to weighting observations by relative EF instead of by relative population, it is important to keep in mind that conceptually, the *between* inequality as defined above would involve transfers among observations, which could also lead to interpretation problems. For that

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[22] Despite existing different techniques being available in the literature, this paper will use the analytical decomposition approach (Bourguignon, 1979; F. A. Cowell, 1980; A. F. Shorrocks, 1980; A. F. Shorrocks, 1982) and the Shaply value decomposition (Sastre & Trannoy, 2002; A. F. Shorrocks, 1999). Regression-based decomposition is becoming popular as a useful tool for decomposing the inequality - however it can decompose inequality by explanatory factors defined as is common in regressions, so that it requires more and different data and, hence, is beyond of the scope of this paper (see F. A. Cowell & Fiorio, 2009; Fields, 2003; Morduch & Sicular, 2002). A wide-ranging review of inequality decompositions may be found in (Heshmati, 2004)

reason, the Theil measure with *β =0* is the most unambiguous solution (see Goerlich, 1998; Shorrocks, 1980)

Subgroup decomposition has been performed using exogenous groups of countries such as those defined by the World Bank[23]. Table 3 illustrates this decomposition using three GE indices. The main result is that the bulk of the inequality during the analysed period is largely explained by the *between* inequality component (between 83%-88% according to *GE(0)*). Therefore, it could be said that the inequality in EF would be drastically reduced if differences among groups were eliminated, or equivalently, that if the inequality *within* groups were null, there would be no significant reduction in global inequality. Such an empirical finding has important policy implications in terms of achieving international agreements. In the light of these results, the probability of achieving broader and deeper consensus would increase if, instead of holding international meetings where all countries participate, the framework were in regional terms such as those defined by World Bank groups (assuming there are no other political issues on the table within these regions). This is because inequality within these groups is not so marked.

It is also worthwhile analysing the very evolution of these *between* (*within*) differences. Looking in in more detail at the subgroup decomposition of *GE(0)* (Table 3, left), we see that the between-group component displays an inverted U-shape in the course of the period: in 1961 it accounted for 83% of the EF inequality. This *between* factor grows to 88% in 1972 and stays around 86-87% until the beginning of the 90s - it then shrinks to 81% of the overall inequality in 2007. On the other hand, also in Table 3 (middle and right), there are the same subgroup decompositions for both *GE(1)* and the neutral index *GE(2)*. The *Between* component of *GE(1)* shows a similar tendency as that described for *GE(0)*, although it exhibits some differences which may be explained, on the one hand, by a sensitivity to different parts of the distribution and, on the other, to different weights for countries. *GE(1)*, as described above, corresponds to weight contributions by EF where *GE(0)* does this by population. In contrast, *GE(2)* cannot be interpreted in this manner, it is a neutral index. The *Between* component of *GE(2)* shows a more drastic increase in its contribution to the overall EF inequality: from 73% in 1961 to 86% to 1991, after which there is a slight reduction to 81% by 2007. Despite the differences in the groups used to decompose inequality in other studies which also use different indicators, the pattern observed in the between-component (and inversely in the within-component) usually shows drastic decreasing for either CO_2 emissions (Duro and Padilla 2006; Padilla and Serrano 2006) or energy intensities (Alcantara and Duro 2004).

Table 3. Decomposition by country subgroups using World Bank geographical groups. T(0), T(1) and GE(2).

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[23] World Bank groups are: East-Asia and Pacific, Europe and Central Asia, South Asia, Industrial countries, Latin America and the Caribbean, Middle East and North Africa, and Sub-Saharan Africa.

	Between I. GE(0)					Between I. GE(1)					Between I. GE(2)				
year	Within I.	**%**	Between I.	%	T(0)	Within I.	**%**	Between I.	%	T(1)	Within I.	**%**	Between I.	%	T(2)
1961	0.0305	17%	0.1487	83%	0.1792	0.0386	20%	0.1505	80%	0.1891	0.0599	27%	0.1619	73%	0.2218
1962	0.0301	16%	0.1581	84%	0.1883	0.0377	19%	0.1607	81%	0.1984	0.0586	25%	0.1746	75%	0.2331
1963	0.0300	15%	0.1659	85%	0.1959	0.0386	19%	0.1685	81%	0.2070	0.0622	25%	0.1836	75%	0.2458
1964	0.0299	15%	0.1635	85%	0.1934	0.0380	19%	0.1668	81%	0.2048	0.0602	25%	0.1824	75%	0.2425
1965	0.0301	15%	0.1757	85%	0.2058	0.0380	17%	0.1796	83%	0.2176	0.0605	23%	0.1981	77%	0.2586
1966	0.0318	15%	0.1833	85%	0.2151	0.0401	18%	0.1876	82%	0.2277	0.0660	24%	0.2082	76%	0.2743
1967	0.0298	14%	0.1907	86%	0.2205	0.0374	16%	0.1961	84%	0.2335	0.0599	21%	0.2192	79%	0.2791
1968	0.0316	13%	0.2051	87%	0.2368	0.0416	16%	0.2125	84%	0.2541	0.0721	23%	0.2408	77%	0.3129
1969	0.0338	14%	0.2153	86%	0.2491	0.0430	16%	0.2238	84%	0.2668	0.0735	22%	0.2557	78%	0.3291
1970	0.0312	13%	0.2158	87%	0.2470	0.0374	14%	0.2256	86%	0.2629	0.0604	19%	0.2595	81%	0.3199
1971	0.0344	13%	0.2314	87%	0.2658	0.0423	15%	0.2413	85%	0.2836	0.0715	20%	0.2789	80%	0.3504
1972	0.0340	12%	0.2415	88%	0.2755	0.0408	14%	0.2520	86%	0.2928	0.0684	19%	0.2929	81%	0.3613
1973	0.0358	13%	0.2489	87%	0.2847	0.0421	14%	0.2621	86%	0.3041	0.0707	19%	0.3085	81%	0.3792
1974	0.0341	12%	0.2401	88%	0.2742	0.0395	14%	0.2498	86%	0.2893	0.0650	18%	0.2898	82%	0.3548
1975	0.0346	13%	0.2234	87%	0.2581	0.0422	15%	0.2349	85%	0.2771	0.0715	21%	0.2731	79%	0.3446
1976	0.0366	13%	0.2405	87%	0.2771	0.0437	15%	0.2531	85%	0.2968	0.0743	20%	0.2969	80%	0.3712
1977	0.0361	13%	0.2438	87%	0.2800	0.0438	15%	0.2577	85%	0.3015	0.0761	20%	0.3044	80%	0.3805
1978	0.0381	14%	0.2417	86%	0.2798	0.0453	15%	0.2553	85%	0.3006	0.0776	20%	0.3020	80%	0.3796
1979	0.0376	13%	0.2497	87%	0.2873	0.0440	14%	0.2634	86%	0.3074	0.0756	19%	0.3130	81%	0.3886
1980	0.0343	13%	0.2342	87%	0.2685	0.0374	13%	0.2450	87%	0.2825	0.0580	17%	0.2868	83%	0.3448
1981	0.0374	14%	0.2255	86%	0.2630	0.0437	16%	0.2368	84%	0.2805	0.0722	21%	0.2773	79%	0.3495
1982	0.0374	14%	0.2252	86%	0.2626	0.0442	16%	0.2363	84%	0.2805	0.0747	21%	0.2775	79%	0.3523
1983	0.0342	15%	0.2006	85%	0.2348	0.0379	15%	0.2129	85%	0.2508	0.0577	19%	0.2500	81%	0.3078
1984	0.0369	14%	0.2195	86%	0.2564	0.0424	15%	0.2336	85%	0.2760	0.0695	20%	0.2779	80%	0.3473
1985	0.0363	14%	0.2269	86%	0.2632	0.0427	15%	0.2425	85%	0.2852	0.0727	20%	0.2912	80%	0.3639
1986	0.0338	13%	0.2248	87%	0.2586	0.0390	14%	0.2406	86%	0.2797	0.0650	18%	0.2891	82%	0.3541
1987	0.0340	13%	0.2280	87%	0.2619	0.0370	13%	0.2439	87%	0.2808	0.0587	17%	0.2936	83%	0.3524
1988	0.0338	14%	0.2146	86%	0.2483	0.0345	13%	0.2317	87%	0.2662	0.0506	15%	0.2801	85%	0.3307
1989	0.0349	14%	0.2221	86%	0.2570	0.0366	13%	0.2422	87%	0.2787	0.0563	16%	0.2967	84%	0.3531
1990	0.0338	13%	0.2225	87%	0.2564	0.0340	12%	0.2427	88%	0.2767	0.0511	15%	0.2988	85%	0.3499
1991	0.0348	14%	0.2075	86%	0.2423	0.0334	13%	0.2253	87%	0.2588	0.0466	14%	0.2750	86%	0.3215
1992	0.0362	15%	0.2128	85%	0.2490	0.0377	14%	0.2342	86%	0.2720	0.0603	17%	0.2902	83%	0.3506
1993	0.0366	16%	0.1934	84%	0.2300	0.0361	15%	0.2080	85%	0.2441	0.0512	17%	0.2514	83%	0.3026
1994	0.0394	16%	0.2048	84%	0.2442	0.0398	15%	0.2227	85%	0.2625	0.0589	18%	0.2733	82%	0.3322
1995	0.0382	16%	0.1986	84%	0.2368	0.0368	15%	0.2139	85%	0.2506	0.0499	16%	0.2600	84%	0.3099
1996	0.0402	17%	0.1988	83%	0.2389	0.0392	16%	0.2116	84%	0.2508	0.0550	18%	0.2552	82%	0.3103
1997	0.0402	16%	0.2036	84%	0.2438	0.0406	16%	0.2204	84%	0.2610	0.0597	18%	0.2702	82%	0.3298
1998	0.0347	14%	0.2108	86%	0.2455	0.0361	13%	0.2312	87%	0.2672	0.0568	17%	0.2872	83%	0.3440
1999	0.0387	16%	0.2072	84%	0.2459	0.0403	15%	0.2273	85%	0.2677	0.0608	18%	0.2823	82%	0.3431
2000	0.0372	15%	0.2116	85%	0.2488	0.0375	14%	0.2308	86%	0.2684	0.0560	16%	0.2866	84%	0.3427
2001	0.0393	16%	0.2097	84%	0.2490	0.0392	15%	0.2278	85%	0.2670	0.0569	17%	0.2819	83%	0.3388
2002	0.0396	16%	0.2118	84%	0.2514	0.0391	15%	0.2282	85%	0.2673	0.0558	17%	0.2810	83%	0.3368
2003	0.0399	16%	0.2073	84%	0.2472	0.0398	15%	0.2241	85%	0.2639	0.0582	17%	0.2763	83%	0.3345
2004	0.0412	16%	0.2126	84%	0.2539	0.0409	15%	0.2279	85%	0.2688	0.0598	18%	0.2801	82%	0.3399
2005	0.0412	17%	0.2077	83%	0.2489	0.0409	16%	0.2214	84%	0.2623	0.0600	18%	0.2709	82%	0.3309
2006	0.0446	19%	0.1949	81%	0.2394	0.0425	17%	0.2049	83%	0.2474	0.0573	19%	0.2460	81%	0.3034
2007	0.0440	19%	0.1896	81%	0.2336	0.0423	18%	0.1986	82%	0.2409	0.0555	19%	0.2369	81%	0.2925

