UNIVERSITAT ROVIRA I VIRGILI

THE INTERNATIONAL DISTRIBUTION OF THE ECOLOGICAL FOOTPRINT: AN EMPIRICAL APPROACH

Jordi Josep Teixidó Figueras

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I STATE that the present study, entitled "The International Distribution of the Ecological Footprint: an empirical approach", presented by Jordi J. Teixidó-Figueras for the degree of Doctor of Philosophy in Economics, has been carried out under my supervision at the Department of Economics at this university, and that it fulfils all the requirements to receive the European/International Doctorate Distinction.

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The Doctoral Thesis supervisor

Dr. Juan Antonio Duro

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CONTENTS

CHAPTER 1
INTRODUCTION

Ecological distribution refers to the social, spatial and temporal asymmetries in the human use of environmental resources and services (Martinez-Alier and O'Connor, 1999); a typical example is the depletion of natural resources. This doctoral thesis focusses on empirical analyses of such ecological distribution from an Inequality economics perspective and also makes its primary contribution in this area.

Specifically, we will analyse the international distribution of natural resource consumption as measured by the Ecological Footprint (henceforth, EF) (Wackernagel and Rees, 1996). To do so, we have borrowed from the tool box of inequality economics, which traditionally focused on *income* inequality. As a result, our main contributions represent an assessment of the international distribution of EF by analysing its change over time, as well as its underlying drivers. In the process, however, some methodological aspects are discussed in order to properly repurpose them from the *income* inequality viewpoint to that of *environmental* inequality –this, as it will be shown, implies modifying them on occasion.

There are already some papers which analyse the international inequality of natural resource consumption using either EF. (White, 2007; Dongjing et al., 2010; Duro and

Teixidó-Figueras, 2013)[1], or other indicators of resource consumption (Hedenus and Azar, 2005; Steinberger et al., 2010), all of these have played their part in inspiring the proposed analysis. However, to the best of our knowledge, no other analysis has focused on the distribution of natural resource consumption, as measured by EF, by reviewing all the wide range of accepted methodologies borrowed from income inequality economics. Some methodologies we consider have never been applied to natural resource consumption or have considered a time dimension which in some cases spans a forty-six year period. Besides the methodological aspect, this thesis has been orientated towards contributing to the discussion of the range of topics found in the ecological economics literature, which usually have been tackled with different methodologies (if indeed they have had any methodological component). This Chapter has two main sections; the first's primary aim is to describe specific topics in Ecological Economics literature. The second section describes the thesis structure and its contents.

1.1 WHY DISTRIBUTIONAL ANALYSES ARE IMPORTANT IN ECOLOGICAL ECONOMICS?

In this section we wish to unravel the significance of the proposed empirical analyses by exploring different topics of Ecological Economics literature where our distributional analyses differ from the standard treatment. In other words, this section states the raison d'être of the empirical ecological distributional analysis in the context of sustainability.

At least four theoretical frameworks of Ecological economics main literature include and justify the empirical analysis here proposed: firstly, the current scenario of resource scarcity unavoidably demands the monitoring of the distribution issues; secondly, fair

[1] Duro and Teixidó-Figueras (2013) is a publication deriving from this thesis. Its results can be found in Chapter 4.

consumption natural resources is also driven by the ethical motivation of environmental justice; thirdly, global environmental governance may improve its effectiveness if it considers distributional issues; and finally, the political economy of ecologically unequal exchange may underlie the distribution of natural resources itself.

In the following sections, these four frameworks are briefly introduced, and concomitantly, relevant literature is suggested for giving a deeper view on each issue. The last section concludes with the general remarks.

1.1.1 RESOURCE SCARCITY: SCALE, ALLOCATION AND DISTRIBUTION

An ecological crisis in any species is commonly defined as a situation where changes in the environment on which its life depends, seriously threaten the survival of the species. Humanity, in this sense, is no different from any other species. Human societies are highly dependent on three highly correlated ecological functions: resource supply, waste assimilation and environmental services such as the life support. Whenever these functions are threatened, humanity faces a severe ecological crisis. According to the scientific community, anthropogenic pressures on the Earth System have reached a scale where discontinuous global environmental changes, "shocks", can no longer be excluded (Rockstrom et al., 2009). Indeed, these scientists identify nine interdependent planetary boundaries[2] within which human societies can operate safely, however, the never ending growth of human economies has already breached three of these

[2] Climate change (CO_2 concentration in the atmosphere <350 ppm); ocean acidification (mean surface seawater saturation state with respect to aragonite 80% of pre-industrial levels); stratospheric ozone (<5% reduction in O_3 concentration from pre-industrial level of 290 Dobson Units); biogeochemical nitrogen (N) cycle (limit industrial and agricultural fixation of N_2 to 35 Tg N yr^{-1}) and phosphorus (P) cycle (annual P inflow to oceans not to exceed 10 times the natural background weathering of P); global freshwater use (<4000 km3 yr^{-1} of consumptive use of runoff resources); land system change (<15% of the ice-free land surface under cropland); the rate at which biological diversity is lost (annual rate of <10 extinctions per million species), chemical pollution (unknown boundary) and atmospheric aerosol loading (unknown boundary).

boundaries (climate change, rate of biodiversity loss and changes to the global nitrogen cycle), while the exact status of two of them are still unknown (chemical pollution and atmospheric aerosol loading). Other analyses, such as those of Ecological Footprint Network (on whose data the empirical analyses of this thesis are based), also corroborate the hypothesis that human economies are placing an excessive burden on the biosphere. As will be discussed in further detail in the next chapter, according to the latest data available (2007), humanity's total Ecological Footprint worldwide was 50 per cent larger than that which the ecosystem can accommodate (Ewing et al., 2010).

The human economic system is embedded in the earth ecosystem, which is a closed system. This means that, while the human economy continuously requires additional (low-entropy) material and energy inputs to fuel its increased population, the ecosystem and its resources are not growing, hence so the necessary resources are being inescapably exhausted. Yet the ecosystem tries to assimilate the metabolic output of human society, waste (high entropy material and energy), which quite often exceeds its sink capacity. As a result, the greater the scale of the economy with respect to the ecosystem, the greater the risk of destroying the very conditions on which human life on earth depends. A good scale for the economy is one which is at least sustainable, one that does not erode the environmental carrying capacity over time (Daly, 1992). However, current economic growth is certainly leading to an ecological crisis. In this context, distributional issues are necessarily brought to the head of the agenda of the global environmental governance.

The standard economics concept of proper economic performance is often narrowed to economic growth, which at the end of the day means growth in GDP, because that is supposed to increase society's welfare. However, this growth-based economy is increasingly becoming, at the very least, a controversial concept for an increased proportion of society and academia[3]; not only because it threatens the environment (it goes against the sustainable scale of the economy), but also because GDP growth is failing to provide higher levels of social welfare (Bergh, 2009). Neglecting, as mainstream economic does, these critical considerations has allowed standard economics to primarily focus on the efficiency of resource allocation as main goal. There is no doubt that efficient allocation is desirable in order to allocate resources to the most valuable uses. However, what is in the stake here is how these valuable uses should be defined – according to standard economics, GDP growth is *the* valuable use. This has been possible in part because orthodox economics has overlooked the goal of sustainability proposed by Daly (1992). The assumption of an unlimited ecosystem has allowed the mainstream economics paradigm to avoid the potential conflict between economic efficiency and just distribution by advocating that economic growth will lead to a rising standard of living for all (White, 2007), providing thus an ethical justification to economic growth. The conventional wisdom is that “a rising tide lifts all boats”, so that politically, although not technically, it is easier to make the cake bigger than to try to cut it up in a different way. However, as briefly described above, ecological boundaries are being transgressed, and therefore, the cake can no longer be made bigger.

In the face of this resource limitation, at some point the increasing demand of natural resources by countries will become physically infeasible. Hence, equity considerations of limited and scarce resource usage should replace the growth goal of market based economies. Some analysts argue for a Steady State economy (which should be achieved after a process to return the economy to within the ecosystem boundaries. i.e. a de-

[3] See Berg (2009) for an example of a review of different aspects of GDP (and by extension its growth) being far from a reliable measure of welfare. Also, initiatives such as the “Beyond GDP” of the European Commission certify that society is making eco of those criticisms in order to develop more inclusive indicators of environmental and social aspects of progress.

growth process), while others go one step further by questioning Capitalism as a socio-economic system. Certainly, deep political changes are required from any perspective. In any case, tracking the international inequality of natural resource consumption and its underlying factors emerge as a key policy instrument for the achievement of a fair sharing of natural resources in order to achieve both feasible and equitable human development opportunities for all countries in the world.

1.1.2 AN ETHICAL PRINCIPLE: INTER AND INTRA GENERATIONAL EQUITY

Concern for future generations, one stemming from a Sustainable Development framework, is a quite recent phenomenon which has never seen in the history of humanity. According to Neumayer (2010), the reason for this must be sought in the fact that never before has the human economic system reached a scale big enough to threaten the welfare prospects of future generations (ecological crisis)[4]. Therefore, such concern stems from an ethical commitment toward the principle of justice.

By definition, future generations are vulnerable to the choices made by today's generations; they have no way of expressing their preferences when such choices are made, and of course, there is nothing they can do to undo any harm they inherit from previous generations. Consequently, protecting the environment emerges as an ethical principle which argues that we should attempt to guarantee that future generations can continue to enjoy similar opportunities of leading worthwhile lives as are enjoyed by the generations which precede them. However, at the same time, it could be stated that, since the present generation does not receive any compensation for sacrifices made today and since they cannot force future generations to commit to the same ethical

[4] As a result, scrutinizing the consequences of economic activity on the capacity for generating future utility has become an explicit academic enterprise in the recent years.

choice they have made themselves, the best choice for the present generation might be to exploit their dominant position in time and use the resources available to them, otherwise some subsequent generation will do just that. This counterargument might make us reflect on how do we know what is just and what is not.

According to John Rawls and his liberal *Theory of Justice* (1971), the principles of justice are chosen behind a veil of ignorance, which consists in designing a hypothetical situation where no one knows his place in society, his class position or social status, nor does anyone know his fortune in the distribution of natural assets and abilities, his intelligence, strength, and the like. Therefore, under such circumstances, there is a guarantee that no one is advantaged or disadvantaged in the choice of principles by the outcome of natural chance or the contingency of social circumstances (Rawls, 1971) [5]. All the parties involved in the social contract are given an original position from which the principles of justice are the result of a fair agreement or bargain. Behind the veil of ignorance thus, no one knows to what generation he or she shall belong. Consequently, under the Rawlsian veil of ignorance, what best protects the individuals' interests is that no generation is allowed to gain at the expense of future generations. Notice that at the end of the day, this is a distributional concern between different generations which is being discussed from the Sustainable Development frame. Such inequality *between*

[5] The Rawlsian Concept of Justice (1971) stems from the Kantian moral imperative and became extremely popular perhaps in response to the Neoliberal conception of the World, for which the only justice emanates from private property and from market mechanisms (Hayek, 1978), becoming stronger than ever. Nonetheless, Rawlsian Justice can be criticized from different grounds of political philosophy and at different depths: for instance, the anthropocentric view of such distributional justice in contrast to an eco-centric view; or also from the fact that the isolated rational individual does not exist outside of social theories insofar as community is *ex ante* to the rational choice of such individual. These discussions and others can be found in Okereke (2006) and in Pelletier (2010). A deeper criticism, however, of the liberal concept of Rawlsian justice is rooted in Marxist thought, from which perspective the grounds of Rawls are seen as founded in the same philosophical underpinnings as the Neoliberal fundamentals which he claimed to overpass (in fact Hayek recognized the bulk of Rawlsian theory as not significantly diverging from his libertarian concept of Justice (Boron, 2000). In this regard, Rawlsian justice is essentially of a supra-historical character and neglects the specificity of the social mode of production in Capitalism, where human exploitation is the fundamental social relationship (Ibid).

generations in terms of natural resource consumption is thus universally perceived as inequitable.

Subsequently, such rationale can also be applied to the equity *within* generations. In fact, poor people, as happens with future generations, do not have any way of expressing their preferences in a market that measures them in monetary units (Padilla, 2002). In this regard, it might become a gross violation of such a Universalist principle embodied in Sustainable development if we were to become obsessed about *inter*generational equity while neglecting the *intra*generational equity (Anand and Sen, 2000). What ethical system can justify a concern about the well-being of those yet to be born, while not caring for the well-being of those alive today? (Daly and Farley, 2004). Under the veil of ignorance then, the rational choice would be an equitable distribution of natural resource consumption between countries. Imagine a rational individual on board a spaceship who has to decide whether to land on a planet where the countries share natural resources equally or on a planet where natural resources are shared unequally, but he cannot know in which specific country he will land (veil of ignorance).

The Human Development Report (2011) argued that contemplating policies to restore sustainability, independently of policies to address inequality among countries (within generations), would be equivalent to framing policies to address inequalities between certain groups, such as rural and urban, while neglecting the equity interrelationships with between other groups, such as poor and rich (UNDP, 2011). Indeed, according to International Declarations issued by summits from Stockholm (1972) to Rio de Janeiro (2012), Sustainable Development is a concept that relies on three main pillars: environmental, economic, and social. Intragenerational equity is crucial for the fulfillment of the social pillar (UNDP, 2011), and so measuring inequality in terms of natural resource consumption within generations becomes a fundamental analysis which is required to track such ethical considerations.

1.1.3 INTERNATIONAL GOVERNANCE (MULTINATIONAL ENVIRONMENTAL AGREEMENTS)

The international allocation of natural resources is determined neither by ethical nor by ecological criteria, but by the dominance of market mechanisms (Røpke, 2001). Some countries consume many more natural resources than others in order to maintain their living standards. According to the Ecological Footprint Network (Ewing et al., 2010), an average citizen of Cuba (in 2007) needed 1.85 global hectares[6] to fulfil its biocapacity demand, while the average Belgian citizen[7] needed 8 global hectares. Clearly, some countries have been responsible for the depletion of such natural resources than others. Consequently, any international initiative to correct, or at least stop, such depletion will certainly be deeply affected by these differences among countries.

The economic development of rich countries has led to their greater appropriation of the earth's natural resources. In this sense, those poor countries who struggle to achieve greater levels of development cannot afford the ‘environmental’ price of sacrificing such development in order to solve a global problem that they actually have not caused. At the same time, rich countries are not willing to compensate poor countries for such historical inequalities, since their main aim is economic growth[8]. As a result, there is no easy consensus among countries to deal with these ecological global problems, given

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[6] A global Hectare is the average biological productivity of the whole earth. Further details are given in Chapter 2

[7] In 2007 Cuba had 11.2 million of inhabitants and Belgium 10.53 (Ewing et al., 2010).

[8] Canada, one of the first members to ratify the United Nations Convention to Combat Desertification (UNCCD), has become the first country to withdraw from such a convention; some media point to that decision as being part of the Government’s plan to cut their budget deficit.

their different interests and historical backgrounds. Indeed, in Multilateral Environmental Agreements, where the concern is to reach a common decision as to the benefit of sustainability, the main output of such conventions is often motivated by a concern for fairness among participants rather than sustainability itself[9].

The success of any international agreement critically depends on the perception of equitability by the parties; greater responsibilities should involve greater efforts toward global sustainability. Actually, in the context of climate change mitigation, where there are actual multilateral Environmental Agreements, article 3 of UNFCCC (1992) states that "The Parties should protect the climate system [...] on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" [10]. Furthermore, as far as Climate change is concerned, all climate models predict that the negative consequences of such transgression of earth boundaries (for example, extreme weather conditions) will be more strongly felt by countries closer to the equator, independently of their historical responsibilities in CO_2 emissions. Therefore, equity becomes an even more serious concern.

From Rio (1992) to Rio+20 (2012), via Kyoto 1995, distributional issues have unquestionably determined the international agreements reached. From this perspective, distributional analyses come to the fore as important tools for global environmental governance (Maguire and Sheriff, 2011; Stanton, 2012); an in-depth understanding of ecological inequalities may be critical in achieving greater levels of consensus. Following this line of thought, many papers have dealt with the issue by analysing

[9] Indeed, there is some evidence from field experiments demonstrating this very behavior among individuals: in an experimental setting among 240 students, Tavoni et al. (2011) demonstrate that more inequality among them complicates group agreements on public goods provision; apparently because more inequality focuses their minds on the fairness of the outcome rather than on the outcome itself.

[10] However, the core policies are rooted in the libertarian idea of Justice by which the just distribution emerges from the freedom to pursue one's own desires through free market and property rights; both are viewed as inherently just since they express the sum of selfish desires (see Boron, 2000; Okereke, 2006; Pelletier, 2010). Such an idea of justice will not be chosen under the veil of ignorance of Rawls (see footnote 3).

environmental inequalities in terms of CO_2 emissions (Alcantara and Duro, 2004; Cantore, 2011; Duro and Padilla, 2006; Duro and Padilla, 2008; Duro and Padilla, 2012; Ezcurra, 2007; Heil and Wodon, 1997; Heil and Wodon, 2000; Padilla and Serrano, 2006). These distributional analyses can provide critical clues as to how to design International Multilateral Environmental Agreements in order to minimize the inequality of the participants and so increase the likelihood of consensus among the heterogeneous participant countries, in the context of Climate Change mitigation. The analysis of EF distribution might significantly complement those studies (as would distributional analyses of other ecological indicators) since EF is a more comprehensive ecological indicator, one which actually includes CO_2 emissions. Also, given that the EF is a consumption-based indicator, tracking its inequality will provide interesting insights on the international distribution of ecological impacts directly affecting the effectiveness of global environmental governance.

1.1.4 Ecologically unequal exchange theories

Finally, the last framework in which environmental distributional analyses are conceptually covered is within the political economy theories of Ecologically Unequal Exchange (EUE). While in the three previous frameworks, EF distributional analyses emerge as a helpful tool to manage Sustainability from different perspectives; this last framework serves as a political economy umbrella for the empirical results obtained through such empirical analyses of international Ecological Footprint distribution. In other words, ecological unequal exchanges theories seek the historical and socio-economic causes of the ecological distribution patterns observed.

Unequal exchange theories (from which *ecological* unequal exchange theories derive) were a central concern of development economic theories since the early analyses of

Prebisch (1950) and Singer (1950) on the deterioration of the trading terms in Latin America. Since then, different strands of Marxist social theory such as the effects of imperialism, dependency or World System perspectives have added new insights to the same core idea of unequal exchange[11]. The basis of the concept is that, from a market economic point of view, the exchange between two countries is always an equal exchange of something for something as far as market prices is used as the exchange value. However, from an ecological economics point of view, an equal exchange in money can be perfectly well be consistent with an unequal exchange in regard to other value measurements such as labour or land which are embodied in the commodities interchanged (Røpke, 2001; 2010); a million dollars' worth of Swedish Volvos exchanged for a million dollars' worth of Venezuelan oil is, by definition, perfectly equal in terms of the general exchange value or money (Hornborg, 2011), however, another picture emerges if we compare them in terms of ecological entropy.

From this perspective, and considering the history of international division of labour since the 16th century (Wallerstein, 1974-1989), the global economy can be seen as a World System economy where some countries have specialized in providing raw materials and ecological resources while others have become industrialized and technologically advanced. In terms of the classical trade theory of Ricardo and Heckscher-Ohlin, the former will produce labour and land intensive goods, while the latter will produce capital intensive goods; their trade will result in a win-win situation provided that countries specialize in their relative abundant factor. Supposedly, doing so will improve efficiency, lower production costs, and maximise world product. Such a theory, however assumes, inter alia, that there is no international capital mobility, a

[11] See Bunker (1985) pp 38-48 for a brief review. For deeper reviews, see the works of Emmanuel (1973), Frank (1967) and Wallerstein (1974-1989) among other theorists of dependency and uneven development.

difficult assumption to maintain in today's globalized economy. In such a situation, the view of this literature is that ecological resources are constantly being transferred from developing countries to developed countries, and that, furthermore, this process involves a sub-optimal utilisation of the ecological potential of the peripheral countries in the long term (Røpke, 2001). As a result, international differences in natural resource consumption are driven by a social relationship among countries resulting from a core-periphery division of countries according to the role played by each of them in the flow and consumption of energy and materials within this global economy (Rice, 2007) [12]. The fundamental theoretical question of this approach is whether the global distribution of environmental deterioration is somehow structurally determined (Hornborg, 2011). If that is the case, then we are facing a distribution of natural resource consumption which is a by-product of a world social system and so, the goal of equity (and all that involves) may be more complex to achieve since it will require deep political transformations.

In recent years, different empirical works have approached ecological Unequal Exchange using different methodologies and indicators (Andersson and Lindroth, 2001; Dittrich and Bringezu, 2010; Dittrich, Bringezu, and Schütz, 2012; Duro and Teixidó-Figueras, 2013; Giljum and Eisenmenger, 2004; Global Footprint Network; Muradian and Martinez-Alier, 2001; Muñoz et al., 2009; Niccolucci, et al., 2012; Pérez-Rincón, 2006; Rice, 2007). The present thesis not only provides new insights into the empirical

[12] Such a dualist division of countries, at the end of the day, consists in distinguishing between rich and poor countries – these are commonly referred as North and South Countries, 1st versus 3rd world economies, or Developed versus Developing. However, such divisions link the wealth of countries to either the latitude level (Northern countries are rich, Southern are poor), to the historical positions which originated in the Cold War (3rd world economies, today poor countries, were those countries which aligned themselves neither to the Capitalist bloc nor to the Soviet bloc) or finally to the idea of a development *process* (developing countries are just in an earlier phase of this process). In contrast, Core and Periphery countries denote a sort of social relationship of dependence among them, which actually is the idea of World System theories (see Wallerstein, 1974-1989) and Unequal Exchanges theories (Prebisch, 1950; Singer, 1950; Emmanuel, 1973).

literature devoted this approach, but also provides a new methodology for approaching this issue; the empirical distributional analyses of inequality economics.

It is easy to see that all these frameworks described are highly interconnected among themselves and overlap in different dimensions. Their common thread is their link with international ecological distribution and it is here that this thesis makes its main contribution in the area of empirical analysis of inequality economics. The results and discussions of them in the present Thesis will focus on these topics and on the resulting policy implications.

1.2 Thesis Structure and Research Questions

In this section, we will briefly describe the empirical strategy of the different chapters in order to contribute to these four ecological economics frameworks. In doing so, some implications of such analyses are noted.

This thesis consists of seven Chapters; the first one introduces the thesis and the second contextualizes the EF in the ecological economics literature relating to measuring sustainability. The next three Chapters, (3, 4 and 5), analyse the international EF distribution using the inequality approach, studying inequality trends and disentangling the main drivers using different methodologies. In doing so, these methodologies are revised in order to adapt them to the particularities of ecological economics. The sixth chapter complements the distributional analyses, thus far approached from an inequality perspective, by analysing the distribution from a polarization perspective. Finally, the seventh chapter summarises all the general remarks and policy implications found in the course of the previous chapters.

Let us discuss in more detail what is done in each of these chapters:

The EF is a widely recognized ecological indicator which measures the impact on the environment arising from the demand for natural resources in each country. In order to contextualise the use of such an indicator, and indicate its origins, Chapter 2 discusses some of the main debates held in the literature of ecological economics in relation to the question of measuring Nature from an economics perspective. In doing so, we define precisely what the EF measures and what are the main advantages and drawbacks. Arising from those debates, different ecological indicators have been considered apart from the EF. However, the availability of data and some specific properties of the EF indicator led us to perform our distributional analyses using this indicator.

According to the main literature, different available indicators sometimes point in different directions which makes it necessary to adopt multi-criteria decision making in order to take advantage of the information given by different indicators —we thus approximate more accurately the complexity of reaching a sustainable scale in the economy (Martinez-Alier and Roca, 2001). Indeed, the use of multi-criteria analyses for Sustainability assessment will be defended in this thesis as being critical for environmental equity issues (and not only to scale issues). Additionally, some descriptive statistics of the EF data used are given in that chapter.

Then, in Chapter 3 we discuss the fundamentals of inequality economics by applying them to the international distribution of EF. Such methodologies are typically focused on income distribution, and this chapter attempts to contextualize, from a methodological point of view, their use in environmental analyses. To do so, we review some of the most basic tools of income inequality, such as stochastic dominance and inequality indices, and discuss the underlying axioms. There are certain issues with these in the context of environmental inequalities and so, some caution needs to be taken when such tools are applied to environmental outcomes. Additionally, some preliminary empirical results are obtained for such analyses of the international inequality trends of EF in the course of the period 1961-2007.

Chapter 4 consists in the analytical decomposition, using the classical methods of Shorrocks (1980, 1982) and Duro and Esteban (1998), of the inequality observed in the previous chapter. These decomposition techniques have allowed the breakdown of the EF inequality in terms of inequality both between and within groups (using World Bank regional classifications), in terms of the EF sources (such carbon footprint, cropland, forest, grazing, fishing and built up land) and finally in terms of multiplicative factors (such as affluence and environmental intensity). The particularity of these methods is based on the mathematical properties of certain inequality indices, whereas the Regression-Based Decomposition of Fields (2003), performed in Chapter 5, breaks down inequality in terms of econometric explanatory variables. Such a methodology allows much more flexibility than analytical techniques and permits disentangling the causal determinants of the EF inequality.

Finally, Chapter 6 approaches the distributional analyses from a different angle, the polarization approach, which is related to the inherent conflict in a distribution by jointly measuring the alienation between groupings and the identification within those groupings. The polarization measurement complements the previous trends observed from the inequality perspective since one of the main motivations for such an approach is the fact that polarization behaves differently from inequality, that is to say that inequality might decrease at the same time as polarization increases, and hence there is a possibility of conflict.

In this regard, some of the research questions addressed in this doctoral thesis are:

- Why is the measurement of environmental inequalities between countries critical to Sustainable development? This is addressed in the current introductory chapter and also in the conclusions and policy implications of each subsequent chapter of this thesis.

- Why is the international EF inequality of particular interest compared to other environmental indicators? Chapter 2 includes a discussion of different ecological indicators and the relationship with Economics. Some specific characteristics of EF and the availability of EF data led us perform our analysis using this indicator.

- Which is the most suitable way of measuring environmental inequalities? Chapter 3 discusses some methodological considerations in the use of typical income inequality tools as applied to environmental issues. In particular, we propose a concrete family of inequality indices.

- How much EF inequality (or intragenerational equity) existed in the last decades (1961-2007) and how has it evolved? Using a representative sample of countries from 1961 to 2007, Chapter 3 assesses the evolution of inequality taking into account the particularities of different inequality indices taking into account the specific features of different inequality indices.

- Is the inequality observed a by-product of regional groups of countries? Which particular EF sources and factors explain the inequality trend observed? Chapter 4 performs the analytical decomposition of inequality, allowing a decomposition by subgroups of countries, by EF sources and by multiplicative factors such as affluence and ecological intensity

- Which are the causal EF drivers which foster international Inequality? Chapter 5 performs a regression-based decomposition of international EF inequality, disentangling which EF drivers explain the majority of international EF differences.
- Is the international distribution of EF becoming a polarized distribution? Chapter 6 deals with the analysis of the same distribution, but now from the polarization perspective, which allows the capture of different features of distribution.
- What policy implications arise from our results? Chapter 7 summarizes the general conclusions of this thesis, with special emphasis on the policy implications for global governance.

The answers we find to these questions involve deep and significant policy implications. For instance, the trajectory of the EF inequality reveals that, not only is a sustainable scale of the economy important for the preservation of life in the earth (and so we should monitor changes in different ecological indicators using a multi-criteria analyses), but it is also important to do this to maintain equity. We observe that EF inequality is mainly and persistently driven by the mean differences between defined groups of countries, which points to structural EF inequality patterns and the important role of the carbon footprint; not because of its own inequality but because of its weighting within the EF. In this regard however, and given that climate change international agreements are negotiated on the basis of the CO_2 emissions of countries, the source decomposition of EF inequality reveals that there are critical implications in terms of Sustainability and Equity. This is largely because wrong incentives are given to the countries participating in such negotiations as a result of the non-application of multi-criteria analysis (which would suggest that negotiations should be based on a wider set of indicators, and not only carbon emissions). The roles played by affluence and the population structures of countries deserve particular attention in developing an understanding of what determines the direction of natural resource flows and so shapes the international distribution of such scarce resources. Additionally, this distribution is driven more by polarization between rich, emergent, and poor countries than by inequality in certain periods.

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CHAPTER 2
SUSTAINABILITY: MEASURING NATURE FROM ECONOMICS

Interest in sustainable development has prompted a search for suitable indicators which might complement or substitute the traditional models of economic success. For this reason, GDP based indicators have come under criticism as they fail in various dimensions, not only in perceiving the global degradation of the environment (with consequent serious threats to humanity), but also in measuring social success. GDP per capita is traditionally used as a measure of society's welfare. However, it only measures the total amount of money interchanged in an economy, in other words, the monetary value of goods and services produced within a country's borders in a given year. It does not take into account the depletion of natural resources or ecological production. Indeed, GDP may appear to grow commensurate with an increased use of fossil fuels or any other depletion of natural resources, yielding an illusionary increase in wealth when the reality is exactly the contrary. Furthermore, those defensive expenditures which aim at avoiding or correcting the effects of GDP growth, either in the social or in the environmental dimension are also added to GDP accounts[13]. As a result, the search for sustainable indicators necessarily involves overcoming such deficiencies of GDP-based indicators. Nevertheless, the search for better indicators may stem from quite different assumptions despite sharing Sustainable Development as their ultimate aim. This is because there are at least two, sometimes contradictory, paradigms of Sustainability itself; the Weak Sustainability paradigm (WS) and the Strong Sustainability paradigm (SS) (see Neumayer (2010) for a detailed discussion of both).

This aim of this chapter is to contextualize the different ecological indicators available, with special emphasis on the Ecological Footprint indicator, which will consequently be used to analyse its international distribution with regard to solvency. The chapter is organized as follows, the first section discusses the two main, and most widely divergent, paradigms from which Sustainability, understood as ecological performance of national economies, can be measured; these are the WS and SS approaches. The second section looks at the physical ecological indicators of the SS approach and how different ecological indicators, apart from EF, are derived. Finally, the third section discusses the technical and conceptual aspects of EF, and provides some statistics of how it has changed, based on the most recently-available data.

2.1 WEAK AND STRONG SUSTAINABILITY APPROACHES

The differences between the weak and strong sustainability approaches are as deep as the existing differences between the two main schools of thought in Economics which deal with the socio-economic system and the environment: Environmental Economics

[13] There are many other dimensions that GDP per capita does not capture properly in measuring social welfare (such as wealth distribution, domestic work, quality of goods and services, etc). Indeed some claim that GDP represents an information failure and its removal would be helpful in improving human wellbeing. However, despite all the theoretical and empirical criticism, this indicator is still widely used by many agents. See Bergh (2009) for further discussion. In any event, whenever it is used, some caution must be taken when interpreting GDP per capita.

and Ecological Economics. Probably the greatest difference between the two paradigms derives from the so-called substitutability assumption[14]. WS assumes that Natural Capital, defined as an aggregate of the different ecological functions with special emphasis on those of resource supply[15], can be replaced by further human-made Capital (manufactured and human capital), by encouraging technological change, as long as the total capital (human-made and natural capital) remains constant. Thus, from this perspective, an economy is sustainable even if it draws down its stock of Natural Capital, provided that there is enough human-made Capital to compensate for such a loss – what matters is the total amount of Capital, rather than its specific components. In contrast, SS considers Natural and Human-made complements rather than substitutability and it claims that at least some ecological services are simply impossible to substitute, these being the basic life support function of the environment.

The WS approach stems from the neoclassical theory of Economic growth and its well-known Cobb-Douglas production function which was extended to account for Non-Renewable Natural resources as a factor of production

$$Y = K^a L^b R^c \quad \text{with} \quad a,b,c > 0 \quad \text{and} \quad a+b+c=1 \qquad (1)$$

Where Y is the Output, K the manufactured capital, L the labour (or human capital) and R the resources (or Natural Capital); a, b and c are the elasticities of output with respect to the factors of production. According to this model, sustainability depends on the amount of total output Y which depends on the total amount of capital available. Therefore, the crucial question is whether or not $a>c$. If we take the above to be true, then it is possible to maintain a permanent output level, despite the declining

[14] See Daly, (1997a; 1997b), Solow (1997), Stiglitz (1997), Victor (1991).
[15] Natural capital may be defined as the "stocks or funds provided by nature (biotic or abiotic) that yield a valuable flow of either natural resources or natural services in the future" (Daly and Farley, 2004) i.e. the population of fish in the ocean generating the flow of fish; the forests that generate timber; the oil reserves whose exploitation provides petrol (Chiesura and de Groot, 2003).

availability of natural resources (Victor, 1991). By construction, expression (1) assumes a constant degree of substitution between inputs, and thus it assumes that Natural resources *R* can be made very small as long as *K* or *L* compensate for it[16]. WS thus can be seen as an extension and generalization of the Hartwick rule (Hartwick, 1977), which maintains that, in order to ensure the standard of living of a society into the indefinite future, it is necessary to invest in human-made Capital, at least to the extent that we offset the declining stocks of non-renewable resources (Martinez-Alier and Roca, 2001). In so doing, earlier generations are entitled to draw down the Natural Capital (optimally) as long as they add (optimally) to the stock of reproducible capital (Solow, 1974).