Source: Present Authors.

We have discussed the fact that GE(2) is the inequality index which, because of its neutrality property, is in best accord with this paper's aim. However, we have also shown that the best choice for decomposing such an inequality by subgroups is GE(0). Hence, we must be careful and consider the minutiae of each index when interpreting any results obtained by subgroup decomposition. Nevertheless, as far as our empirical results are concerned, the three subgroup decompositions performed by EF are quite close and, since they point to the same conclusion, this makes this conclusion quite robust.

4.2 The source decomposition

Source decomposition aims to quantify how much EF inequality can be attributed to different EF components – this may have deep policy implications for the achievement of equity.

However, the contribution of a component to the whole inequality can adopt different forms (see Shorrocks, 1982; 1988). It can be stated that the contribution of component *k* to the overall inequality is three-fold, consisting of: the component's inequality, the component's share in whole EF, and the correlation between components.

It may be instructive to begin by considering the inequality of each EF component. Indeed, that may be regarded as a component's contribution to overall EF inequality[24]. Table 4 shows the *GE(2)* for each EF component. The Fishing, Forest, and Built footprints show stable trends, with a relatively high inequality for Fishing. On the other hand, the Cropland footprint exhibits a quite stable low inequality trend (a slight reduction); such a low inequality in the Cropland footprint could be indicative of the special status of some biomass consumption from cropland (food and fibre for human consumption), this being necessary for the most basic subsistence (Steinberger et al., 2010). In contrast, the Grazing footprint inequality, despite also registering a reduction in the course of the period, always remains the most unequal distribution as compared to the remaining EF components. The explanation of such a high inequality may be found in the meat-intensive diets of industrialized countries (White, 2000). Finally, the Carbon footprint inequality displays a significant reduction during the period - this is consistent with the findings of Padilla and Serrano (2006), Ezcurra (2007), Heil and Wodon (1997) and Heil and Wodon (2000) who analyse CO_2 emissions inequality[25].

In 1961, the most unequal distributions of footprint were for grazing, followed by carbon and then by fishing. However, by the end of 2007, the ranking shows grazing as still the being the most unequal, but now followed by fishing rather than carbon, which becomes the third most unequal distribution. Hence, the most unequal distributions, and thus the main contributors to EF inequality, according to this relatively simplistic interpretation, are diet-related issues followed by a decreasing energy-related issue.

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[24] It is a common practice in the empirical literature to use each component's inequality as a contribution to the overall inequality (see Shorrocks 1988). Actually, Steinberger et al. (2010) analysed international inequality in Domestic Material Consumption and the inequality of its components (biomass DMC, construction minerals DMC, ores/industrial minerals DMC and fossil fuels DMC). Chen and Ma (2010) analysed international inequality of Ecological Footprint and also the inequality of two aggregated subcomponents: Renewable Resources Footprint and Energy Footprint.

[25] Steineberger et al. (2010) estimated the Gini index of Domestic Material Consumption (DMC) and of its different components (biomass, construction minerals, fossil fuels, ores/industrial minerals) for the year 2000. Despite both indicators sharing raw data, the results obtained are not comparable, since the indicators deal with different research questions and so are constructed differently. EF focuses mainly on biomass consumption. Nevertheless, it is interesting to observe some relatively similar results: the Gini coefficient for total DMC is 0.35 and the Gini coefficient in the same year of EF is 0.39; the Gini coefficient for fossil fuels DMC is 0.58 while the Gini coefficient for Carbon Footprint for our data is 0.576. Additionally, if the Cropland, forest, grazing, and fishing footprints are added together in order to construct a "pure biomass footprint", the resulting Gini coefficient for 2000 would be 0.300, very close to the 0.29 Gini for Biomass Material Consumption of the Steinberger et al. paper. Therefore, our analysis is in line with that of Steinberger et al. 2010, while adding new which are compatible. Our calculations are available on request.

Table 4. GE(2) for per capita EF components, 1961-2007

Year	Fishing	Cropland	Grazing	Forest	Carbon	Built
1961	0.9997	0.1465	1.7905	0.4863	1.4592	0.1803
1962	1.0482	0.1455	1.8151	0.4861	1.4503	0.1813
1963	1.0365	0.1517	1.7664	0.4707	1.4120	0.1691
1964	0.9558	0.1271	1.7351	0.4788	1.4383	0.1732
1965	1.0003	0.1332	1.7172	0.4824	1.4194	0.1608
1966	0.9738	0.1281	1.6214	0.4694	1.4166	0.1555
1967	1.0892	0.1361	1.6404	0.4541	1.4707	0.1793
1968	1.0377	0.1484	1.6601	0.4513	1.4596	0.1638
1969	0.9912	0.1555	1.7041	0.4561	1.4028	0.1569
1970	1.0205	0.1230	1.7050	0.4530	1.2936	0.1519
1971	1.0003	0.1577	1.7919	0.4884	1.2702	0.1591
1972	1.0469	0.1620	1.8830	0.4456	1.2940	0.1688
1973	0.9507	0.1424	1.8276	0.4891	1.2770	0.1591
1974	0.9328	0.1347	2.0625	0.4710	1.2573	0.1614
1975	0.8952	0.1477	2.2071	0.4490	1.1857	0.1502
1976	1.0011	0.1535	1.9760	0.4545	1.2014	0.1323
1977	0.9650	0.1664	1.8776	0.4511	1.2101	0.1537
1978	0.8711	0.1532	1.7607	0.4892	1.1715	0.1519
1979	0.8311	0.1640	1.6985	0.5048	1.1442	0.1633
1980	0.9751	0.1607	1.7188	0.4645	1.0931	0.1663
1981	0.9443	0.1528	1.6555	0.4549	1.0860	0.1650
1982	1.0136	0.2665	1.6433	0.4050	1.0384	0.1744
1983	0.9520	0.1437	1.5238	0.4589	1.0392	0.1536
1984	0.9053	0.1563	1.6245	0.4975	1.0521	0.1844
1985	1.1217	0.1746	1.7650	0.4983	1.0373	0.1635
1986	1.1034	0.1613	1.7775	0.5277	1.0233	0.1567
1987	1.1545	0.1490	1.6340	0.5483	1.0416	0.1616
1988	1.1171	0.1434	1.4993	0.5433	0.9940	0.1582
1989	1.1301	0.1309	1.5891	0.5482	0.9808	0.1574
1990	0.9568	0.1404	1.6072	0.5124	0.9509	0.1388
1991	0.9772	0.1369	1.6033	0.4501	0.9130	0.1603
1992	0.9724	0.1391	1.4900	0.4625	1.0062	0.1547
1993	0.9185	0.1245	1.5145	0.4706	0.8252	0.1482
1994	0.8977	0.1372	1.4504	0.4802	0.8704	0.1434
1995	0.9848	0.1233	1.3874	0.4910	0.8231	0.1537
1996	0.9024	0.1136	1.4505	0.4583	0.7598	0.1565
1997	0.9457	0.1038	1.3730	0.4763	0.8239	0.1576
1998	0.8736	0.1096	1.3955	0.4966	0.8851	0.1624
1999	0.9780	0.1075	1.3522	0.4823	0.8832	0.1708
2000	0.9780	0.1061	1.3414	0.4958	0.8561	0.1664
2001	1.0859	0.1063	1.3608	0.4773	0.8445	0.1574
2002	0.9842	0.1165	1.3106	0.4970	0.8656	0.1813
2003	0.9323	0.1204	1.3039	0.4815	0.8050	0.1405
2004	0.9191	0.1265	1.2927	0.5010	0.7752	0.1529
2005	0.8226	0.1161	1.2583	0.5585	0.7321	0.1405
2006	0.7943	0.1040	1.1924	0.4729	0.6824	0.1302
2007	0.7820	0.1060	1.2286	0.4592	0.6199	0.1296