One of the most famous WS indicators is the Genuine Saving (GS) indicator which is used by the World Bank[17]. Circumnavigating the more complex derivations, it is measured as:

$$\begin{aligned}\text{GS} &= \text{investment in man-made capital} - \text{net foreign borrowing} + \text{net official} \\ &\text{transfers} - \text{depreciation of man-made capital} - \text{net depreciation of natural} \\ &\text{capital} + \text{current education expenditures}\end{aligned} \tag{2}$$

Expression (2) is clearly inspired by expression (1). Another closed example of the WS indicator can be found in Pearce and Atkinson (1993). All of these share the same assumptions of substitutability among forms of capital and, apart from some additional criticisms (see Dietz and Neumayer, 2004), they by and large conclude that the developing countries have the more unsustainable economies[18].

[16] Some models assume that there is a minimum *R* beyond which Production is not possible: the critical natural Capital.
[17] World Bank call it "Net Adjusted Savings"
[18] According to Neumayer (2010) such a dismal conclusion crucially depends on the method of resource accounting, which is actually rather arbitrary.

SS, in contrast, emphasizes the gravity of our uncertainty and ignorance[19] regarding the detrimental consequences of the depletion of natural capital, especially when such depletion is often irreversible. Therefore, SS calls for the preservation of the physical stock of natural capital in order to maintain its functions intact, which allows for basic life support for humanity, something which WS often neglects when discussing natural capital substitution. Some authors refer to such vital functions as *Critical* Natural Capital. Consequently, SS and ecological economics schools demand a drastic change in economic thought: macroeconomics cannot be envisioned as “the whole” but as a subsystem of the *finite* ecosystem (Daly, 1992). A SS perspective thus pays attention to both the limitedness of resources and the limitedness of the waste- and pollution-absorbing capacity of the environment (Neumayer, 2010), which at the end of the day, entails the use of renewable resources so that their stock does not deteriorate and use the sink capacity of the environment to the extent that its natural absorptive capacity does not deteriorate over time. On the other hand, non-renewable natural resources can be used at the same rate at which renewable alternatives are provided.

So, from this perspective, the substitutability assumption does not hold. Instead, SS states that the relationship between human-made capital and natural capital is that of a complement rather than that of a substitute[20]. Indeed, natural resources are needed to build further human-made Capital (the worker considered as a machine needs a form of

[19] Risk refers to the situation where the set of all possible states of the world, its probability distribution and its resulting payoffs can be objectively known. Uncertainty refers to the same situation but without knowing either the probability distribution or the resulting payoffs of the set of possible estates of the World. Ignorance refers to the situation where even the set of possible states of the world is completely unknown.

[20] “Since the production function is often explained as a technical recipe, we might say that Solow's recipe calls for making a cake with only the cook and his kitchen. We do not need flour, eggs, sugar, etc., nor electricity or natural gas, nor even firewood. If we want a bigger cake, the cook simply stirs faster in a bigger bowl and cooks the empty bowl in a bigger oven that somehow heats itself. Nor does the cook have any cleaning up to do, because the production recipe produces no wastes” from (Daly, 1997a)

external energy). Recalling equation (1), and stating that Capital is a function of Capital, Labour and Resources, we get that

$$K = K^{d} L^{e} R^{f} \quad \text{with} \quad d, e, f > 0 \quad \text{and} \quad d + e + f = 1 \qquad (3)$$

As Victor (1991) shows, by solving equation (3) for Capital[21] and substituting it into the production function (1), another Cobb-Douglas production function is obtained in which output is a function only of Resources and Labour[22]

$$Y = L^{\frac{ae}{(1-d)}+b} R^{\frac{af}{(1-d)}+c} \qquad (4)$$

Such a result removes any possibility of substitution.

Furthermore, SS adds an additional epistemological criticism which is rooted in the notion of c*apital* itself: – notice that in expressions (1) to (4) prices are used as the common denominator, so that the different factors can be linked between them. Prices thus allow for the adding up things such as buildings, tractors, roads, expenditure in education, fossil fuel reserves, forests, etc. However, aggregating heterogeneous things such as tractors, buildings and other capital goods and convert them into a single indicator of Capital (as far as human-made capital is concerned) may represent a meaningless consistency. This has become huge debate in recent years and stems from one of the most discussed disagreements in economics, known as the Cambridge Controversy, where Capital measurement (human-made capital only) became the battlefield between Neoclassical economists such as Paul Samuelson and Robert Solow

[21] From (3) we get that $K = L^{\frac{e}{(1-d)}} R^{\frac{f}{(1-d)}}$

[22] Actually, the result expressed in equation (4) could be linked to the Marxist approach where any new value can only come from either a human being's work or nature, so that the combination of both nature and labour under the specific social relationship entailed in the capitalist production is what Capital actually is according to this school of thought — the specific social combination of labour and nature.

(at the Massachusetts Institute of Technology, in Cambridge, Massachusetts) and Post-Keynesian economists such as Joan Robinson and Piero Sraffa (at the University of Cambridge, England). Neoclassical theory assumes as its basic principle that the quantity of Capital can be measured independently of its price, however, as Post-Keynesian economists noticed, such an assumption is circular when Neoclassical economists measure the *quantity* of Capital by using its *price*, which at the same time depends on the available *quantity*[23]. Turning back to natural capital, this rationale becomes even clearer when it is applied to natural resources: the value of oil, by way of example, depends on current and future expected prices, extraction costs, rates of interest, and future demands which at the same time depend on the quantity of present and future reserves (Victor, 1991).

However, the main criticism by SS of the Natural Capital concept is the very monetization of nature involved in such models: the pollution of a river might be valued in terms of crop losses, the costs involved in cleaning the river, or even a decrease in tourism, but what about the illness contracted by the children who bathe in it? Here, economic theory faces a basic problem, one better known in Ecological Economics as the incommensurability problem (Martinez-Alier et al., 1998); there is no objective basis for the comparison of various alternatives (Røpke, 2001). WS assumes that all values can be translated into money[24]. However, it is not that simple.

Furthermore, the concept of “natural capital” simplifies the complexity of different ecological functions into a single aggregate, despite the fact that such functions are not

[23] See Cohen and Harcourt (2003) for a review of the Cambridge Controversy.
[24] Foster et al. (2011) refers to the conversion of ecological values into monetary values as the Midas effect in reference to the Greek and Roman Myth. According to Ovid in his *Metamorphoses* “the God Bacchus (Dionysus) offers to King Midas of Phrygia his choice of whatever he wishes, in return for the help he had given to the satyr Sylenus, Bacchus’ tutor and foster father. Midas decides he want his gift to be that he touches turns into gold.[...] The folly of Midas’ choice, however, materializes when he discovers that his food and drink also turns into gold at his touch, leaving him hungry and thirsty” (Foster et al., 2011)

substitutable among themselves (the depletion of the ozone layer cannot be substituted by increasing the number of whales, for example). So, from an SS approach, not only can human made capital not be substituted by natural capital, but also substitution within natural capital itself is not acceptable, (and so it cannot be constructed on such an aggregate). Yet, the very concept of natural capital, or in other words, the capitalization of nature, entails the idea that the environment is nothing more than a form of capital, and so it is seen as a mere source of material and energy at the service of economic output[25]. The social and cultural dimensions of nature's functions fulfil crucial human needs and contribute to the sustainable development of human societies at large, rather than market appraisal (Chiesura and Groot, 2003).

This thesis is set within the Ecological Economics framework of analyses, and so we consider the Strong Sustainability approach to be more realistic. Indeed, its empirical analyses (Chapters 3 to 6) are performed by using data of the Ecological Footprint (EF), a physical indicator in the area of SS. In the next section, physical indicators other than EF will be discussed briefly, these are Material Flows (MF) and the Human Appropriation of Net Primary Production (HANPP).

2.2 PHYSICAL INDICATORS OF STRONG SUSTAINABILITY

WS indicators tend to be monetized indicators (such as GS), while SS indicators tend to be physical indicators more connected to the ecological sciences. In this sense, the ecological economics school has been developing new methods to carry out calculations

[25] In Marxist terms, such "natural capital" is one of the Conditions of production, together with the health and skills of labour power ("human capital") and the communal conditions (infrastructures). James O'Connor (1998) argues that the underproduction of these conditions, is what has been called the second contradiction of Capitalism, since the collective interest of Capital is to secure its provision, however, at the same time the capitalist firms and states fail to renew or protect the conditions of production (they are thus under produced). The contradiction is that capitalist firms and states are intrinsically motivated by a drive for accumulation in order to minimize costs such as worker welfare and ecological protection.

on Nature in order to overcome those problems identified by the neoclassical school (some of which are described above), and to become more consistent with the ecology. However, such attempts are not entirely free of shortcomings.

Take carrying capacity for example: it is a well-known term in ecology which is widely used to "measure the maximum rates of resource harvesting and waste generation (the maximum load) that can be sustained indefinitely without progressively impairing the productivity and functional integrity of relevant ecosystems wherever the latter may be located" (Rees, 2000). In other words, in biology, the carrying capacity of say, a frog pond, is the maximum population of frogs which its environment (the pond and surrounding area) can sustain indefinitely. Hence, from this purely biological perspective, ecologists can define how many individuals of any species can be maintained by its environment, and so sustainability is clearly defined. Human population, also subject to its natural environment, cannot grow indefinitely however, for various reasons, it is highly problematic to apply such a concept to human societies (Martinez-Alier and Roca, 2001)

Firstly, in general, all the frogs in a pond consume more or less the same amount of resources, however, there are huge differences among people in the amount of resources and energy used to satisfy endosomatic and exosomatic needs[26]; if we wish to know the carrying capacity of a certain area it is necessary to specify the acceptable consumption level in advance, results will differ if we use a rich country's standard of living as opposed to the standard of living in a third world country. Let us assume that we agree that such delimitation be calculated by each person possessing certain basic necessities,

[26] Endosomatic energy refers to the use of energy inside the body in the form of food energy. Human adults use 3.65GJ per year (Gigajoules, thousands of million joules). Exosomatic energy, in contrast, is the energy used outside of the body, such as for instance the energy used in cooking the food that we eat. Exosomatic energy highly depends on income level and style of living. According to Fischer-Kowalski and Haberl (2007), human adults in industrial societies need around to 200–300 GJ per person per year.

but then, another question automatically emerges – what do we consider to be basic necessities? Are they biophysical necessities or do they also include social necessities? What level of welfare are we aiming to sustain? Hence, the problem is not only related to the size of the population which is to be sustained, but also of how *large* we want that population to be in terms of availability of necessities. In human societies, the amount of resources consumed is not ecologically, but socially and even politically determined. Clearly, a finite world can support only a finite population, however, as Neumann and Morgestern (2007) stated, we cannot maximize two variables (population number and population size) at the same time; one of them is always assumed to be constant. Depending on the approach adopted, the carrying capacity (population size) will be very different.

Secondly, technological change can easily modify those necessities, demanding more or less capacity to sustain the human population, however, our agricultural production systems have evolved to such an extent that the advances we have made in agricultural productivity arise from the development of the chemical industry and the use of fossil fuels. By taking this into account, we acknowledge that the carrying capacity has once more to be modified.

Thirdly, it is quite possible that migrations play an important role. The movement of people is again politically, rather than ecologically, determined i.e. migration occurs only for certain people with certain characteristics. In addition, human activity often results in the displacement of other species.

Finally, international trade is also an important factor which needs to be considered since it can actually be viewed as the appropriation of carrying capacity of some other location or species. Therefore, it is clear that the measurement of the carrying capacity of the human species is far from being straightforward.

Thus, the carrying capacity of human beings might not be as useful as it is in Ecology for the assessment of other species. Nevertheless, this critical deliberation about the suitability of the carrying capacity of human societies has helped to enlighten us as to the principal factors which must be taken into account in determining the ecological impact of human societies in the environment: a growing population, larger population (higher per capita consumption) and the technology used. This yields the IPAT identity which emerged from an intensive academic debate held in 70s between Ehrlich and Holdren (1971) and Commoner (1972)[27]. According to the IPAT identity, the environmental impact (I) is related to Population (P), Affluence (A) and Technology (T), so that I=PAT.

$$I = P \times \frac{Y}{P} \times \frac{I}{Y} \tag{5}$$

where I is the environmental impact, P, the Population and Y the economic output. This identity allows us to calculate (assuming unit elasticities) a concrete environmental impact – probably the best-known application of this for CO_2 emissions (Kaya, 1990). Such a methodology will be used later on in this thesis however, at this point, the IPAT identity (despite being a useful tool for researchers and policy makers) does not allow us to measure how sustainable human society is. Some of the most popular aggregate indicators of SS in this area are Ecological Footprint (EF), Human Appropriation of Net Primary Production (HANPP) and Material Flow Accounting (MFA).

The **EF** consists in turning around the carrying capacity question: instead of how many people can be fed in a given habitat (land), the EF considers how much land is needed to sustain the consumption and waste absorption of a given population using available

[27] For a detailed history of this full-scale academic war in the 70s in relation to the IPAT identity, see (Chertow, 2000).

technologies (Martinez-Alier and Roca, 2001). The Ecological Footprint (EF) method was proposed by Wackernagel and Rees as the outcome of a series of discussions which focused on applying the carrying capacity concept to the human species. EF is formally defined as the area of productive land and water ecosystems, located anywhere around the world, which is required to produce the resources that the population consumes and assimilate the wastes that the population produces. To do this, the EF considers different categories of bioproductive lands useful for human societies[28]. It was designed to represent the human consumption of biological resources and the generation of waste in terms of appropriated ecosystem area (Kitzes et al., 2009). In other words, what is being answered in the EF framework is how many hectares, with average biological productivity of the whole earth (global hectares), are needed to maintain a given population consumption, such as a country, a city, a business or even an individual (Kitzes et al., 2009).

The typical application of sustainability measurement is the comparison of the EF of a country with its available biocapacity and to see then whether the country has an ecological deficit (needing more hectares than is actually available in its national territory) or an ecological surplus (the EF is lower than the available biocapacity within the country). It should be kept in mind that EF is a consumption-based indicator, so the resources extracted from a developing country, but exported to a developed country, count towards the EF of the latter. As will be discussed in more detail later, the empirical analyses of the present thesis will use EF data and it should be noted that the assessment of sustainability by this indicator can be highly problematic, for instance, it only takes into account renewable resources and a single type of waste product (carbon).

[28] Croplands, grazing lands, fishing ground, forests, built-up land and finally carbon land, which is the only land use type included in the EF exclusively dedicated to tracking a waste product: amount of land needed to uptake CO_2 emissions.

An earlier measure of the impact of humans on the ecosystem is the Human Appropriation of Net Primary Production, or **HANPP**, first introduced by Vitousek et al. (1986), which measures the intensity of human use of ecosystems by looking at a country's territory – life on Earth ultimately depends on solar energy, which is absorbed by plants and through photosynthesis transformed into biomass. This stored energy in the form of biomass is the Gross Primary Production which serves, on one hand as input for the plants themselves and, on the other hand to nourish other species such as humans, animals, fungi, etc. (Haberl et al., 2004). The amount of such energy available for other species is the Net Primary Production (NPP). The HANPP thus consists of the human domination of such NPP. It is the sum of changes in NPP resulting from land conversion and human drawdown of NPP from the ecosystem through harvesting, including plants, livestock grazing, fires, etc. extracted during this process (Haberl et al., 2012).

Its calculation requires first estimating the natural potential vegetation (derived from vegetation models), this is the vegetation that would exist in the absence of human land use under current climate conditions. HANPP is thus defined as the difference between the NPP of the potential natural vegetation (NPP_0) and the amount of biomass currently available in ecological cycles (NPP_t). Two are the main processes that contribute to human appropriation of NPP: (1) changes in the average productivity of ecosystems (NPP per unit area and year), e.g. the construction of a road in a forested ecosystem; and (2) human withdrawal of NPP from ecosystems through harvest. If the NPP of the actual vegetation is denoted as NPP_{act} and harvest as NPP_h, HANPP can be defined as (Haberl, 1997):

$$HANPP = NPP_0 - NPP_t \text{ with } NPP_t = NPP_{act} - NPP_h \qquad (6)$$

HANPP measures to what extent human activities alter the availability of biomass, and so it can be seen as a measure of the scale of human activity compared to natural processes, by which sustainability can be examined. Of course, the result of the HANPP is highly influenced by the regional characteristics of the territory analysed. Indeed, HANPP was designed as a regional impact indicator and so it provides information about the physical scale within a country's territory, without taking into account important goods, which is important in many contexts, however it does not consider land use outside the country borders to produce imported goods. Subsequently, the concept of "embodied HANPP" (eHANPP) emerged – in contrast to traditional HANPP, it takes into account trade and therefore it adds to the HANPP of a country's imported goods and subtracts from the HANPP of exported goods (Haberl et al., 2012). In so doing, eHANPP is also a consumption-based indicator and so more comparable to EF, despite answering different research questions (see Haberl et al., 2004). In any case, EF, as an indicator, only measures a certain type of natural resources and neglects others.

Finally, **MFA** indicators, inspired by the early works of Ayres and Kneese (1969), are based on the idea of the analysis of the metabolism of certain societies (Fischer-Kowalski and Hüttler, 1998; Fischer-Kowalski, 1998) They look at what materials (measured in tonnes) enter a society, and explain that according to the first law of thermodynamics (mass conservation), the same amount of material either is either released from the society or accumulates in the system. In this regard, some of the spirit of the MFA indicators is rooted in the dissatisfaction with environmental policies which mainly, if not exclusively, focus on emissions and waste products, that is to say, the output of societal metabolism, while neglecting the material inputs. Continuous accumulation of materials within the economy also presents certain problems which are related to future waste flows as well as land use. The MFA thus seeks to account for the physical counterpart of the monetary economy in mass units.

The MFA is often used to test the industrial ecological hypothesis of dematerialization (Cleveland and Ruth, 1998; De Bruyn and Opschoor, 1997), according to which countries tend to use less material in absolute terms (strong dematerialization), or at least per unit of service produced (weak dematerialization or decoupling), due to technological progress, which is in turn made possible by economic growth (Canellas et al., 2004). To do this, different indicators are derived from the MFA framework[29] and provide information about the different flows of the societal metabolism. Some of these are focused on the input measurement, while others concentrate more on material output. However, such indicators cannot be used to measure sustainability since different materials have vastly different impacts on the environment (the prototypical example is a tonne of sand compared to a tonne of mercury), however, an analysis of the insights of the physical economy can provide valuable information as to how we can achieve sustainability. Measuring the ecological impact of human societies involves certain difficulties with regards to the accounting and the assumptions used, even when physical indicators are taken into account. However these assumptions are necessary to make such calculations in Nature. The various different ecological indicators approach sustainability measurement from different perspectives, and so their conclusions at times point in opposite directions. In such a situation, the assessment of a given development path must derive from multi-criteria decision making and the acceptance of the incommensurability faced when calculations are made in Nature (see Martinez-Alier et al., 1998). Therefore, even though each indicator provides us with contrasting information, this information is nonetheless important for economists and sustainability

[29] See Bringezu et al., 2003

assessment should accept it, in all its complexity. Perhaps the best way of exploring this information is by using multi-criteria decision making, and by also including monetary valuations (Kitzes et al., 2009; Martinez-Alier and Roca, 2001). A sensible judgement does not require the distillation of all the available information into one single value unit.

The main purpose of this thesis, however, is not to make a multi-criteria assessment of sustainability, but to focus on the distributional analysis of natural resource consumption in order to discuss and analyse one of the social aspects of Sustainable Development: that of international Equity. To do so, the indicator used will be the EF framework, not because we believe that this indicator is superior to the other indicators[30] above, but because, on the one hand, of its pedagogical strength, and, on the other, of the availability of data. The EF of a country is based on how much land is being acquired by its consumers, regardless of where or when land is located, so that in some cases a country may even be consuming the land of other countries; indeed, the whole world may be consuming the land (and sea) of the countries of future generations. The EF index thus captures a clear distributional content (Martinez-Alier, 2002); EF encapsulates in its construction the unequal relations that exist between countries and generations, something which cannot be reflected so clearly by the other environmental indices. Broadly speaking, the distributional analysis of EF allows us to understand how the planet is being shared by current generations and at what expense to future generations.

[30] See Van den Bergh and Verbruggen (1999) for a strong criticism of EF as a sustainability indicator.

2.3 THE ECOLOGICAL FOOTPRINT

If we accept the incommensurability problem, the Ecological Footprint (EF) framework can provide us with a very illuminating view of how valuations can be made in nature. The EF, introduced by Rees and later developed with the help of Wackernagel, proposes as a common denominator a global bio-productive hectare, each hectare having the average biological productivity of the whole earth. So then, the question becomes how many global hectares a given population needs to maintain its consumption patterns; the answer is the Ecological Footprint.

As mentioned above, the EF does not account for all natural resources, on the contrary it only accounts for the renewable natural resources that can be converted into land and sea by photosynthetic activity and the production of biomass for human usage. In fact, the EF framework addresses one particular research question: how much of the regenerative capacity of the biosphere is being taken up by human activities via resource consumption? This includes 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). Since both renewal and absorption depend on the health and integrity of ecosystems, regenerative capacity is interpreted for some authors as a reliable proxy for the life-support capacity of natural capital (Monfreda et al., 2004). Therefore, this indicator can be read as the amount of *critical* natural capital available (Ekins, 2003; Victor, 1991) as it accounts for one of the key aspects of natural capital, the Earth's ability to provide conditions conducive to life[31].

[31] This may be subject to criticism as far as Natural Capital assumptions are concerned. See the previous section.

2.3.1 CALCULATION OF THE EF

EF accounts are made up of six types of land use which are assumed to produce useful resources for humans: cropland, grazing land and fishing grounds to supply food and clothes, forest land for timber and wood fuel, built-up land, including land covered by human infrastructure, and finally, forests for the intake of carbon emissions (the carbon footprint).

$$EF = \sum_k EF_k \tag{7}$$

where k = cropland, grazing land, fishing ground, forest land, carbon land, built-up land.

Cropland: It is considered the most bioproductive of all lands (according to human needs). It accounts for the area required to grow all crop products for food or fibre, including livestock feeds, oil crops and rubber.

Grazing land: It measures the area of grassland used in addition to crop feeds to support livestock. Thus, it accounts for land needed to raise livestock for meat, dairy, hide, and wool products.

Fishing ground: It is calculated on the basis of the estimation of primary production required to support the fish caught (taking the average of the trophic level of species in question).

Forest land: Its calculation is based on the amount of lumber, pulp, timber products and fuel wood consumed in a country on an annual basis.

Carbon land. It is the area of forests that would be needed for the uptake of all the anthropogenic CO_2 emissions released in order to prevent an increase in the atmospheric concentration of CO_2. This includes fossil fuel emissions, changes in land use and emissions from the international transportation of passengers and freight. Since the world's oceans absorb about 1.8 Giga tons of carbon (IPCC, 2001), only the remaining carbon is accounted for by the EF.

It is thus clear that EF measures land appropriation by consumed products where some of them appropriate land directly (paper, food, housing, etc.), however the use of fossil energy included in all products involves fictive and indirect use of land. Such fictive land can seem strange but Røpke (2001) justifies it from three different perspectives: first, a (strong) sustainable economy must not drain natural energy but itself produce the energy needed for consumption; second, exhaustible resources (fuel) cannot be used more quickly than the availability of renewable replacements, for example, an economy could primarily rely on biomass as fuel through the planting of trees; and third, as mentioned above, the calculated area needs to be approximately substantial enough to soak up the extra emissions of CO_2, which are the result of the use of fossil fuels[32].

The basic intuition of converting the mass of resources consumed into units of area is more clearly seen by rearranging a simple equation: the land yield of a given year may be defined as tons produced per unit of area (Yield= Tons per year / Area). Hence, it is easy to see how many average areas there are: Area = Tons per year / Yield (Wackernagel et al., 2004). More formally, the EF calculation begins by computing the EF of production of a country, EF_P:

$$EF_P = \frac{P_i}{Y_N} \cdot YF \cdot EQF \tag{8}$$

where P is the amount of a product harvested or waste emitted i, Y_N is the national average yield for P_i. YF is the yield factor used to capture the difference between national average and world average (ratio of national average to world average), and

[32] Further details on the different data used and the methods employed to calculate each land use type, as well as the underlying assumptions, can be found in Ewing et al., (2010).

finally *EQF* is the equivalence factor which is used to convert all of the average productivities of the different land use types into a global biologically productive area. Hence, the process of constructing the EF consists firstly of converting consumption in terms of area needed (P/Y_N), secondly, the different types of land of the different countries are standardized to the world average productivity for each type of land (*YF*), for example, a cropland hectare of Zambia in 2007 is equivalent to 0.2 world average hectare of cropland, while forest land in Germany is 4.1 times the world forest average hectare. Finally, it is necessary to convert all types of land into a *single* earth average bioproductive land (*EQF*), only then can all of the components be added to the global Ecological Footprint of each country. So the *EQF* is used to convert the areas of different land use types, at their respective world average productivities, into their equivalent areas at global average bioproductivity across *all* land use types (Ewing et al., 2010). To do so, the different land use types are weighted in terms of their capacity to produce resources useful for humans. In this sense, *EQF* varies by land use type as well as by year, and captures the different "quality" of the different land use types, for example, in 2007 the cropland area had an *EQF* of 2.51 meaning that cropland productivity was more than double the average productivity for all lands combined. This same year, however, grazing land was 0.46 times, or just under half of, the world average productivity[33].

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):

$$EF_C = EF_P + EF_I - EF_E \tag{9}$$

[33] For more details, and the assumptions involved see Ewing et al. (2010)

In summary, EF describes consumption in terms of land (and sea) regardless of *where* and *when* is located: a country may be consuming the land of other countries or even of future generations.

2.3.2 ADVANTAGES AND DRAWBACKS OF THE ECOLOGICAL FOOTPRINT

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 considerable debate, resulting in several criticisms of the measure (Fiala, 2008; Bergh and Verbruggen, 1999). Such debates are beyond the scope of this thesis since EF is here merely used as an indicator to measure the quantity of natural resources consumed by a country, and measured in global hectares. In any case, the EF as an indicator of the quantity of resource consumption still has some drawbacks. Indeed, any aggregate indicator (as it is the case of measures of aggregate economic output) will have both strengths and weaknesses, and this also applies to EF. It is worth saying that the EF has benefited from the academic scrutiny of its properties and limitations and this has led to its continual improvement. Its strengths and weaknesses are now well-known, allowing transparent and unequivocal interpretation of EF analyses (Caviglia-Harris et al. 2009; Kitzes and Wackernagel, 2009; White, 2007). As a result, the EF has been adopted by a number of prominent institutions and academic scholars.

Different methods of country-level EF assessments have been developed for many nations (Aubauer, 2011; Bicknell et al., 1998; Ferng, 2001; Monfreda et al., 2004; Van Vuuren and Smeets, 2000; Wackernagel and Rees, 1996; Wiedmann et al., 2006). However the most widely used methodology for national footprint accounting is that of the 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, the EF has been adopted by a growing number of government authorities, agencies, and policy makers as a measure of ecological performance. Notable examples include 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 in measuring the environmental performance of the European Union, or the United Nations Development Programme (UNDP, 2010).

The main advantage of the EF is its pedagogical strength which comes from its relationship with the carrying capacity concept. It is fairly straightforward to conceptualize the ecological impact in terms of space, and so it becomes easier to raise ecological awareness in society and to influence policy makers. Since space on earth is unquestionably limited, (there is a finite number of global hectares), any country that exhibits a relatively high EF should automatically be concerned about the inequality which emerges using this indicator. This fact, together with the availability of data, allows us to use the ecological impact to analyse the distribution of natural resource consumption. Indeed, the EF explored in this thesis can be also be found in the literature concerned with Unequal Ecological Exchange: according to Hornborg (2011), departing from the early work on structural economic inequalities driven by international trade in Latin America (Prebisch, 1950), the concepts of ‘embodied labour’ (Emmanuel, 1973) and structural relations of dependency between peripheries and cores (Frank, 1967) built what today is known as World-system analyses (Wallerstein, 1974-1989). At the same time, other similar but ecologically-based literature was being developed; Borgström (1965) and Catton (1982) conceptualized the idea of 'embodied land', that is to say the consumption of resources which might require more land area than is actually available in one's own national territory; Borgström called these 'ghost acreages' to emphasize the fact that some foodstuffs (such as meat or dairy products) consumed by rich countries were typically imported from poorer countries, something of which consumers were unaware. By combining all of these concepts, Bunker (1985) assembled the first formulation of unequal *ecological* exchange. A few years later, Wackernagel and Rees (1996) popularized the EF which can be seen as a direct by-product of this tradition in the literature. Several researchers have found this measure useful in order to analyse asymmetrical flows in ecological terms (Anderson and Lindroth, 2001; Torras, 2003; York et al., 2003; Rice, 2007; Niccolucci et al., 2012, among others[34])

However, the EF has some drawbacks regarding how it calculates the quantity of natural resources consumed (not sustainability). Firstly, it does not consider the demand of non-organic materials, although it does take into account the use of fossil fuels (the carbon footprint)., through the calculation of a fictitious land, For this reason, another aspect which also needs to be taken into account is the intensive method of converting CO_2 emissions in global hectares as represented by the forests which are needed to absorb such emissions. (Bergh and Verbruggen, 1999). We note that such absorption depends on the type and the age of forest considered. Indeed, the EF accounting limits different types of lands to one single service, despite the fact that lands can, in reality, provide multiple services. Actually, the EF implicitly assumes the possibility of the

[34] This work is remarkable as it focuses on capturing unequal ecological Exchange by using the 'framework of 'social metabolism' (Fischer-Kowalsky, 1998) through the Material Flow analysis. Some examples are Pérez-Rincón (2006), Giljum and Eisenmenger (2004), Dittrich and Bringezu (2010, 2012). Their results generally show that Core countries import much more weight (materials) than they export, whereas in the peripheral countries, the opposite applies.

substitution of different categories of environmental pressure which shows one of its clear weaknesses. Finally, EF does not distinguish between cropland worked using sustainable techniques and cropland on which pesticides and fertilizers were used; interestingly, the latter actually results in a lower EF than the former. These inconsistencies must be taken into account when looking at the EF as a whole, it is important to keep in mind that the distributional analyses performed in this thesis focus on the differences between countries in terms of resource consumption, and not differences in sustainability between countries. Therefore, the distributional analysis of natural resource consumption is developed by using the EF framework, which allows a direct comparison between countries (in global hectares) but at the expense of some additional assumptions (see Ewing et al. 2010a).

The distributional analyses performed in this thesis look at how the distribution of consumption is modelled, and how this has evolved in the last few decades. Also, we discuss what drives the shapes such distributions. Once we know what the EF is and from where it comes, before entering into distributional issues, it is necessary to know where we are in terms of sustainable scale when EF is used.