Source: Present Authors.

The component's inequality does not take into account the weight of each component in the EF, so, despite providing critical information, this approach does not distinguish the relative importance of having a high inequality in a component which accounts for 99% share of EF versus having a high inequality in the component which accounts for 1% share of EF. Hence, the second issue which must be considered in accounting for component's *k* contribution is its weight (importance) in the EF. Along these lines, any contribution to inequality consists of a weighted inequality index of each component.

By definition, EF can be broken down into the sum of its components, i.e.

$$EF_i = \sum_{k=1}^{K} C_{ki} \ , \tag{4}$$

where subindex *k* indicates each EF Component (cropland, grazing land, fishing ground, forest land, carbon land, built-up land) and subindex *i* indicates country. The idea behind the weighted source decomposition is thus to break down overall EF inequality into the part for which each EF component is responsible. Therefore, the source decomposition will have the form

$$I(EF) = \sum_{k=1}^{K} S_k = \sum_{k=1}^{K} \lambda_k I(C_k) = \sum_{k=1}^{K} \frac{\mu_k}{\mu} I(C_k) \tag{5}$$

where S_k is the absolute contribution of component C_k to the overall EF inequality which is a function of the component's inequality $I(C_k)$ and its weight (or importance) λ_k in the EF, μ_k and μ being the k^{th} component's mean and EF's mean respectively. If we normalize it by the inequality index, the relative contribution will be obtained, i.e.

$$s_k = \frac{S_k}{I(EF)}, \ \sum_{\mathrm{k}}^{\mathrm{K}} s_k = 1 \tag{6}$$

Such a decomposition of an inequality index has several technical problems which will lead us to consider the role of correlations among components. We illustrate this by the most famous and widely used weighted decomposition, the natural decomposition of Gini index proposed by Fei et al. (1978)[26].

Such decomposition is based on weighting pseudo-Gini indices[27] of the different components. If real Gini indices were used instead to measure a component's inequality, the equality in equation 5 would not hold any more unless the rankings of overall EF and its components happened to coincide, that is to say unless EF and its components were perfectly correlated. This, of course, rarely happens, and so the decomposition would not be consistent[28]. Therefore, the problem with Gini decomposition by sources is the necessity of using pseudo-Ginis to make the source decomposition consistent[29]. However, such an approach makes the contribution of component *k* independent of its own distribution and dependent on the aggregate variable distribution (here EF). This is what a pseudo-Gini actually is. As a result, the source

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[26] White (2007) used this methodology in decomposing EF.

[27] Also known as concentration indices: this is to rank the distribution of the different components according to the ranking performed by the aggregate factor.

[28] Specifically, the sum of the weighted *k* factor inequalities would be greater than the inequality of the aggregate (see Goerlich, 1998, Shorrocks 1982, 1983; Cowell 2000). This result happens because of the correlations among components

[29] The procedure can also be extended to inequality measures other than the Gini coefficient (Shorrocks, 1983).

decomposition turns out to be an uninteresting and trivial exercise. In fact, without further restriction on the decomposition rule, the results obtained are non-unique (Cowell, 2000). Depending on the functional form of the Gini index used, the contribution to the whole inequality turns out to be the component's share to EF λ_k (Goerlich, 1998; Shorrocks, 1983). This is why the literature does not consider Gini to be a decomposable index (see Bourguignon, 1979; Cowell 2000; 2011; Shorrocks, 1982; 1983b).

As a result, the contribution of a component to an overall inequality is not only about its inequality and its weight, but also it is about the correlations among components, the last piece of the source contribution jigsaw. Nonetheless, such correlations are often neglected despite their significance in any empirical results obtained (Duro and Teixidó, 2012).

The correlations involve interaction effects among components; for instance, cropland footprint may be correlated with carbon footprint. Accordingly, the inequality contribution of, say, a cropland footprint would be a combination of its weighted direct effects to the overall EF-inequality and its weighted indirect effects through any other component to the overall inequality. Those indirect effects must be allocated to the different contributions (see Theil, 1979; Goerlich, 1998; Cowell, 2000, 2009; Shorrocks, 1982, 1983b, 1999). In the Gini source decomposition described above, the indirect effects are being assigned implicitly (by ordering components according to EF ranking) and arbitrarily (depending on the functional form of Gini[30]). In contrast, the decomposition of the variance shows clearly what the interaction effects are and also allows an explicit allocation of them:

$$Var_{\omega}(EF) = Var_{\omega}(\sum_{k=1}^{K} C_k) = \sum_{k=1}^{K} \lambda_k Var_{\omega}(C_k) + \sum_{k}^{K} \sum_{j \neq k}^{K} \lambda_k Cov_{\omega}(C_k, C_j) \tag{7}$$

where the contribution of source *k* is a combination of a weighted factor's dispersion (first term) plus its weighted indirect effects (second term). Only when the EF components are uncorrelated, is the second term null (Shorrocks, 1982, Goerlich 1998). Consequently, the results on source contribution will depend on the researcher's decision in allocating those indirect effects, i.e. on the decomposition rule chosen. Following this line of thought, let us consider two simple ways of allocating indirect effects which will also leads us to interpret inequality contributions in different way (Shorrocks, 1982):

a) The pure contribution of component *k* is that where all the indirect effects are removed from its contribution. Then, the contribution of component *k* will be equal to the inequality observed when all the remaining components are evenly distributed: $S_k^a = I(C_k + \mu - \mu_k)$

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[30] See Shorrocks (1983b)

b) All the indirect effects of component k are allocated to its contribution. Now, the contribution of component *k* will be equal to the variation observed in global inequality when component *k* is evenly distributed: $S_k^b = I(EF) - I(EF - C_k + \mu_k)$

These two methods yield different results because of different allocation of a component's indirect effects - this can be seen by using *CV*² as the inequality index:

$$S_k^a(CV^2) = CV_\omega(C_k + \mu - \mu_k)^2 = \lambda_k \frac{Var_\omega(C_k)}{\mu^2} \tag{8}$$

$$S_k^b(CV^2) = CV_\omega(EF)^2 - CV_\omega(EF - C_k + \mu_k)^2 = \frac{\lambda_k Var_\omega(C_k) + 2\sum_{j\neq k} \lambda_k Cov_\omega(C_j, C_k)}{\mu^2} \tag{9}$$

In the absence of further information, it appears that a sensible rule is to apply both approaches equally. Consequently, each component's contribution will be a combination of its weighted direct effect to whole inequality, plus one half of its weighted indirect effects. In doing so, we obtain the "natural decomposition of *CV*²" proposed by Shorrocks (1982):

$$S_k^*(CV^2) = \frac{1}{2}(S_k^a + S_k^b) = \lambda_k \frac{Cov_\omega(C_k, EF)}{\mu^2} \tag{10}$$

Shorrocks (1982) proves that, under some very plausible axioms[31], the natural decomposition of *CV*², is the only unambiguous decomposition method independent of the index used to measure the whole inequality[32]. Thus, if the researcher asserts that the best way to analyse the inequality in his specific topic is, for instance, *A(0.5)*, there is nothing to which one may object. However, as far as source decomposition is concerned, the researcher must use the natural decomposition of *CV*² in order to avoid trivial factor contributions. This result is very opportune in environmental analyses, since *CV*² benefits from the neutrality property defined above.