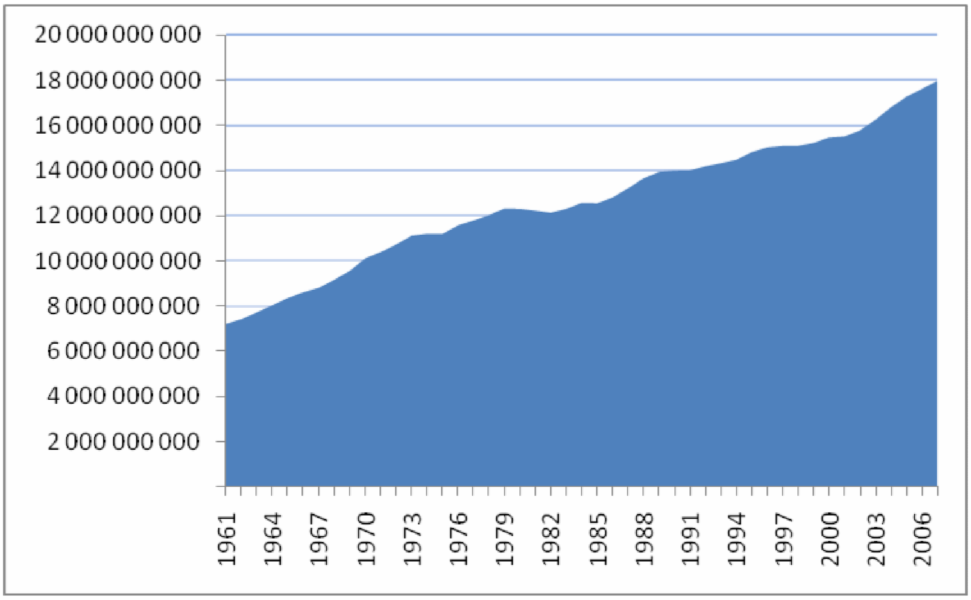
2.3.3 ECOLOGICAL FOOTPRINT DATA TRENDS

According to the Ecological Footprint Atlas 2010 (Ewing et al., 2010a), natural resource consumption is not evenly distributed around the world. Some countries register an EF per capita which is ten times that of other countries[35]. Indeed, some countries may require more global hectares than those already available within their national boundaries in order to maintain their consumption patterns. At the same time, countries

[35] For the year 2007, the average Spanish citizen had 4.44 times the EF of an average Moroccan citizen; An average US citizen had 8.75 times the EF of an average Indian citizen; and finally, in the extreme values of the distribution, an average citizen of UAE had 24.46 times the EF of an average citizen East Timor.

in Africa, Latin America and South East Asia have some of the lowest EF per person in the world, which in many cases is not enough to satisfy their basic needs for food, shelter, health and sanitation (op. cit.). Yet, the results obtained by the Ecological Footprint Network show that the Ecological Footprint of the whole world in 2007 was about 18 billion global hectares, which clearly indicates the lack of capacity of the earth, since the whole world contains only approximately 12 billion of hectares. Figure 1 shows the trend of EF over the last four decades. It can be seen that since the mid-70s the world consumption patterns have required more than 12 billion hectares (or one earth) to sustain consumption. This continued to increase and reached 18 billion hectares in 2007, which means that 1.5 earths were required to meet the needs for that population, or in other words, it took the earth one year and six months to regenerate the resources used in that year.

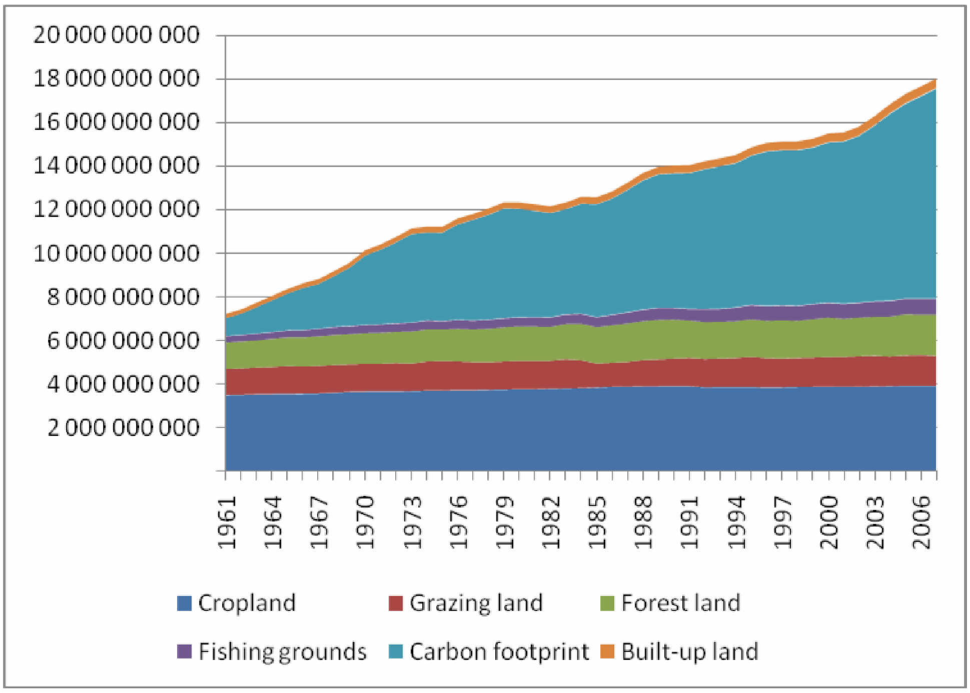
Figure 1. World EF in Global Hectares, 1961 to 2007.



Source: own elaboration from data (Global Footprint Network, 2010)

Therefore, the EF framework unambiguously says that the natural resource consumption of human kind has been continuously increasing in recent years, and that this is resulting in the depletion of natural capital, which in other words is worsening the welfare of future generations in terms of resource availability. However, as can be seen in figure 2, such excess has been mainly driven by the Carbon Footprint, whose increase reflects the fuel-based economic growth of the last few decades.

Figure 2. World EF in Global Hectares, 1961 to 2007 (by source).



Source: own derivation from data (Global Footprint Network)

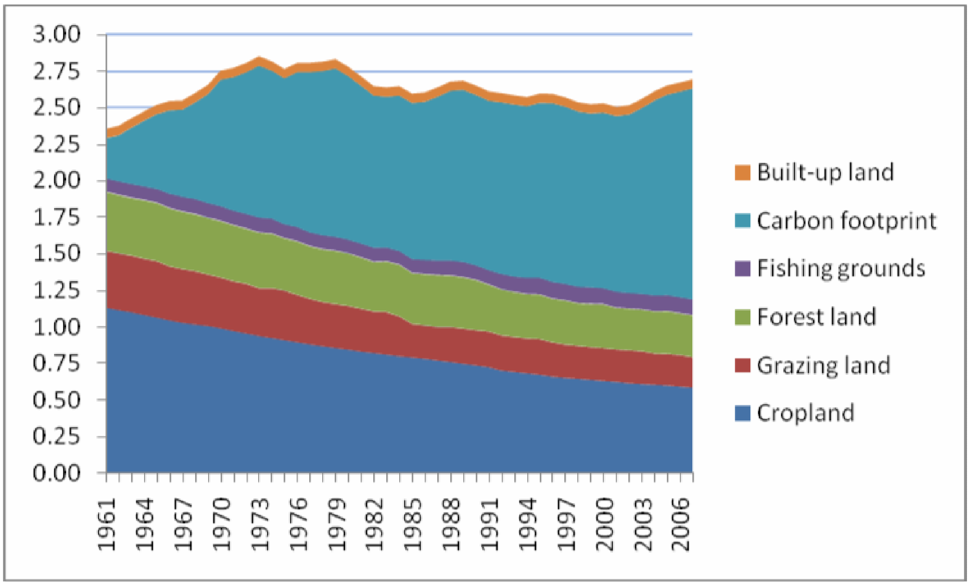
In the period 1961-2007, the world Population has also increased. Therefore it might be more sensible to look at the per capita levels of the EF. Figure 3 shows how, despite population growth[36], the EF per capita also tended to increase in the course of the period, from 2.36 in 1961 to 2.70 in 2007 (a 14.4% increase). Once more, carbon

[36] During the period 1961-2007, World population increased a 116% while World EF increased a 149%. Hence the EF per capita increased.

footprint plays an important role in this increase one but which was mainly compensated for by the decrease in the cropland Footprint. Notice that in 1961, the bulk of the World EF per capita was largely dominated by the cropland footprint but that this later turned into carbon footprint.

According to the Ecological Footprint Network, there is a generalized trend by which countries go from a crop-dominant EF per capita to a carbon-dominant EF per capita as they increase their income (measured as GDP per capita). While low income countries maintained a relatively low carbon Footprint with a biomass-based footprint accounting for most of their EF, high income economies saw a rapid growth in the share of the EF from carbon dioxide (Ewing et al., 2010).

Figure 3. World EF per capita in Global Hectares, 1961 to 2007 (by source).



Source: own elaboration from data (Global Footprint Network, 2010)

Indeed, EF per capita only represents a world average without reflecting the huge differences among countries. The same occurs when we refer to a specific country EF per capita. However, they provide critical information: if everyone in the world in 2007 lived like an average resident of the USA or of the United Arab Emirates, more than 4.5 planet earths would be required to support humanity's consumption rates. If instead the population of the world lived like the average person in India, humanity would use less than half the planet's biocapacity (Ewing et al., 2010). Such disparity amongst countries violates environmental equity postulates whereby no group or community should bear a disproportionate share of the harmful effects of environmental hazards. In the present EF framework, these hazards are accounted for in terms of lack of natural resource consumption. Moreover, since the achievement of sustainability is a global issue rather than local one, a certain consumption pattern may be considered sustainable insofar as it is generalized on a global scale, otherwise one of the basic social pillars that of equity, is being neglected. Indeed, as several studies have suggested, the Netherlands fallacy[37] must be taken into account, since a country's trade may play an important role in this issue.

In the next chapter, we will examine international inequality trends in terms of natural resource consumption per capita as measured by the EF framework and we will disentangle some of the underlying factors which lie behind such inequality. In doing so, we hope to aid in advancing toward the achievement of sustainability without neglecting one of its basic dimensions, known as environmental equity.

The Ecological Footprint data used in this thesis comes from the Global Footprint Network. Since other sources are also employed (mainly World Bank data), the

[37] The concept of the "Netherlands fallacy" refers to the idea of wrongly assuming that the ecological impacts of a certain country are contained within its own territory. It was first introduced by Ehrlich and Holdren in their seminal paper of 1971 when discussing the inequitable utilization of natural resources: "We call this notion 'the Netherlands fallacy'. The Netherlands actually requires large chunks of the earth's resources and vast areas of land not within its borders to maintain itself. For example, it is the second largest per capita importer of protein in the world, and it imports 63 percent of its cereals, including 100 percent of its corn and rice. It also imports all of its cotton, 77 percent of its wool, and all of its iron ore, antimony, bauxite, chromium, copper, gold, lead, magnesite, manganese, mercury, molybdenum, nickel, silver, tin, tungsten, vanadium, zinc, phosphate rock (fertilizer), potash (fertilizer), asbestos, and diamonds. It produces energy equivalent to some 20 million metric tons of coal and consumes the equivalent of over 47 million metric tons." (Erhlich and Holdren, 1971).

different empirical analyses performed may be based on different subsets of data available as some observations are lost in the process of merging datasets. However, all of the samples keep their statistical representativeness and we will carefully account for this as it arises.

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CHAPTER 3
INEQUALITY ANALYSIS IN INTERNATIONAL EF DISTRIBUTION

This chapter aims at analysing, from the perspective of inequality, how natural resources have been shared among countries in the last four decades. This analysis should be considered as an extension of what analyses on global sustainability typically do – they often focus only on the magnitude of ecological impacts and neglect their distribution. The EF consists in measuring such impacts in terms of a plot of bioproductive land (global hectares[38]), therefore, our analysis will consider how unequal is this allocation of bioproductive land among the countries of the world and how it has changed over time.

The development of distributional analysis methods in economics has been tackled in the context of Social Welfare Theory (Atkinson 1970, Theil 1979, Cowell 1980, Shorrocks 1980, Blackorby and Donaldson 1978), which has traditionally focused on the measurement of income inequality and its direct implication for social welfare. In order to conduct our analysis, such methodology will be borrowed from the income inequality field and used to analyse environmental inequality. Here, however, the direct

[38] See Chapter 2 for details on EF.

implications of such inequalities may be related to Sustainable Development in the form of further equity within generations. Besides, the economist's toolbox to measure income inequality might need some tailoring when the discussion is moved from Social Welfare Theory to Sustainable Development. In this regard, the current chapter not only is aimed at measuring the EF inequality, but also wishes to discuss the methodology insofar as it is applied to environmental outcomes instead of income.

It is worth knowing that the inequality approach is not the only methodology for dealing with distributional issues; there is also the Convergence approach, which emerged from economic growth theories (Sala-i-Martin 1994, Barro and Sala-i-Martin 1992) and has also become a widespread methodology for measuring dispersion in ecological indicators[39]. Despite both literature traditions having evolved independently, there is a growing consensus that they are complementary (Esteban 1996; Quah 1996, 1997; Goerlich 1998). Indeed, at the end of the day, both literatures have focused on the evolution over time of the distribution of an economic variable which is considered important for either social welfare (inequality approach) or economic activity (convergence approach) (Goerlich 1998). In this thesis, we will use the Inequality approach. In doing so, however, we will need to discuss some of the underlying axioms of the typical inequality tools since, although environmental inequality may be deeply

[39] It is necessary to distinguish two different concepts of convergence: on the one hand, there is SIGMA-convergence, consisting of analysing the changes in cross-country dispersion over time of the environmental indicator. The main method for doing this is to calculate the standard deviation of the natural logarithm of the indicator. If this measure of dispersion declines over time, then there is a convergence in a SIGMA-sense. Additionally, there are alternative ways to test the convergence hypothesis such as the stochastic convergence approach, which uses unit root tests in order to find out whether the time series is stationary or not. Any evidence of a unit root in the relative series of the pollutant treated supports divergence among countries, while the rejection of a unit root suggests convergence across countries (see evidence for different pollutants and energetic indicators in (List 1999, Aldy 2006, Miketa and Mulder 2005). On the other hand, there is the BETA-convergence approach. BETA-convergence will exist when evidence is found of a tendency for countries with relatively low initial pollution emissions (or natural resources consumption) to grow relatively fast. To do this, a necessary first step is to calculate the growth rates of countries' emissions, and as a second step, to regress such growth rates on the initial pollution values. A negative sign of the beta coefficient (slope) indicates convergence in a BETA sense. See for instance (Van 2005, Criado and Grether 2010, Strazicich, List 2003). However, it is worth knowing that such an approach has been widely criticized because of a statistical phenomenon known as Galton's fallacy (Quah 1993).

interconnected with welfare and economic activity, the translation from income inequality to environmental inequality is not always direct (Duro 2012). Actually, income is a 'good' while the ecological impacts (EF, emissions, toxic waste, etc.) are not.

This chapter thus, on one the hand, calculates the inequality trend of the international distribution of EF by using a sample of 119 countries from 1961 to 2007[40], and on the other, discusses and reviews different methods of inequality economics for so doing. To the best of our knowledge, the existent evidence on international EF inequality is limited to a one year cross-section (White 2007), or to five years cross-sections covering from 1996 to 2005 (Dongjing et al. 2010); in this chapter, a wider set of inequality indices has been considered at the same time as the underlying properties of the ecological distribution framework has been reviewed. In doing this, following Duro (2012), we propose a family of indices that, because of their particular axiomatic properties, fit better into the measurement of environmental inequality. Additionally, it is shown how inequality changes might be driven by changes in the weighting factor, here population, rather than by changes in the very distribution of EF. Consequently, following Duro (2013), we perform a decomposition of the inequality changes to see what role is played by world population structure.

This chapter is organized as follows: the first section deals with the partial ordering tools of inequality by using EF data and discussing their results as framed in Ecological Sustainability. In the second section, the standard inequality indices are introduced together with as their underlying axioms, emphasising which indices fit best in the assessment of environmental inequalities. The empirical trend of EF inequality is presented and discussed in the third section. Section four decomposes this EF inequality

[40] Data on Ecological Footprint have been taken from Global Footprint Network (2010).

trend in terms of changes both in the EF per capita and in the population weights. Finally, section five concludes the chapter.

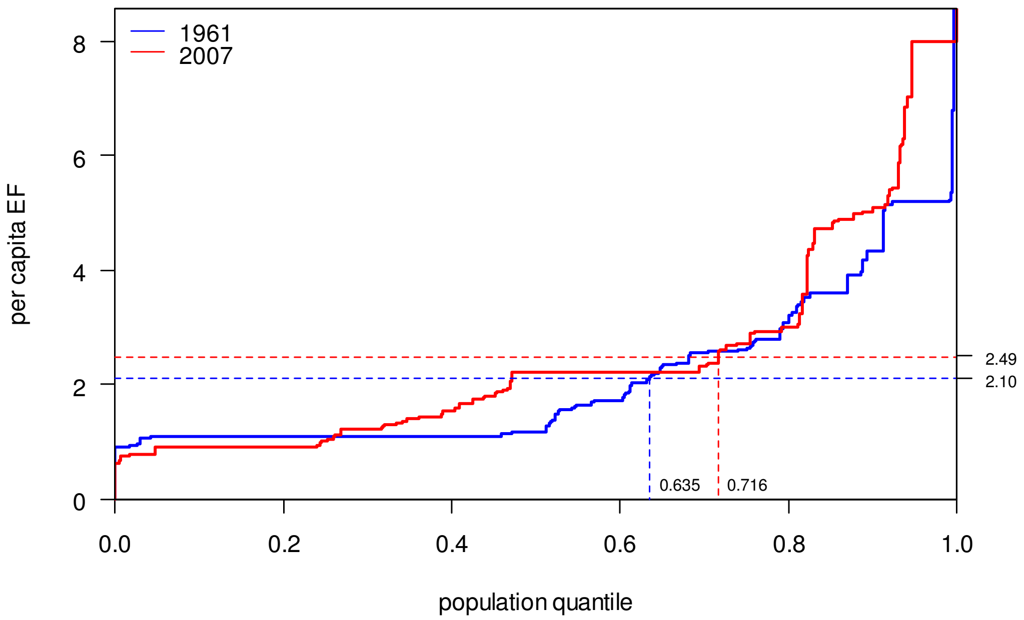
3.1 INEQUALITY MEASUREMENT: PARTIAL ORDERING

At the root of inequality analysis, we will find that the key issue is the comparison of 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 first approach is based on what are known in the literature as first-order stochastic dominance criteria. It uses the quantiles of the distribution which are given by the (generalized) inverse of the distribution function, often represented by Pen's Parade[41]. The idea behind this is the simple and compelling image of a parade, in which the EF of each average citizen of each country is represented by their physical height and they are ranked according to it (see Figure 1). This provides more than just an appealing parable of inequality in terms that a lay person can appreciate (Cowell 2000). In terms of comparison, the income literature states that one distribution dominates another (and so it is preferable) provided that it lies completely above the other at all the points of the distribution. In terms of income, that situation may make sense since despite there still being many dwarfs and few giants, at least, everybody is a bit taller. In terms of EF, the opposite would have be more sensible, the preferable distribution would be the one that lies wholly below the other since this involves less environmental pressure. Hence, according to first-order stochastic dominance, the distribution with lower per capita EF, regardless of the EF inequality, would be preferable.

[41] The "parade of dwarfs and few giants" is related by Jan Pen in 1971 (Cowell 2000)

Figure 1. First-order stochastic dominance between 1961 and 2007, using Pen's Parade.



Source: own elaboration

Figure 1 shows the Pen's Parade of per capita EF distributions of 1961 and 2007[42]. As can be seen, the two curves intersect at many points and so there is no first-order stochastic dominance as defined above. Consequently, it cannot be stated that 1961 is a better situation than that of 2007. Nonetheless, this tool provides essential information in order to capture what is going on in the EF distribution: for instance, we see how the first quintile (0.2) has reduced its per capita EF in these forty-six years, whereas the remainder of the quintiles have increased their per capita EF, with the exception of fourth which is quite similar. Consequently, the average EF per capita increased from

[42] Data on Ecological Footprint have been taken from (Global Footprint Network) covering 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. See previous chapter for descriptive statistics. The results presented must be read correctly: EF per capita is the EF of the whole country, divided by the country's population. 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.

2.1 to 2.49 global hectares, thus indicating that the world demands further natural resources because of the top and median quintiles. Furthermore, it is remarkable that, whereas in 1961 63.5% of World population was below the World average EF, in 2007 a full 71.6% the population were.

Nevertheless, the underlying axioms of such ranking distributions must be taken into account: the population of first quintile in 1961 is not necessarily the same as the population in 2007. In the Welfare literature this is the so called *anonymity* axiom (or symmetry axiom) which states that all permutations of individual labels are regarded as distributionally equivalent. Therefore, we require that the ordering principle use only information on EF variable and not any other characteristics that might be discernible. Such an axiom is required for all partial ordering methods[43].

The Lorenz criterion (also known as second-order stochastic dominance) is clearly the most popular tool for making such rankings[44] and consists of graphing the cumulative proportion of EF against the cumulative Population proportion[45]. As a result, if we observed that 10% of population consumed 10% of the world EF, 20% of population, consumed 20% of world EF, and so on, that would mean that the distribution is perfectly evenly spread. In contrast, if we observed, for example, that the same 10% of population consumed the 40% of EF, and then 20% of population consumed 50% of resources, and so on, that would imply some degree of inequality. As can be seen in Figure 2 (left) the latter would be the case in the Lorenz Curve for 2007, while the

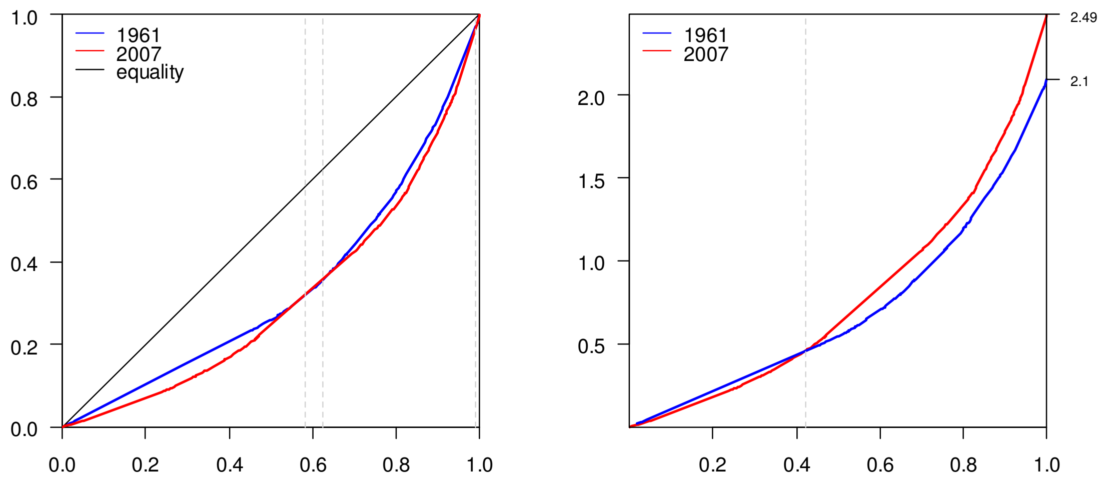
[43] The Axiom of Anonymity is fundamental in the *inequality* approach but not necessarily in other distribution approaches, such as *mobility* analyses, where it does matters which countries (individuals) have what amount of resources (income). See (Fields and Ok 1996).

[44] Groot (2010) and Padilla and Serrano (2006) used Lorenz Curves for analysing international distribution of CO_2 emissions. Steinberger et al (2010) used them for Material Flow indicators while White (2007) used for the EF.

[45] Therefore, second-order stochastic dominance is more restrictive than first-order: notice that with the latter, the principal element is the quantile (population proportion) which needs to dominate in terms of EF level. In contrast, with second-order stochastic dominance, it is the proportion of EF corresponding to the proportion of population (quantile) which gives rise to the dominance.

former would be the case of total equality, as represented by the diagonal line.

Figure 2. Second Order stochastic dominance between 1961 and 2007 using Lorenz Curves and Generalized Lorenz Curves (GLC).



Note: The Lorenz Curves intersect at 0.581, 0.635, and 0.99. GLC intersect at 0.423.
Source: own elaboration.

Therefore, Lorenz dominance takes place when one's distribution curve lies wholly inside of a second Lorenz Curve, implying that the first is closer in all its points (cumulative proportions) to the equality line. In our case, if the Lorenz Curve of the 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 in every quantile. However, as can be seen in Figure 2-left, the two 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 54%, the latter could involve a higher EF level than the former (this in fact is what actually occurs. See Figure 2-right). Therefore, it may be inappropriate to conclude that the 1961 situation is preferable to that of 2007 just because of there being more equity (Maguire and Sheriff 2011).

Shorrocks (1983) proved that, by multiplying the original Lorenz curve by its mean, some of those intersections could be resolved, thus removing its ambiguity; this is the well-known Generalized Lorenz Curve (GLC), which consists in multiplying the Lorenz Curve by the distribution mean[46]. In the income literature, this implies that (holding inequality constant) the distribution with the greater mean will necessary be GLC-dominant (better welfare). Unfortunately, the GLC can also yield intersections even when the means are different. Figure 2 (right) illustrates a situation of non-GLC-dominance. Nevertheless, greater mean income might be desirable, although greater EF mean might not since the latter implies greater environmental impact (scale goal). Hence, focussing on the lower part of the distribution (first and second quintiles), the 2007 distribution 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, as has been noted, it is in the nature of the general ranking distribution tools that, in many practical situations, they yield an indecisive answer. For instance, observing Lorenz curves we see which parts of the distribution are closer to the equality line and which ones are farther away. Therefore, stating which year exhibits a more desirable situation depends on which part of the distribution is considered to be more relevant. This is where the main literature concludes that the existence of such

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

intersections in the stochastic dominance curves, necessarily involves value judgements (Atkinson 1970, Shorrocks and Foster 1987, Cowell 2011). Here, inequality indices show their true worth by ranking distributions unambiguously, based on the selection of specific value judgements. Indeed, in the next section we argue strongly that, since inequality assessment cannot be done without value judgements, such judgements, which in the case of the distributional analysis of environmental outcomes do not necessarily coincide with the most common frame of income distribution, should be explicit and so, appropriate to the problem being analysed.

3.2 INEQUALITY MEASUREMENT: INDICES

The literature on the measurement of inequality, as it stems from Social Welfare Functions, has many axioms which may be desirable or not depending on the situation under analysis. However, the literature most focused on the inequality measurement has identified three basic axioms which any inequality index should satisfy:

- *Anonymity*. This assumption states that all permutations of individual labels are regarded as distributionally equivalent. $(x_1, x_2, x_3 \ldots x_n) \sim (x_2, x_1, x_3 \ldots x_n)$
- *Population principle*: the inequality index remains unchanged with replications of the population[47]. $(x_1, x_2, x_3 \ldots x_n) \sim (x_1, x_1, x_2, x_2, x_3, x_3 \ldots x_n, x_n) \sim \ldots$
- *Scale independence* (homotheticity): the inequality measure remains unaltered by changes of the same proportion in all the observations. This means that the measured inequality of the slices of the cake should not depend on the size of the

[47] As far as Social Welfare functions are concerned in the income literature (see Cowell, 2000, 2011), the population principle jointly with the anonymity axiom (which states that welfare does not change when two individuals just swap their incomes) permits the comparison of welfares by using density and distribution functions. Hence, first-order stochastic dominance does satisfy these two axioms, but not the Pigou-Dalton Principle.

cake. $(x_1, x_2, x_3 \ldots x_n) \sim (\lambda x_1, \lambda x_2, \lambda x_3 \ldots \lambda x_n)$

- *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. Consider an arbitrary distribution $x_A := (x_1, \ldots, x_i, \ldots, x_j, \ldots x_n)$ and a number such that $0 < \delta < x_i \leq x_j$; then being $x_B := (x_1, \ldots, x_i - \delta, \ldots, x_j + \delta, \ldots x_n)$, the latter is set as more unequal than the former. This axiom is probably the most essential one, insofar as the inequality approach is concerned.

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, 2000; Wu and Xu 2010, Dongjing et al. 2010, Steinberger et al., 2010, Cantore and Padilla 2010), the Theil family of indices[48] (Alcantara and Duro 2004, Duro and Padilla 2006, Duro et al., 2010, Cantore 2011) or the Atkinson index (White 2007, Hedenus and Azar 2005). These authors take advantage of the properties of such indices in order to unambiguously analyse inequalities in environmental impact indicators.

In addition, it is also useful that the *Decomposability* axiom be satisfied in order to disentangle the main contributions to the Total inequality, however, not all inequality indices satisfy such an axiom. Formally, an inequality index is decomposable if the total inequality of the specific variable can be broken down consistently in terms of the inequality of distinct subgroups of the population. So, *ceteris paribus*, if the inequality of one subgroup increases, then total inequality must also increase. Formally, consider

[48] Since Theil measures belong to a wider family of indices, the Generalized Entropy indices, we will refer to these indices as GE(0) and GE(1). However some authors refer to them as T(0) and T(1).

three different distributions *F*, *G*, *K* which have the same mean and $\delta \in [0, 1]$. Then $G \succ F$ implies that $[1-\delta]G + \delta K \succ [1-\delta]F + \delta K$. This means that if the same distribution *K* is mixed with *F* and *G*, then ordering of the resulting mixture distribution must be determined solely by the distribution of *G* and *F* (Cowell 2000). Only the family of Generalized Entropy indices (GE) satisfies such an axiom. However, apart from group decomposition, there is also the source decomposition which consists in decomposing inequality in terms of the variable sources (here the EF components[49]). In this case, also, only few inequality measures allow a convenient breakdown by components of EF – examples are the Coefficient of Variation (CV) and its ordinally equivalent measures (Cowell 2011). Chapter 4 of this thesis deals with EF Inequality decomposition.

Up to this point, all underlying axioms in inequality indices fit properly into the analysis of environmental outcomes. Nonetheless, as mentioned above, these indices were built axiomatically based on several assumptions which are a good fit for the measurement of income inequality in a social Welfare Function context, but which do not necessarily fit so well for ecological variables. Our first example is another axiom which, despite being fundamental to income inequality analyses, it is not so in environmental inequality analyses. This is the *Monotonicity* axiom, which claims that any increase in the income of any individual of the society, without involving income reduction of any other, will necessarily increase that society's Welfare. Consider $x_{A}:= (x_1, \ldots, x_i, \ldots, x_n)$ and a number such that $\delta>0$, then $x_B:= (x_1, \ldots, x_i+\delta, \ldots, x_n)$ exhibits a better welfare. However it is easy to see that, from a sustainability point of view, higher ecological impact (here approximated by EF) would not automatically involve a better situation.

Then, still reviewing the axioms, it is worth considering a remarkable property which is

[49] Cropland, grazing land, fishing ground, forest land, carbon land and built-up land. See Chapter 2.

present in many inequality indices: the *Diminishing Transfer Principle* (DTS) (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. The reason is to be found in the concavity of the implicit Social Welfare Function of any inequality index. From this perspective, any society prefers that the poor, rather than the rich, become better-off. In this regard, some inequality indices will decrease more when there is a fixed transfer to a relatively poor individual than they do when the same transfer is made to a relatively richer person. This rationale does not make such sense when, for example, that transfer is in terms of ecological impact. Should we consider that inequality reduces more if there is equalization among the low resource demanding countries as opposed to when the same equalization occurs among the highest resource demanding countries? 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.

In Table 1, the different axioms, rooted in the welfare analyses, which have been discussed so far are presented and rated (whether they are appropriate or not for the analyses of environmental inequality in a sustainability context). The first three axioms, Scale Independence, Population Principle and Pigou-Dalton Transfers were referred above as the basic axioms of any inequality measure. These axioms jointly with the anonymity axiom are not only appropriate but are also required in any inequality index. In contrast, Decomposability is desirable, but not strictly necessary. Finally, as discussed, Monotonicity is senseless in the environmental inequality assessment as is Diminishing Transfers Sensitivity:

Table 1. Main Welfare axioms of inequality indices

Axiom	Social Welfare	Sustainability
Anonymity	✓	✓
Scale Independence	✓	✓
Population Principle	✓	✓
Pigou-Dalton transfers	✓	✓
Decomposability	✓	✓
Monotonicity	✓	
Diminishing Transfer Sensitivity	✓	

Source: Present Authors.

Table 2 shows the most common inequality indices used in the specialized literature by describing whether the index satisfies the basic axioms (Anonymity, Scale Independence, Population Principle and Pigou-Dalton Transfers) and where the index sensitivity is located in the distribution (those that satisfy the DTS axiom will have the sensitivity located in the bottom of the distribution).

Table 2. Summary of inequality indices considered and their characteristics

Index	Formula	Basic axioms	Decomposability	Transfer-Sensitivity
Variance	$\sigma^2_\omega = p_i \sum_{i=1} (e_i - \mu)^2$	No	Yes	Neutral
Log variance	$\mathrm{v}_1 = p_i \sum_{i=1} \left[\log \frac{e_i}{\mu *} \right]^2$	Yes(*)	No	Bottom of distribution. *DTS axiom*
Gini	$G = \frac{1}{2\mu} \sum_i \sum_j p_i p_j \left| e_i - e_j \right|$	Yes	No	On the distribution mode
Squared Coefficient of variation	$CV^2_\omega = \frac{\sigma^2_\omega}{\mu^2}$	Yes	Yes	Neutral.
Atkinson index	$A(\varepsilon) = 1 - \left[\sum_i p_i \left(\frac{e_i}{\mu} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \varepsilon \neq 1$ $A(\varepsilon) = 1 - \exp\left[\sum_i p_i \log\left(\frac{e_i}{\mu} \right) \right], \varepsilon = 1$	Yes	No	Bottom of distribution (*ε>0*). *DTS axiom*
GE(0)(**)	$GE(0) = \sum_i p_i \log\left(\frac{\mu}{e_i} \right)$	Yes	Yes	Bottom of distribution. *DTS axiom*
GE(1)	$GE(1) = \sum_i p_i \left(\frac{e_i}{\mu} \right) \log\left(\frac{e_i}{\mu} \right)$	Yes	Yes	Bottom of distribution. *DTS axiom*
GE(2)	$GE(2) = \frac{1}{2} \sum_i p_i \left[\left(\frac{e_i}{\mu} \right)^2 - 1 \right]$	Yes	Yes	Neutral

Notes: p_i is the population share of country i, e_i is the EF per capita, or the per capita value of any variable of interest; μ is the mean of such variable and ε is the inequality aversion parameter.