Although the specialized literature has adopted this decomposition method as the most consistent one for the reasons explained, it is not free from criticism. The interpretation of the contribution of component *k* as its direct effect plus one half of the interaction terms for each *k* factor is not as intuitive as in most of cases (Shorrocks, 1999). One possible solution is to use

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[31] The conditions are: a) the inequality index and the sources are continuous and symmetric. b) The contributions do not depend on the aggregation level. c) The contributions of the factors sum to the global inequality. d) The contribution of source *k* is zero if factor *k* is evenly distributed. e) With two only factors, where one of them is a permutation of the other, the contributions must be equal.

[32] The variance also satisfies the Shorrocks axioms and the same result is obtained in applying the methods outlined above. Actually in the literature this decomposition rule is also known as the 'natural decomposition of the variance'.

the Shapley value decomposition, which has its origins in game theory[33] (Shapley, 1953) and which can be understood as a generalization of the natural decomposition of the CV^2 (Rodriguez-Hernadez, 2004)[34]. This technique implies considering the impact on global inequality of eliminating the inequality in each EF component (i.e. change the real distribution of component k by μ_k to all observations). Since there is no natural order for equalizing each k component, Shapley decomposition averages all these impacts over all possible sequences of component's k inequality elimination[35] (Sastre and Trannoy, 2002). So, the Shapley contribution will be $S_k^{SD} = I(SEF) - I(SEF - \{C_K\} + \mu_k)$ where SEF is a Subset of EF`s components $(SEF \subseteq EF, k \in SEF)$. It takes the form:

$$S_k^{SD}(K,I) = \sum_{\substack{S \subseteq K \\ j \in S}} \frac{(k-sef)!(sef-1)!}{k!}\left[I(SEF) - I(SEF - \{C_k\} + \mu_k)\right] \qquad (11)$$

The main advantages of using Shapley methods are that consistent and unambiguous decompositions can be performed using any inequality index, provided that the method is sensitive to the index chosen (in contrast to the Natural decomposition rule described). The major shortcoming, however, is that the contributions obtained are not independent from the level of disaggregation[36]. The resulting contribution is defined as the expected marginal contribution of the factor k when such an expectation is made over all possible sequences of factor k's inequality elimination.

An interesting theoretical result of the Shapley Value decomposition described is that it yields the same contributions as the Natural decomposition of CV^2 as long as this index is used to measure inequality[37] (Shorrocks 1999). Hence, as far as CV^2 has been stated above as one of the most suitable indices to measure environmental inequalities because of its neutrality and

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[33] The Shapley value is an allocation method which assigns the gains of a player coalition among its members as a function of what they contribute to the coalition, taking into account all possible orders in which players join the coalition

[34] The Shapley value decomposition also takes into account all existing factors in the estimation of the inequality contribution, it is symmetric and consistent, but in contrast to Shorrocks (1982), the Shapley value decomposition is sensitive to the index used. For deeper details see (Araar, 2006; Rodriguez-Hernadez, 2004; Sastre and Trannoy, 2002; Shorrocks, 1999)

[35] Shapley Value Decomposition can also be performed by completely removing the source instead of equalizing it – this is the as Zero Shapley decomposition. However, such an approach assigns negative contributions to evenly distributed factors, which is against the conditions advocated by Shorrocks (1982) as reasonable properties of decomposition rule (see footnote 31). Moreover, Sastre and Trannoy (2002) propose avoiding the Zero Shapley decomposition because it is more volatile due to its higher sensitivity to the aggregation level. For further details see Shorrocks (1999) and Sastre and Trannoy (2002).

[36] Shapley Decomposition does not guarantee that the contributions assigned to the (sub)components of a given source sum up to the inequality contribution of that source.

[37] If the variance is used, the Zero Shapley procedure (see footnote 35) also yields the natural decomposition of CV^2. Any other index used will not yield that result (Shorrocks, 1999)

decomposition properties, this result also allows interpreting the contributions in a marginal way[38].

Thus Figure 5 (Table A4) shows the changes in contribution of EF components during the period, as estimated by the natural CV^2 decomposition. In the first place, the result (in Table A4) shows a clearly growing trend of Carbon footprint contribution to EF inequality, until this becomes the main contributor to the overall inequality. This result is consistent with White (2007) who constructed the natural decomposition of the Gini index for the year 2003. Nonetheless, the White (2007) decomposition allocates indirect effects in an arbitrary and non-explicit way. Fortunately, the results are quite similar on this occasion[39].

If we consider the long term trend (which has not yet been evidenced empirically) it is worth noting the significant growth of the Carbon footprint's contribution to the EF Inequality (from 18% to 69%). In contrast, the Cropland footprint which was originally the main contributor to inequality has reduced its contribution drastically (from 36% to 11%). Grazing and Fishing footprints also follow a shrinking inequality contribution trend (from 20% to 4% in the former and a smaller reduction in the latter, from 7% to 3%).

Figure 5: Relative contributions of EF components estimated by Natural decomposition of CV^2 (1961-2007)

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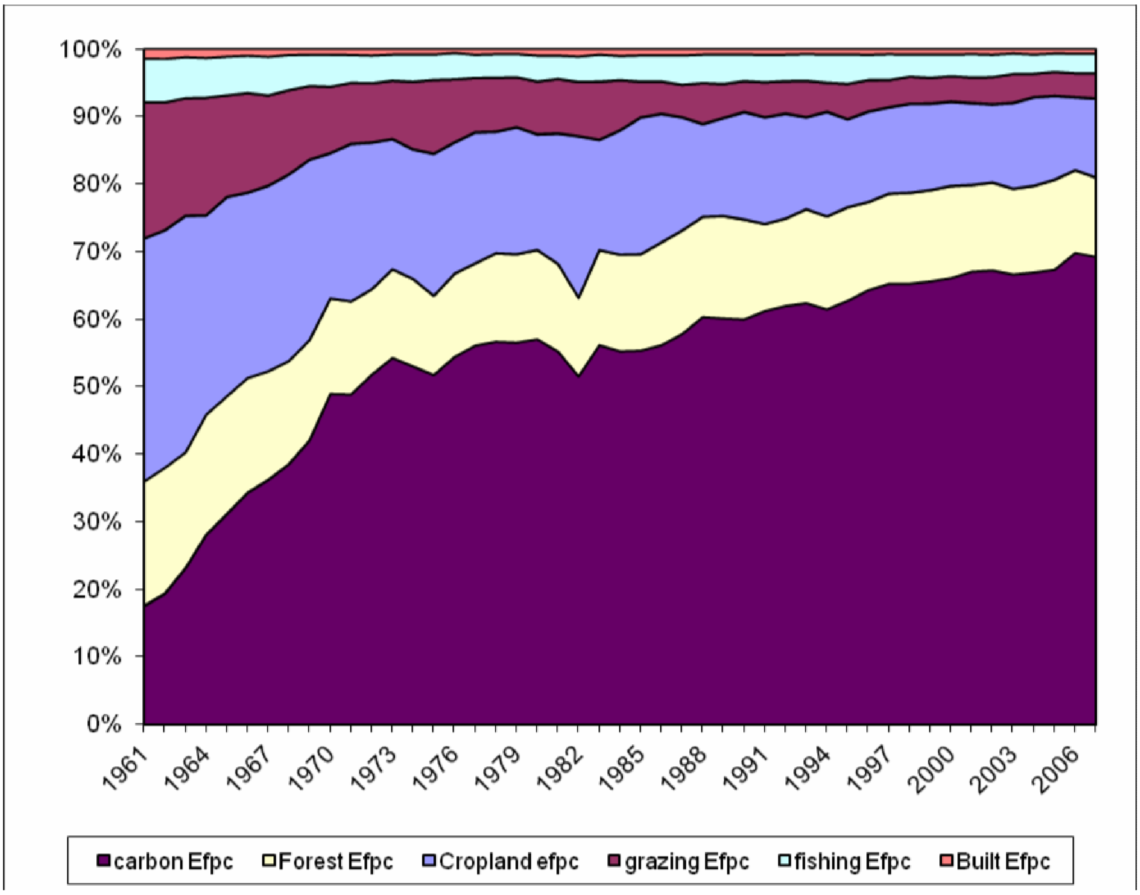
[38] Empirical calculations have been made by two methods, the Shapley rule and the Natural rule and they coincide. Such calculations are available on request.

[39] Araar (2006) discusses, among other issues, the decomposition of Gini index and gives a clue as to why its decomposition can be close to the Shorrocks solution; this is the low-ranking effect.



Note: The contributions can be read according to a Shorrocks (1982) or Shapley value decomposition.
Source: Present Authors.