* The Log variance only satisfies the Pigou-Dalton Principle when observations are lower than e times the geometric mean of the distribution analysed (Foster and Ok 1999, Cowell 2011). In our case, only a few observations are affected by this and they have no significant effect in the results obtained.

** GE(0) and GE(1) refer to the Generalized Entropy indices with β=0 or β=1, which coincide with the measures of Theil (1979).

Source: Present Authors.

Some notation is now useful[50]: the variable whose inequality is being analysed is the EF per capita, denoted as e_i; $e_i = \frac{EF_i}{P_i}$, being EF_i the EF of county *i* and *Pi* the Population of country i. Hence the mean EF per capita can be expressed as $\mu = \frac{EF}{P} = \sum_{i=1}^{n} p_i e_i$ where p_i is the relative population of country *i;* $p_i = \frac{P_i}{P}$.

The Gini Index, though not explicitly defined, is more sensitive to transfers occurring close to the distribution mode[51]. *GE* indices (when $\beta<2$) 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)[52]. On the other hand, weighting the top of the distribution more is not really suited to environmental analysis. Therefore, as Duro (2012) 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.

Progressive indices (weighting low part of distribution) have been particularly valued in the income inequality research. This is because transfers to the poor are more valued than the same transfers to the rich (i.e. the concavity of the Social Welfare Function). However, when there are low EF countries in the low part of the distribution, we do not require changes in the global inequality of these countries to be weighted more than the same changes in high EF countries. Consequently, we propose the use of neutral indices

[50] This notation will be used in the rest of this thesis.
[51] The Gini index is the weighted sum of the different observations and where the weights are dependent on their position in the ranking. In such circumstances, the index is very sensitive to changes emerging in the sections with the highest concentration of observations and, therefore, typically around the mean of the distribution (Duro 2012).
[52] When $\beta \to -\infty$ or $\varepsilon \to \infty$ the distribution tends to be assessed according to Rawls: only the lowest observation mattering

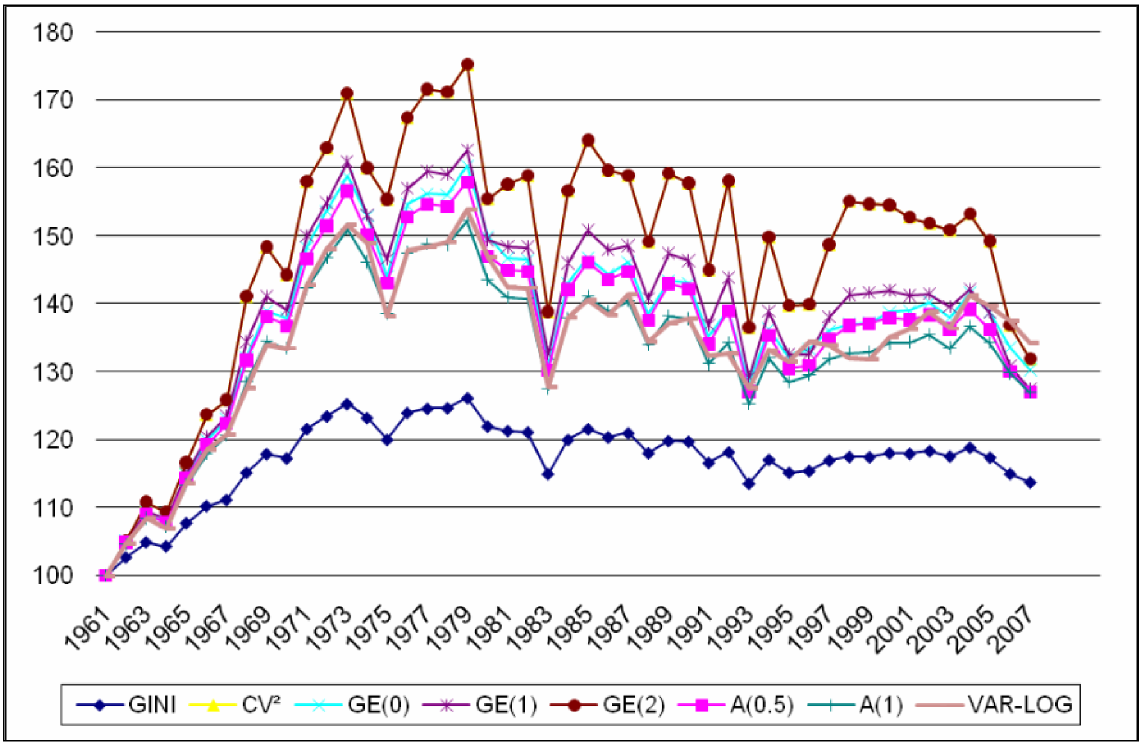
as reference line to assess EF inequality.

3.3 EMPIRICAL RESULTS: INTERNATIONAL EF INEQUALITY

Choosing neutral indices, however, is not free of empirical implications. Figure 3 shows the changes in inequality over the course of the period, analysed according to different well known indices[53]. Despite all of them sharing a similar pattern, there are significant differences in the growth rates between them. Firstly, the Gini index is considerably more stable than the other indices, what might be attributed to the distribution mode preference of the Gini index. In contrast, *GE(0), GE(1), A(0.5)* and *A(1)*, which favour the low part of the distribution show a greater variation in their rates. Finally, *GE(2)* and CV^2, which are neutral indices and cardinally equivalent show even a greater variability. Moreover, a detailed observation of Figure 3 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[54].

[53] See Appendix, Table A1, for the inequality indices.
[54] Notice that measures used in this stage of the analysis are population-weighted. This means that the various observations (countries in our case) are being treated in a heterogeneous way with respect to their influence on the inequality measure. Hence, greater weight is assigned to the largest observations according to their population-share (p_i). This approach avoids the impact on the inequality values attributable to very small countries at the same time as it gives more importance to higher-populated countries. In appendix A2, we show the same graph using the same indices but no longer weighted by population share. In such an approach, international EF inequality registers a constant increase along the period analysed. However, weighted indices will be the ones analysed in the analytical decompositions of inequality (classical decompositions). In Chapter 5, however, when Regression-Based decomposition is performed, we will use non-weighted observations for methodological convenience.

Figure 3. Inequality trends in EF according to the main inequality indices (1961 – 2007)



Note: 1961=100 for all indices
Source: Present Authors.

Focusing on the results, one sees that, from a global perspective, it could be stated that the EF inequality had three marked trends in the course of the period 1961-2007; a steep increase in the first decades, slightly decreasing stability from 1980 to 2000, and lastly a pronounced decrease from 2000 to 2007. Whereas, if we consider the whole period analysed (1961-2007), the international EF inequality has increased significantly whichever the index used. In this sense, since the different indices point to different rates, we will focus our discussion on the trend observed according to the GE(2) or CV^2 (cardinally equivalent) taking into consideration the above discussion of their underlying axioms. According to these indices, inequality increased 70% from 1961 to 1973, reaching a relatively high level of inequality that lasted until 1980, when the EF inequality began a slight decrease. In 2000 though, the inequality began to decrease more strongly, registering the most pronounced decrease from 2004 to 2007, when CV^2 fell by almost 20%. On the one hand, such inequality decrease is a direct cause of the heavy industrialization performed in the super-populated China in the last decades. Since China account for a huge proportion of the World population (20%), the (population weighed) inequality indices are very sensitive to changes in this country. Consequently, China's increase in the demand for natural resources in the last decades of the period, contributed to equalising the EF distribution[55]. On the other hand, the countries with highest EF per capita of the distribution reduced their demand for natural resources and initiated a convergence toward the mean during that subperiod; these included the United States of America, Canada, Australia, Belgium, Luxembourg and Denmark (among others). Both effects combined made the EF distribution less unequal, however, the World EF per capita still increased by 7% from 2000 to 2007 (see Chapter 2). Therefore, from a distributional perspective, the redistribution which happened in the last few years, despite it improving the distribution, was still accompanied by an increase of the global EF per capita[56] and so worsened the distribution *between* generations.

Nevertheless, considering the whole period from 1961 to 2007, the distribution of EF per capita has become more unequal; it becomes interesting to observe how, from a 1961 perspective, people born in 2007 might represent future generations. Let us assume that, during that forty-six years' period, the EF of the whole world had remained constant so that the scale of the economy had remained sustainable within the earth's

[55] The same analysis as shown in Figure 3 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 CO_2 emissions inequality was found to be less evident without China and India in the sample.

[56] Hedenus and Azar (2005) found a slight decline in the inequality (measured with an Atkinson index) of consumption of different specific resources (paper, electricity, energy, carbon, animal food, food). The authors explain that the reason for such a decline, although very slight, may be found in the effect caused by a saturation of the consumption of rich countries plus a rapid increase (in relative terms) of poor countries in some basic consumption.

limits thanks, say, to the implementation of more sustainable habits. However, if we consider the increase of the EF inequality registered (an increase of between 13% and 34%, depending on the index used), although the generation of 2007 might have enjoyed the same level of natural resource availability as the 1961 generation, higher inequality might prevent some of them from doing that. Therefore, despite natural resource depletion being assumed to have halted, that still does not guarantee future generations having the same developmental opportunities unless intragenerational equity is considered.

From a methodological point of view, however, those changes described in the EF inequality may be driven by a change in the population weight of the country rather than by a change in the EF per capita. For instance, India, like China, represents a huge proportion of the world population, however, its EF per capita reduced during the period, not because of less total EF but because of an increase in population (China increased in both total and per capita EF). The population proportion of India increased from 16.8% in 1961 to 19.4% in 2007. As a result, the inequality indices became more sensitive to India's behaviour. The next section decomposes the inequality changes in the course of the period in terms of changes in the population share and of changes in the EF share. This decomposition allows us to disentangle whether the observed inequality trend is the result of the changes in the "size" of EF countries or in the number of people in countries.

3.4 Population Weights and inequality changes

Inequality measures used up to now are population weighted, which means that the various countries are being treated in a heterogeneous way with respect to their influence on the inequality measure by giving greater weight to those countries with larger share of World Population (p_i). Thus EF inequality as described above consists in measuring differences in *per capita* natural resource consumption weighted by (relative) populations. This approach avoids the impact on the inequality values attributable to very small countries while giving more importance to higher populated countries. In this regard, we are assuming that China's or India's EF performance is more important in terms of the EF distribution than Belgium's.

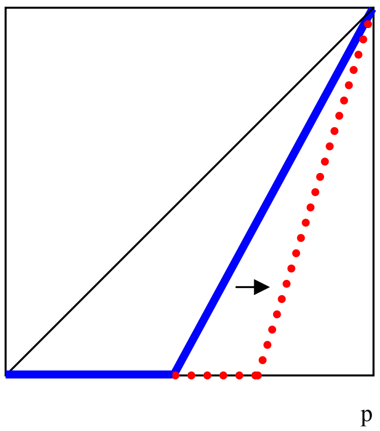
Thus, for the Lorenz-based indices, the weight of each country is the relative population[57]. Despite the significant role that such weights may play in inequality measurement, they have not received enough attention in empirical analyses (Duro 2013). An increase of EF inequality in the course of the whole period (as it 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). Indeed, the scale impact of humankind on the environment is a function of both growing population and of growing *per capita* consumption; $EF = e \cdot P$ where e is the vector of EF per capita and P is the vector of population; so that sustainability depends on accommodating more people and on accommodating "larger" people (Rees, 2000). In this sense, environmental inequality issues are driven by both vectors. In this section, we analyse whether the changes in EF inequality are a result of relative changes in countries' ecological 'size' or in their population 'size'.

Let us illustrate this by an example: consider a world where there are only two countries, A and B. Initially, country A is the one responsible for all the environmental impact on the earth while country B does not have any environmental impact, it lives in

[57] 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.

a completely sustainable way. Now suppose that in the next period, country A continues to have exactly the same environmental impact per capita but with a lower relative population because of an increase of population in country B (for whatever the reason). Figure 4 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 4. Lorenz curves of two-country world with change in relative population.



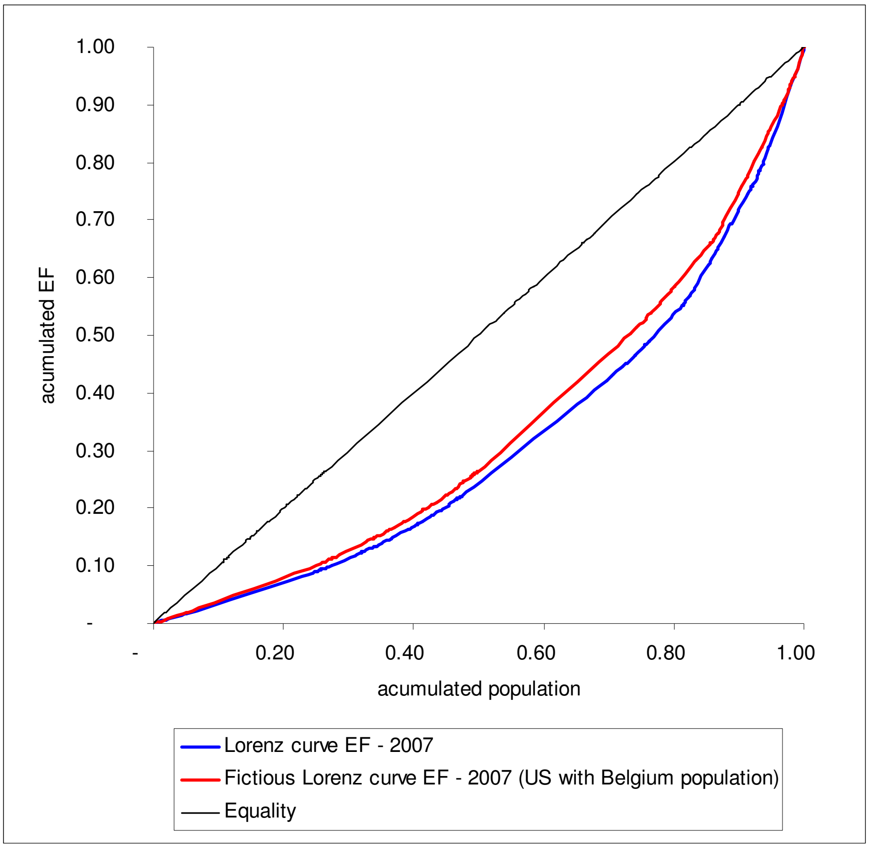
Source: Present Authors, based on Duro 2012

Thus, although the per capita EF of the average Belgian and the average US citizen were equal in 2007 (8.00 *gh* per capita), both countries are not weighted equally in the inequality measurement because of the large difference in their population shares: Belgium had 0.16% of the world population, while the USA had 5% (2007 data). However, picture a situation where the US population decreased until it represented the same population share as Belgium. In such hypothetical situation, the EF inequality would reduce in Lorenz terms[58]; less accumulated population would entail less accumulated EF. Such inequality reduction would have occurred without any change in

[58] And so any Lorenz consistent index will reduce.

the per capita consumption habits of either US or Belgium citizens. Figure 5 shows this hypothetical situation graphically.

Figure 5. Comparison of real EF Lorenz curve with a fictitious EF Lorenz curve which assumes the US has Belgium's population share.