It is interesting to note that the contributions of a component to the overall EF inequality differ from that component's inequality indices as shown in Table 4. It has been shown that all these inequalities decreased in the course of the period, however, some contributions, have not decreased in the same proportion, the Carbon Footprint contribution has even increased significantly. When the Carbon footprint exhibited the highest inequality (in 1961), its contribution according the Shorrocks rule was 17%, whereas it had become 69% by 2007 when its inequality reached the lowest level in the period. The reason must be sought in the Carbon footprint's share of the whole EF, which passed from representing 11% to representing 53% of the EF (see Table A1 in appendix). Similarly, high inequalities in the Grazing and Fishing footprints are compensated by representing a low share of the overall EF. The Cropland footprint, in contrast, exhibited low and reducing levels of inequality. However, its contribution to overall inequality has not reduced in the same proportion because, in spite of a reducing EF share (from 47% in 1961 to 21% in 2007), it still is the second largest EF share. The reason for this is the strong link Cropland has with the basic needs of humanity.

These results point towards deep policy implications. In the first place, regarding international environment agreements, it could be claimed that policies aimed at reducing the carbon footprint (reduction in energy use) of countries will lead, not only to a more sustainable scale, but also to a more just distribution of EF (White 2007), this may lead on to further international consensus. However, converting cropland to bio-fuel land in order to reduce CO_2 emissions will lead unavoidably to an increase in the Cropland footprint share and in its inequality, which may in turn have serious implications, not only for international agreements, but also for society in general, because of its link to basic human needs.

6. Conclusions

Empirical analyses on ecological asymmetries across countries have become an essential tool for policy makers in order to achieve a just sustainability. This paper has focussed on the analysis of international inequality in natural capital consumption, as measured by the Ecological Footprint framework. Our aim in doing so has been twofold: On the one hand, we revise the methodologies on inequality measurement when they are applied to environmental issues rather than to income. Inequality measurement on environmental issues has been commonly performed by directly borrowing techniques from the income distribution literature. These are Gini indices, Atkinson's family indices, Theil measures, etc. Nonetheless, income is a 'good' while environmental impact is not (it is a 'bad'). As a result, this paper highlights some underlying properties in the traditional inequality measurement methods which might not fit in environmental inequality analyses. On the other hand, we extend the empirical evidence relating to the international distribution of Ecological Footprint (EF) by using a longer EF time series than in previous attempts. We have used a database from 1961 to 2007 for a representative sample of countries whereas the existent evidence was limited to a one year cross section (White 2007), or to five years cross sections covering from 1996 to 2005 (Chen and Ma, 2010). The result is the application and discussion of a wide range of inequality methods to a greater EF database.

As far as methodology is concerned, this paper shows that Lorenz dominance analyses are useful in particular parts of the distribution and that they should be accompanied with GLC dominance, otherwise the Lorenz curves could lead to uncertain statements. For instance, it has been shown that in 1961, the low EF countries enjoyed greater equality than those in 2007, nonetheless, the latter had less EF per capita. So in terms of sustainability, as far as low-EF countries are concerned, it is unclear whether one should prefer the distribution of 1961 to that of 2007. By considering toxic waste exposure instead of EF, we may clarify the underlying idea here. Yet, neither Lorenz curves nor GLC allows a *complete* ranking of distributions because of curve intersections. Inequality indices are then indispensable for doing this in an unambiguous way.

We have critically reviewed some of the properties of inequality indices, taking into account an ecological economics framework. Although there exist different types of inequality indices, and several of them are widely used in ecological inequality measurement (such the Gini coefficient), we have demonstrated that some typical properties of those indices does not fit well when environmental issues, rather than income, are being analysed. For instance, Atkinson's and Theil's indices weights the low parts of the distribution more heavily because of their Diminishing Transfers Principle property. Gini coefficient instead weights the distribution mode more heavily. Neither of these behaviours is justified in environmental inequalities. In this sense, the neutrality character (all parts of distribution being treated equally) of $GE(2)$ or CV^2 has been discussed as a desirable property to being satisfied (jointly with those basic properties). As a result, neutral indices show a quite stable inequality trend in the course of the period in spite of a significant increase in the first decade and a significant reduction in the last years of the period.

Finally, we have dealt with inequality additive decomposition methodologies; by subgroup and by sources (EF components). The inequality subgroup decomposition has been performed using exogenous country groups (World Bank classification). $GE(0)$ exhibits the best properties for this kind of decomposition, however it is a non-neutral index (it weights the bottom of the distribution more heavily). Hence, there is a trade-off between $GE(2)$ neutrality properties and $GE(0)$ decomposition properties. Such a trade-off must be considered when the results are being interpreted. Nonetheless, in the EF application there are no significant differences between the decompositions of both indices, which contributes to making the result obtained more robust: subgroup decomposition by World Bank group of countries indicates that *between* group inequality explains almost the totality of international EF-inequality (83-87%). This result leads to two important conclusions: firstly, there is a heavy international division in natural resource consumption patterns defined by World Bank classification groups, indicating highly homogenous consumption patterns within those groups. This result is in line with Environmental Justice theory which points that certain subgroups historically have borne a disproportionate share of environmental burdens. In our case, this disproportion is in terms of natural capital consumption. Secondly, since the *within* inequality in per capita EF is so relatively low, reaching international environmental agreements (as far as they were based on EF) may be more fruitful for global environment protection if these were to be held on a regional basis (such as those defined by World Bank) instead of World agreements.

Regarding source decomposition, we have noted the inappropriateness of the widely used Gini coefficient decomposition since its resulting contributions are non-unique and the interaction effects are allocated in an implicit and arbitrary way. The only non-ambiguous way of decomposing inequality by sources is the natural decomposition of CV^2, which allows, besides, interpreting contributions in marginal terms. The empirical results point out that, although all EF component inequality has reduced, the contribution to total EF inequality has not necessarily followed the same movement. This is due to changes in components proportions in total EF. For instance, Carbon Footprint's inequality has reduced; nevertheless, its contribution to inequality has increased because of its increasing share of the total EF. In contrast, Grazing and Fishing footprints (related to the diets of industrialized countries) exhibit relatively high levels of international inequality, however, they contribute modestly to overall EF inequality because of its low share of the total EF. The Cropland Footprint contribution to EF inequality has reduced significantly as a result of both having historically low inequality (basic subsistence highly depends on cropland consumption) and having decreased its EF share in the course of the period. This analysis provide important clues for international environmental policies: reducing per capita carbon footprint of countries will lead, not only to a more sustainable scale, but also to a fairer distribution of EF, enabling greater possibilities for international environmental agreements. Nevertheless, if that goal is implemented by converting typical cropland utilities in commercial energy (bio-fuels), this policy will necessarily impact on Cropland Footprint equality and probably its share of total EF will also increase. As a result, the subsistence function of cropland will be seriously threatened.

Environmental inequality measurement has been widely analysed in recent years because of its important implications in terms of universal ethics and environmental policy. Such literature, however, has focussed mainly on narrower environmental indicators such as CO_2 emissions and hardly at all on more multifaceted indicators such EF. Additionally, the methods applied to measure inequality are not always correctly adjusted to suit an ecological economics framework. Therefore, the results and discussions presented here may be of interest to researchers and policy makers concerned with a Fair Sustainability framework.

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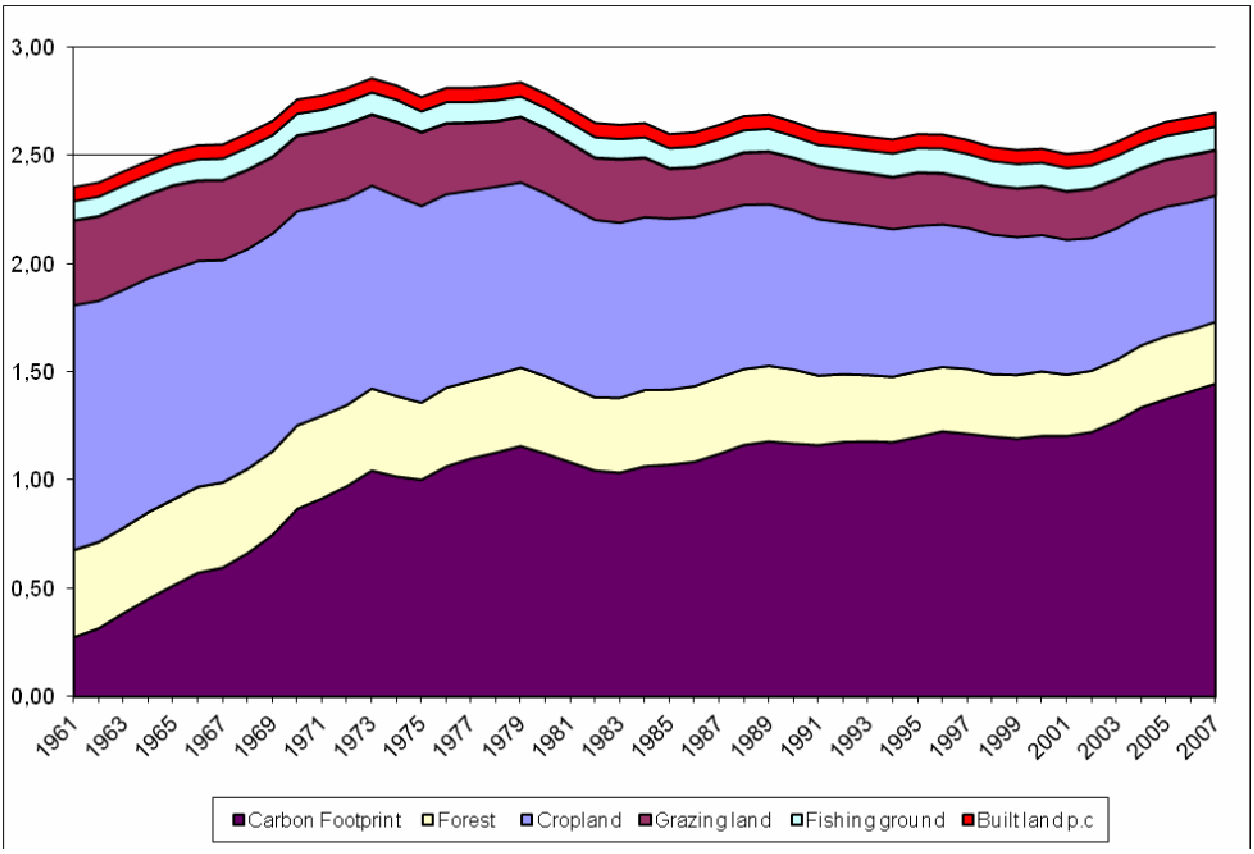
Appendix

Table A1. World Ecological Footprint per capita

Year	Cropland		Grazing land		Forest		Fishing ground		Carbon F.		Built land		EF
1961	1.13	(48.16%)	0.39	(16.54%)	0.40	(17.04%)	0.09	(3.89%)	0.27	(11.63%)	0.06	(2.75%)	2.36
1962	1.12	(47.00%)	0.39	(16.38%)	0.40	(16.70%)	0.09	(3.92%)	0.32	(13.28%)	0.06	(2.72%)	2.38
1963	1.10	(45.41%)	0.39	(16.00%)	0.39	(16.17%)	0.09	(3.87%)	0.39	(15.88%)	0.06	(2.67%)	2.43
1964	1.08	(43.79%)	0.38	(15.53%)	0.40	(16.13%)	0.09	(3.72%)	0.45	(18.22%)	0.06	(2.62%)	2.48
1965	1.07	(42.26%)	0.39	(15.34%)	0.40	(15.71%)	0.10	(3.79%)	0.51	(20.32%)	0.06	(2.57%)	2.52
1966	1.05	(41.09%)	0.37	(14.51%)	0.40	(15.52%)	0.10	(3.89%)	0.57	(22.44%)	0.06	(2.55%)	2.55
1967	1.03	(40.36%)	0.37	(14.41%)	0.39	(15.38%)	0.10	(3.97%)	0.60	(23.34%)	0.06	(2.55%)	2.55
1968	1.02	(39.13%)	0.36	(14.01%)	0.39	(14.91%)	0.10	(4.01%)	0.66	(25.44%)	0.07	(2.50%)	2.60
1969	1.01	(37.96%)	0.35	(13.26%)	0.38	(14.46%)	0.10	(3.80%)	0.75	(28.08%)	0.07	(2.45%)	2.66
1970	0.99	(35.99%)	0.35	(12.61%)	0.38	(13.95%)	0.10	(3.65%)	0.87	(31.43%)	0.07	(2.36%)	2.76
1971	0.97	(35.07%)	0.34	(12.29%)	0.38	(13.75%)	0.10	(3.60%)	0.91	(32.95%)	0.07	(2.35%)	2.78
1972	0.96	(34.04%)	0.34	(12.16%)	0.37	(13.31%)	0.10	(3.60%)	0.97	(34.56%)	0.07	(2.32%)	2.81
1973	0.94	(32.92%)	0.33	(11.44%)	0.38	(13.28%)	0.10	(3.56%)	1.04	(36.51%)	0.07	(2.28%)	2.86
1974	0.93	(32.84%)	0.34	(12.07%)	0.37	(13.17%)	0.10	(3.62%)	1.02	(35.99%)	0.07	(2.31%)	2.82
1975	0.91	(32.91%)	0.34	(12.26%)	0.36	(12.86%)	0.10	(3.47%)	1.00	(36.14%)	0.07	(2.36%)	2.77
1976	0.90	(31.89%)	0.33	(11.59%)	0.36	(12.94%)	0.10	(3.47%)	1.06	(37.78%)	0.07	(2.32%)	2.81
1977	0.88	(31.38%)	0.31	(11.10%)	0.36	(12.73%)	0.10	(3.39%)	1.10	(39.08%)	0.07	(2.32%)	2.81
1978	0.87	(30.89%)	0.30	(10.67%)	0.36	(12.76%)	0.10	(3.41%)	1.13	(39.95%)	0.07	(2.32%)	2.82
1979	0.86	(30.24%)	0.30	(10.60%)	0.36	(12.80%)	0.09	(3.32%)	1.16	(40.74%)	0.07	(2.30%)	2.84
1980	0.85	(30.41%)	0.30	(10.75%)	0.36	(12.86%)	0.09	(3.35%)	1.12	(40.27%)	0.07	(2.36%)	2.78
1981	0.83	(30.64%)	0.29	(10.81%)	0.35	(12.83%)	0.10	(3.53%)	1.08	(39.78%)	0.07	(2.41%)	2.72
1982	0.82	(31.04%)	0.29	(10.76%)	0.34	(12.76%)	0.10	(3.63%)	1.04	(39.34%)	0.07	(2.48%)	2.65
1983	0.81	(30.73%)	0.29	(11.04%)	0.35	(13.08%)	0.09	(3.56%)	1.03	(39.11%)	0.07	(2.47%)	2.64
1984	0.80	(30.23%)	0.27	(10.32%)	0.35	(13.28%)	0.09	(3.58%)	1.06	(40.12%)	0.07	(2.46%)	2.65
1985	0.79	(30.51%)	0.23	(8.83%)	0.35	(13.34%)	0.09	(3.65%)	1.07	(41.16%)	0.07	(2.50%)	2.60
1986	0.78	(30.08%)	0.23	(8.75%)	0.35	(13.40%)	0.10	(3.72%)	1.08	(41.55%)	0.07	(2.50%)	2.61
1987	0.77	(29.24%)	0.23	(8.70%)	0.35	(13.36%)	0.10	(3.82%)	1.12	(42.43%)	0.07	(2.46%)	2.64
1988	0.76	(28.39%)	0.24	(8.97%)	0.35	(13.07%)	0.10	(3.84%)	1.16	(43.30%)	0.07	(2.43%)	2.68
1989	0.75	(27.87%)	0.24	(8.97%)	0.35	(12.99%)	0.11	(3.96%)	1.18	(43.79%)	0.07	(2.42%)	2.69
1990	0.74	(27.82%)	0.24	(9.06%)	0.34	(12.88%)	0.10	(3.79%)	1.17	(43.99%)	0.07	(2.45%)	2.65
1991	0.73	(27.75%)	0.24	(9.34%)	0.32	(12.28%)	0.10	(3.75%)	1.16	(44.39%)	0.07	(2.49%)	2.61
1992	0.70	(27.02%)	0.24	(9.24%)	0.31	(12.03%)	0.11	(4.10%)	1.18	(45.15%)	0.06	(2.46%)	2.60
1993	0.69	(26.82%)	0.24	(9.24%)	0.31	(11.82%)	0.11	(4.12%)	1.18	(45.52%)	0.06	(2.48%)	2.59
1994	0.68	(26.57%)	0.24	(9.28%)	0.30	(11.73%)	0.11	(4.32%)	1.17	(45.61%)	0.06	(2.49%)	2.57
1995	0.67	(25.93%)	0.24	(9.41%)	0.30	(11.68%)	0.11	(4.41%)	1.20	(46.10%)	0.06	(2.47%)	2.60
1996	0.66	(25.46%)	0.23	(9.04%)	0.30	(11.45%)	0.12	(4.45%)	1.22	(47.12%)	0.06	(2.47%)	2.60
1997	0.65	(25.41%)	0.23	(8.83%)	0.30	(11.65%)	0.11	(4.47%)	1.21	(47.14%)	0.06	(2.50%)	2.57
1998	0.65	(25.50%)	0.23	(8.88%)	0.29	(11.36%)	0.11	(4.48%)	1.20	(47.24%)	0.06	(2.53%)	2.54
1999	0.64	(25.32%)	0.22	(8.87%)	0.29	(11.65%)	0.11	(4.51%)	1.19	(47.11%)	0.06	(2.54%)	2.53
2000	0.63	(24.97%)	0.22	(8.88%)	0.30	(11.76%)	0.11	(4.34%)	1.20	(47.51%)	0.06	(2.54%)	2.53
2001	0.63	(24.95%)	0.22	(8.86%)	0.28	(11.30%)	0.11	(4.39%)	1.20	(47.95%)	0.06	(2.56%)	2.51
2002	0.62	(24.46%)	0.23	(8.97%)	0.28	(11.24%)	0.11	(4.31%)	1.22	(48.46%)	0.06	(2.55%)	2.52
2003	0.61	(23.83%)	0.22	(8.77%)	0.28	(11.08%)	0.11	(4.25%)	1.27	(49.56%)	0.06	(2.50%)	2.56
2004	0.61	(23.16%)	0.21	(8.18%)	0.29	(10.96%)	0.11	(4.22%)	1.33	(51.03%)	0.06	(2.45%)	2.62
2005	0.60	(22.62%)	0.22	(8.12%)	0.29	(10.97%)	0.11	(4.18%)	1.37	(51.69%)	0.06	(2.41%)	2.66
2006	0.59	(22.17%)	0.22	(8.07%)	0.28	(10.61%)	0.11	(4.12%)	1.41	(52.63%)	0.06	(2.39%)	2.68
2007	0.59	(21.69%)	0.21	(7.75%)	0.29	(10.61%)	0.11	(4.03%)	1.44	(53.54%)	0.06	(2.37%)	2.70

Source: Present Authors

Figure A1. World Ecological Footprint per capita



Source: Present Authors

Table A2. Inequality indices of EF per capita.

year	GINI Efpc	T(0)	T(1)	T(2)	CV²	A(0.5)	A(1)
1961	0.331863	0.179226	0.189064	0.221799	0.443598	0.088832	0.164083
1962	0.340601	0.18826	0.198431	0.233125	0.46625	0.093128	0.171601
1963	0.348073	0.195861	0.207045	0.245799	0.491598	0.096857	0.177873
1964	0.346067	0.193413	0.204768	0.242528	0.485056	0.095781	0.175858
1965	0.357436	0.205764	0.217594	0.258574	0.517148	0.101607	0.185975
1966	0.365708	0.215069	0.227701	0.274284	0.548568	0.105995	0.193514
1967	0.368823	0.220491	0.233514	0.279064	0.558128	0.108694	0.197875
1968	0.382148	0.236772	0.254051	0.312909	0.625818	0.117006	0.210828
1969	0.391247	0.249119	0.266751	0.329111	0.658222	0.122718	0.220513
1970	0.389138	0.247006	0.262932	0.319889	0.639778	0.121455	0.218864
1971	0.403557	0.265816	0.283596	0.350375	0.70075	0.130326	0.23342
1972	0.40974	0.275489	0.292825	0.361321	0.722642	0.134602	0.240799
1973	0.415801	0.284671	0.304146	0.379181	0.758362	0.139184	0.247738
1974	0.408946	0.27418	0.289289	0.354787	0.709574	0.133488	0.239805
1975	0.398244	0.258086	0.277122	0.344603	0.689206	0.127065	0.227471
1976	0.411443	0.277105	0.29676	0.371164	0.742328	0.135767	0.242025
1977	0.413506	0.279962	0.30151	0.380464	0.760928	0.137442	0.244187
1978	0.413749	0.279761	0.300625	0.37962	0.75924	0.137135	0.244035
1979	0.418671	0.28729	0.307383	0.388589	0.777178	0.140282	0.249706
1980	0.404805	0.268524	0.28246	0.344797	0.689594	0.130622	0.235493
1981	0.402587	0.262972	0.280508	0.349538	0.699076	0.128809	0.231237

1982	0.401942	0.262577	0.280454	0.352258	0.704516	0.128627	0.230933
1983	0.381493	0.23479	0.250775	0.30778	0.61556	0.115723	0.209263
1984	0.398198	0.256443	0.275983	0.347329	0.694658	0.12624	0.226201
1985	0.403467	0.26323	0.285199	0.363881	0.727762	0.129786	0.231435
1986	0.399454	0.258645	0.279678	0.354078	0.708156	0.127559	0.227903
1987	0.401498	0.261941	0.280809	0.352391	0.704782	0.128578	0.230443
1988	0.391679	0.24834	0.266193	0.330683	0.661366	0.122253	0.219905
1989	0.39766	0.257045	0.278703	0.353083	0.706166	0.126997	0.226666
1990	0.397332	0.256368	0.276652	0.349914	0.699828	0.126318	0.226143
1991	0.386913	0.242348	0.258756	0.321538	0.643076	0.11912	0.215217
1992	0.392158	0.248985	0.271967	0.350584	0.701168	0.123491	0.220409
1993	0.376785	0.229976	0.244149	0.302631	0.605262	0.112856	0.205447
1994	0.38846	0.244235	0.262502	0.332241	0.664482	0.120241	0.216696
1995	0.382126	0.23678	0.250645	0.309904	0.619808	0.115911	0.210835
1996	0.382961	0.238944	0.250801	0.310256	0.620512	0.11633	0.212541
1997	0.388101	0.243835	0.260967	0.329826	0.659652	0.119759	0.216383
1998	0.389878	0.245512	0.267234	0.344002	0.688004	0.12154	0.217696
1999	0.389766	0.245884	0.267659	0.343098	0.686196	0.121786	0.217987
2000	0.391711	0.248794	0.268371	0.342659	0.685318	0.122543	0.22026
2001	0.391375	0.249028	0.266981	0.338792	0.677584	0.12228	0.220442
2002	0.39272	0.251387	0.267341	0.336766	0.673532	0.122897	0.222279
2003	0.390124	0.247222	0.263856	0.334474	0.668948	0.121108	0.219033
2004	0.394409	0.253854	0.26877	0.339853	0.679706	0.123678	0.224195
2005	0.389538	0.248936	0.262337	0.330875	0.66175	0.121054	0.22037
2006	0.381548	0.239448	0.247386	0.303389	0.606778	0.115576	0.212938
2007	0.377429	0.233587	0.240921	0.292457	0.584914	0.112849	0.208311

Source: Present Authors

Table A3. Decomposing International EF inequality changes by population share changes and by per capita EF changes by subperiods of 5 years

	CV2		GE(2)		GINI		GE(0)		GE(1)		A(1)		A(0.5)	
Ineq. Index 1961	0.4436		0.2218		0.3319		0.1792		0.1890		0.1641		0.0888	
Total change 1961-1965	0.0735		0.0367		0.0256		0.0266		0.0284		0.0219		0.0128	
Growth rate	17%		17%		8%		15%		15%		13%		14%	
EF share	0.0717	98%	0.0359	98%	0.0268	105%	0.0283	106%	0.0291	102%	0.0233	106%	0.0133	104%
Pop share	0.0018	2%	0.0009	2%	-0.0012	-5%	-0.0016	-6%	-0.0007	-2%	-0.0013	-6%	-0.0005	-4%
Ineq. Index 1965	0.5171		0.2585		0.3575		0.2058		0.2175		0.1860		0.1017	
Total change 1965-1970	0.1227		0.0614		0.0316		0.0412		0.0454		0.0328		0.0198	
Growth rate	24%		24%		9%		20%		21%		18%		19%	
EF share	0.1166	95%	0.0583	95%	0.0344	109%	0.0454	110%	0.0466	102%	0.0362	110%	0.0210	106%
Pop share	0.0061	5%	0.0031	5%	-0.0028	-9%	-0.0043	-10%	-0.0011	-2%	-0.0033	-10%	-0.0013	-6%
Ineq. Index 1970	0.6398		0.3199		0.3891		0.2470		0.2629		0.2189		0.1215	
Total change 1970-1975	0.0493		0.0247		0.0092		0.0112		0.0141		0.0087		0.0057	
Growth rate	8%		8%		2%		5%		5%		4%		5%	
EF share	0.0438	89%	0.0219	89%	0.0121	132%	0.0159	142%	0.0158	112%	0.0123	142%	0.0071	125%
Pop share	0.0055	11%	0.0027	11%	-0.0030	-32%	-0.0047	-42%	-0.0017	-12%	-0.0036	-42%	-0.0014	-25%
Ineq. Index 1975	0.6891		0.3445		0.3983		0.2582		0.2770		0.2275		0.1271	
Total change 1975-1980	0.0006		0.0003		0.0065		0.0103		0.0055		0.0079		0.0035	
Growth rate	0%		0%		2%		4%		2%		3%		3%	
EF share	-0.0057	-1035%	-0.0029	-1035%	0.0085	129%	0.0141	137%	0.0064	116%	0.0108	137%	0.0046	133%
Pop share	0.0063	1135%	0.0031	1135%	-0.0019	-29%	-0.0038	-37%	-0.0009	-16%	-0.0029	-37%	-0.0011	-33%
Ineq. Index 1980	0.6896		0.3448		0.4048		0.2685		0.2825		0.2355		0.1306	
Total change 1980-1985	0.0381		0.0191		-0.0014		-0.0053		0.0027		-0.0040		-0.0008	
Growth rate	6%		6%		0%		-2%		1%		-2%		-1%	
EF share	0.0324	85%	0.0162	85%	0.0010	-73%	-0.0015	29%	0.0038	142%	-0.0012	29%	0.0004	-44%
Pop share	0.0057	15%	0.0029	15%	-0.0023	173%	-0.0038	71%	-0.0011	-42%	-0.0029	71%	-0.0012	144%
Ineq. Index 1985	0.7278		0.3639		0.4034		0.2632		0.2852		0.2314		0.1298	
Total change 1985-1990	-0.0279		-0.0140		-0.0061		-0.0069		-0.0085		-0.0053		-0.0035	
Growth rate	-4%		-4%		-2%		-3%		-3%		-2%		-3%	
EF share	-0.0362	130%	-0.0181	130%	-0.0044	73%	-0.0042	61%	-0.0085	100%	-0.0032	61%	-0.0028	80%
Pop share	0.0083	-30%	0.0042	-30%	-0.0017	27%	-0.0027	39%	0.0000	0%	-0.0021	39%	-0.0007	20%
Ineq. Index 1990	0.6999		0.3499		0.3973		0.2563		0.2767		0.2261		0.1263	
Total change 1990-1995	-0.0801		-0.0401		-0.0152		-0.0195		-0.0261		-0.0152		-0.0103	
Growth rate	-11%		-11%		-4%		-8%		-9%		-7%		-8%	
EF share	-0.0881	110%	-0.0440	110%	-0.0151	99%	-0.0190	98%	-0.0271	104%	-0.0149	98%	-0.0105	102%
Pop share	0.0079	-10%	0.0040	-10%	-0.0001	1%	-0.0005	2%	0.0010	-4%	-0.0004	2%	0.0002	-2%
Ineq. Index 1995	0.6197		0.3099		0.3821		0.2368		0.2506		0.2109		0.1160	
Total change 1995-2000	0.0656		0.0328		0.0096		0.0119		0.0178		0.0094		0.0066	
Growth rate	11%		11%		3%		5%		7%		4%		6%	
EF share	0.0563	86%	0.0282	86%	0.0093	97%	0.0119	100%	0.0162	91%	0.0093	100%	0.0062	95%
Pop share	0.0093	14%	0.0046	14%	0.0003	3%	0.0000	0%	0.0016	9%	0.0000	0%	0.0003	5%
Ineq. Index 2000	0.6853		0.3427		0.3917		0.2488		0.2684		0.2202		0.1225	
Total change 2000-2005	-0.0236		-0.0118		-0.0022		0.0001		-0.0060		0.0001		-0.0015	
Growth rate	-3%		-3%		-1%		0%		-2%		0%		-1%	

EF share	-0.0328	139%	-0.0164	139%	-0.0032	148%	-0.0007	-490%	-0.0082	135%	-0.0006	-490%	-0.0021	144%
Pop share	0.0093	-39%	0.0046	-39%	0.0011	-48%	0.0009	590%	0.0021	-35%	0.0007	590%	0.0007	-44%
Ineq. Index 2005	0.6618		0.3309		0.3895		0.2489		0.2623		0.2204		0.1210	
Total change 2005-2007	-0.0768		-0.0384		-0.0121		-0.0154		-0.0214		-0.0121		-0.0082	
Growth rate	-12%		-12%		-3%		-6%		-8%		-5%		-7%	
EF share	-0.0809	105%	-0.0404	105%	-0.0127	105%	-0.0158	103%	-0.0224	105%	-0.0124	103%	-0.0085	104%
Pop share	0.0041	-5%	0.0020	-5%	0.0006	-5%	0.0004	-3%	0.0011	-5%	0.0004	-3%	0.0003	-4%
Ineq. Index 2007	0.5850		0.2925		0.3775		0.2335		0.2410		0.2083		0.1128	

Source: Present Authors

Table A4. Natural decomposition of the Ecological Footprint per capita

Year	Fishing	Cropland	Grazing	Forest	Carbon	Built	Total
1961	0.0654	0.3593	0.2007	0.1853	0.1751	0.0146	1
1962	0.0646	0.3513	0.1890	0.1871	0.1934	0.0150	1
1963	0.0610	0.3494	0.1733	0.1717	0.2308	0.0124	1
1964	0.0591	0.2949	0.1739	0.1790	0.2807	0.0137	1
1965	0.0576	0.2946	0.1501	0.1751	0.3114	0.0116	1
1966	0.0558	0.2737	0.1468	0.1703	0.3425	0.0102	1
1967	0.0576	0.2744	0.1333	0.1613	0.3620	0.0118	1
1968	0.0526	0.2759	0.1243	0.1532	0.3856	0.0091	1
1969	0.0469	0.2665	0.1086	0.1490	0.4209	0.0085	1
1970	0.0481	0.2146	0.0980	0.1418	0.4892	0.0084	1
1971	0.0418	0.2325	0.0899	0.1382	0.4881	0.0090	1
1972	0.0416	0.2165	0.0872	0.1269	0.5176	0.0099	1
1973	0.0393	0.1922	0.0860	0.1316	0.5424	0.0083	1
1974	0.0413	0.1916	0.0999	0.1302	0.5310	0.0080	1
1975	0.0383	0.2103	0.1091	0.1179	0.5184	0.0083	1
1976	0.0395	0.1937	0.0929	0.1235	0.5437	0.0061	1
1977	0.0350	0.1936	0.0802	0.1221	0.5614	0.0086	1
1978	0.0354	0.1792	0.0796	0.1313	0.5663	0.0078	1
1979	0.0350	0.1874	0.0736	0.1312	0.5655	0.0076	1
1980	0.0390	0.1709	0.0779	0.1328	0.5710	0.0099	1
1981	0.0351	0.1926	0.0804	0.1302	0.5529	0.0100	1
1982	0.0380	0.2385	0.0799	0.1169	0.5150	0.0115	1
1983	0.0404	0.1624	0.0854	0.1407	0.5602	0.0085	1
1984	0.0363	0.1831	0.0738	0.1433	0.5517	0.0105	1
1985	0.0393	0.2015	0.0525	0.1429	0.5523	0.0096	1
1986	0.0393	0.1899	0.0475	0.1526	0.5620	0.0096	1
1987	0.0439	0.1673	0.0478	0.1539	0.5789	0.0098	1
1988	0.0428	0.1368	0.0603	0.1488	0.6038	0.0084	1
1989	0.0440	0.1446	0.0500	0.1517	0.6011	0.0084	1
1990	0.0403	0.1584	0.0454	0.1481	0.5998	0.0080	1
1991	0.0410	0.1571	0.0513	0.1287	0.6108	0.0089	1
1992	0.0399	0.1546	0.0478	0.1297	0.6197	0.0084	1
1993	0.0401	0.1355	0.0534	0.1392	0.6230	0.0077	1
1994	0.0422	0.1540	0.0427	0.1377	0.6139	0.0083	1
1995	0.0441	0.1296	0.0520	0.1385	0.6267	0.0081	1
1996	0.0382	0.1332	0.0462	0.1307	0.6432	0.0087	1
1997	0.0388	0.1273	0.0400	0.1337	0.6530	0.0078	1
1998	0.0334	0.1311	0.0398	0.1347	0.6529	0.0084	1
1999	0.0350	0.1276	0.0379	0.1354	0.6570	0.0085	1
2000	0.0326	0.1241	0.0373	0.1364	0.6610	0.0085	1
2001	0.0352	0.1204	0.0375	0.1284	0.6698	0.0077	1
2002	0.0339	0.1154	0.0398	0.1305	0.6735	0.0086	1
2003	0.0308	0.1262	0.0424	0.1269	0.6652	0.0069	1
2004	0.0291	0.1305	0.0345	0.1284	0.6691	0.0082	1
2005	0.0276	0.1233	0.0352	0.1332	0.6725	0.0069	1
2006	0.0294	0.1074	0.0353	0.1227	0.6986	0.0071	1
2007	0.0292	0.1163	0.0370	0.1172	0.6923	0.0073	1

Source: Present Authors

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