Source: own elaboration

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[59]. Therefore, as far as we are concerned in monitoring of the EF inequality evolution during the period analysed, this section is devoted to understanding to what extent the inequality changes are explained by weighting factors. In this regard,

[59] Duro (2013) shows that 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.

the EF inequality change can be decomposed in the following way:

$$I(p_{t+1},e_{t+1})-I(p_t,e_t)=\{I(p_t,e_{t+1})-I(p_t,e_t)\}+\{I(p_{t+1},e_{t+1})I(p_t,e_{t+1})\} \quad (1)$$

where *p* and *e* 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 reflects the change in inequality caused by changes in per capita EF vector, since relative population remains constant. The second term corresponds 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 3 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 (CV^2 and GE2). 95% of this growth rate was 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 located in 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 is the case in short periods[60]). In such scenarios, the weighting factor role can drive the bulk of inequality change: for example, from 1991 to 2001 the inequality in EF per capita increased by 5% (according to neutral indices), of which 56% was explained by changes in population weighting.

[60] See Table A3 in the appendix for subperiods of 5 years

Table 3. Decomposing International EF inequality changes by population share and by per capita EF over 10-year sub-periods.

	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 1961-1971	**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 may result from not only changes in per capita EF, but also in world population structure. 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.

In any case, the results of such analysis are valuable since often the changes in inequality are interpreted as movements in the vector of the variable of interest when, in fact, it is perfectly plausible that the inequality can change without any change in such vector but rather in the weighting structure. Indeed, as has been shown, those changes in the population structure play their own role in determining the inequality trend of natural resource consumption.

3.5 CONCLUSIONS

Empirical analyses on ecological asymmetries across countries could become an essential tool for policy makers in order to achieve a just sustainability. This chapter 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 commonly been performed by directly borrowing techniques from the income distribution literature. These are Gini indices, Atkinson's family of indices, Generalized Entropy measures (Theil indices), etc. Nonetheless, income is a 'good' while environmental impact is not. As a result, this paper highlights some underlying properties in traditional inequality measurement methods which might not fit into environmental inequality analyses. On the other hand, we extend the empirical evidence relating to the international distribution of EF per capita by using a longer EF time series than in previous studies (1961 to 2007) and a wider range of inequality methods to assess international EF inequality. The results point out that, from 1961 to 2007, the EF inequality increased and so intragenerational equity has worsened along that period. This result, taken together with the increase of the EF beyond the earth boundaries (according to Global Ecological Footprint Network), implies that future generations tend to have less natural resources available, and these tend to be more unequally distributed. Nevertheless, in the last few years of the period there is an apparent equalization of the EF distribution, although the EF scale still grew[61].

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 by a consideration of 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 (2007) had less EF per capita. So in terms of sustainability, and as far as low-EF countries are concerned, it is unclear whether one should prefer the distribution of 1961 (more equitable) to that of 2007 (more sustainable). Yet, now considering the whole distribution, neither Lorenz curves nor GLC allow a complete ranking of distributions because of curve intersections. Inequality indices then become indispensable for doing this in an unambiguous way.

We have critically reviewed some of the properties of inequality indices, taking an environmental economics framework into account. Although different types of inequality indices exist, and several of them are widely used in ecological inequality measurement (such the Gini coefficient), we have demonstrated that some typical

[61] This apparent equalization of the EF distribution in the last years of the period analysed will be reconsidered when we consider the polarization approach in Chapter 6.

properties of those indices do not fit well when environmental issues, rather than income, are being analysed. For instance, Atkinson's and Generalized Entropy indices (Theil's indices) weight the low parts of the distribution more heavily because of their Diminishing Transfers Principle property. The 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 be satisfied (jointly with the basic properties).

Finally, it has been shown how the inequality trend may have been driven by changes in the population structure rather than in the variable of interest (EF) between countries. Our results actually indicate that, in certain periods, the changes in the population structure played a quite important role in the inequality change. However, the bulk of the evidence points to the inequality trend being driven by movements in the EF per capita of countries, meaning that the inequality increase of the whole period has resulted from changes in the size of the average citizen of the countries rather than relative population movements.

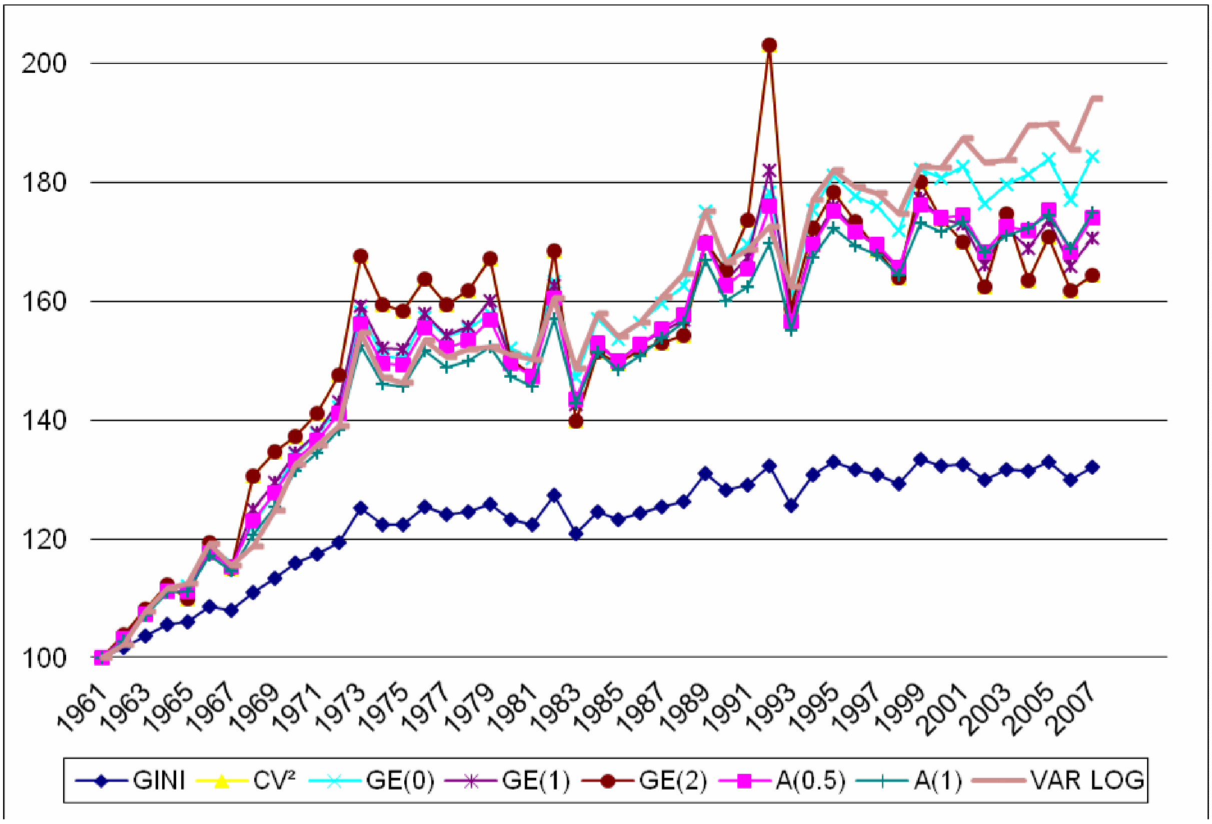
Having reached this point, the next step of the analysis is to recover the building blocks of the observed inequality trend. To do so, the next Chapter performs the classical inequality decomposition methods.

APPENDIX

A1. Table of International EF inequality according to different indices

year	Gini	CV²	A(0.5)	A(1)	A(2)	GE(0)	GE(1)	GE(2)	Var-log
1961	0.3319	0.4436	0.0888	0.1641	0.2718	0.1792	0.1891	0.2218	0.3275
1962	0.3406	0.4663	0.0931	0.1716	0.2825	0.1883	0.1984	0.2331	0.3432
1963	0.3481	0.4916	0.0969	0.1779	0.2911	0.1959	0.2070	0.2458	0.3555
1964	0.3461	0.4851	0.0958	0.1759	0.2878	0.1934	0.2048	0.2425	0.3505
1965	0.3574	0.5171	0.1016	0.1860	0.3021	0.2058	0.2176	0.2586	0.3720
1966	0.3657	0.5486	0.1060	0.1935	0.3135	0.2151	0.2277	0.2743	0.3886
1967	0.3688	0.5581	0.1087	0.1979	0.3174	0.2205	0.2335	0.2791	0.3956
1968	0.3821	0.6258	0.1170	0.2108	0.3328	0.2368	0.2541	0.3129	0.4179
1969	0.3912	0.6582	0.1227	0.2205	0.3457	0.2491	0.2668	0.3291	0.4388
1970	0.3891	0.6398	0.1215	0.2189	0.3441	0.2470	0.2629	0.3199	0.4372
1971	0.4036	0.7008	0.1303	0.2334	0.3631	0.2658	0.2836	0.3504	0.4675
1972	0.4097	0.7226	0.1346	0.2408	0.3733	0.2755	0.2928	0.3613	0.4849
1973	0.4158	0.7584	0.1392	0.2477	0.3809	0.2847	0.3041	0.3792	0.4968
1974	0.4089	0.7096	0.1335	0.2398	0.3743	0.2742	0.2893	0.3548	0.4875
1975	0.3982	0.6892	0.1271	0.2275	0.3548	0.2581	0.2771	0.3446	0.4525
1976	0.4114	0.7423	0.1358	0.2420	0.3739	0.2771	0.2968	0.3712	0.4845
1977	0.4135	0.7609	0.1374	0.2442	0.3755	0.2800	0.3015	0.3805	0.4862
1978	0.4137	0.7592	0.1371	0.2440	0.3771	0.2798	0.3006	0.3796	0.4884
1979	0.4187	0.7772	0.1403	0.2497	0.3862	0.2873	0.3074	0.3886	0.5039
1980	0.4048	0.6896	0.1306	0.2355	0.3710	0.2685	0.2825	0.3448	0.4811
1981	0.4026	0.6991	0.1288	0.2312	0.3635	0.2630	0.2805	0.3495	0.4663
1982	0.4019	0.7045	0.1286	0.2309	0.3639	0.2626	0.2805	0.3523	0.4662
1983	0.3815	0.6156	0.1157	0.2093	0.3342	0.2348	0.2508	0.3078	0.4187
1984	0.3982	0.6947	0.1262	0.2262	0.3560	0.2564	0.2760	0.3473	0.4521
1985	0.4035	0.7278	0.1298	0.2314	0.3617	0.2632	0.2852	0.3639	0.4603
1986	0.3995	0.7082	0.1276	0.2279	0.3572	0.2586	0.2797	0.3541	0.4533
1987	0.4015	0.7048	0.1286	0.2304	0.3625	0.2619	0.2808	0.3524	0.4631
1988	0.3917	0.6614	0.1223	0.2199	0.3483	0.2483	0.2662	0.3307	0.4402
1989	0.3977	0.7062	0.1270	0.2267	0.3546	0.2570	0.2787	0.3531	0.4489
1990	0.3973	0.6998	0.1263	0.2261	0.3563	0.2564	0.2767	0.3499	0.4516
1991	0.3869	0.6431	0.1191	0.2152	0.3444	0.2423	0.2588	0.3215	0.4337
1992	0.3922	0.7012	0.1235	0.2204	0.3467	0.2490	0.2720	0.3506	0.4346
1993	0.3768	0.6053	0.1129	0.2054	0.3348	0.2300	0.2441	0.3026	0.4181
1994	0.3885	0.6645	0.1202	0.2167	0.3470	0.2442	0.2625	0.3322	0.4361
1995	0.3821	0.6198	0.1159	0.2108	0.3425	0.2368	0.2506	0.3099	0.4306
1996	0.3830	0.6205	0.1163	0.2125	0.3484	0.2389	0.2508	0.3103	0.4402
1997	0.3881	0.6597	0.1198	0.2164	0.3483	0.2438	0.2610	0.3298	0.4383
1998	0.3899	0.6880	0.1215	0.2177	0.3458	0.2455	0.2672	0.3440	0.4326
1999	0.3898	0.6862	0.1218	0.2180	0.3452	0.2459	0.2677	0.3431	0.4320
2000	0.3917	0.6853	0.1225	0.2203	0.3516	0.2488	0.2684	0.3427	0.4427
2001	0.3914	0.6776	0.1223	0.2204	0.3536	0.2490	0.2670	0.3388	0.4464
2002	0.3927	0.6735	0.1229	0.2223	0.3581	0.2514	0.2673	0.3368	0.4545
2003	0.3901	0.6689	0.1211	0.2190	0.3537	0.2472	0.2639	0.3345	0.4467
2004	0.3944	0.6797	0.1237	0.2242	0.3631	0.2539	0.2688	0.3399	0.4626
2005	0.3895	0.6618	0.1211	0.2204	0.3600	0.2489	0.2623	0.3309	0.4578
2006	0.3815	0.6068	0.1156	0.2129	0.3541	0.2394	0.2474	0.3034	0.4504
2007	0.3774	0.5849	0.1128	0.2083	0.3471	0.2336	0.2409	0.2925	0.4397

A2. Inequality trends in EF according to the main (non population-weighted) inequality indices (1961 – 2007)



Note: 1961=100 for all indices

A3. Decomposing International EF inequality changes by population share and per capita EF over 5-year sub-periods

	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

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CHAPTER 4
INEQUALITY DECOMPOSITION; ANALITICAL APPROACH

Additive decomposition analysis is 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 might be critical for policy making since it could indicate where the source of the total inequality. We will decompose EF inequality from three different perspectives: in terms of regional subgroups (those which are typically used in international frameworks), in terms of EF sources (as described in Chapter 2) and in terms of multiplicative factors such as those linked to the IPAT identity (see Chapter 2).

Firstly, subgroup decomposition (Shorrocks 1980) might allow us to see, on the one hand, whether the EF inequality observed in the previous chapter comes from mean differences in regional world groups (as defined by the World Bank) or whether, on the other hand, the inequality comes from the inequality within those very groups. Depending on the results, and considering how those groups are formed, several policy implications may be derived.

Secondly, source decomposition (Shorrocks 1982) allows us to decompose EF inequality in terms of the different EF sources described in Chapter 2; these are cropland, forest, grazing land, fishing grounds, carbon land and built-up land. As a result, we will be able to assess how the internal asymmetries of the different components of EF contribute to the whole EF inequality observed.

Finally, multiplicative decomposition (Duro and Esteban 1998, Duro and Padilla 2006) is also considered in order to decompose EF inequality in terms of affluence and EF intensity. Since the multiplicative decomposition is based in the logarithmic properties of Generalized Entropy family indices, it can be understood as a particular case of additive decomposition techniques.

However, a necessary condition for the decomposing inequality is the satisfaction of an extra property: Decomposability (Bourguignon 1979, Cowell 2000, Cowell 2011). This property implies that there should be a coherent relationship between the whole inequality observed and its constituent parts[62]. Such parts may be either in the form of mutually exclusive and exhaustive sub-groups (such as regional-based groups), sources which sum to total EF (such as the EF subcomponents described in the previous chapter) or multiplicative factors (which can be translated as a consistent sum of logarithms). A minimal requirement for an inequality measure to be used for decomposition analysis is that it must satisfy a subgroup consistency or aggregability condition; i.e. if inequality in a component subgroup/source/factor increases then this implies, *ceteris paribus*, that inequality overall goes up (Cowell and Fiorio 2009). Therefore, if it is found that the inequality observed in the variable of interest, here EF,

[62] Classical decomposition is an analytical decomposition approach based on mathematical properties of inequality indices (see Bourguignon, 1979; Cowell 1980; Shorrocks, 1980; 1982). In this approach, theShapley value decompositions methods must be taken into account, which despite being still analytic methods, may allow us to relax some restrictions. (see Shorrocks 1999, Sastre and Trannoy 2002). This will later be used in the Source Decomposition of EF.

stems from a particular subgroup/source/factor, then policies to manage such inequality can be much more efficient. The decomposability property, however, additionally restricts the available inequality indices to a concrete family: those of generalized entropy indices or some cardinally-equivalent transformation.

Subgroup Decomposition and Source Decomposition have enjoyed the bulk of the attention from theoretical literature which provides more clues as to how to interpret results while multiplicative decomposition has been less investigated from a theoretical point of view, despite its numerous empirical applications (Goerlich 1998). This chapter aims to decompose the observed international inequality in EF by using subgroup decomposition (section 4.1), Source decomposition (Section 4.2) and multiplicative decomposition (section 4.3). Finally, section 4.4 concludes the chapter.

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, which in our case will be defined by the regional classification of countries according to the World Bank (see appendix A1). The basic idea of this decomposition is to express inequality as the sum of the inequality *between* groups (I_B) and the weighted inequality *within* groups (I_W). The between-group component is the inequality which would exist if each member of the group had the average EF of that group. The within-group component, in contrast, consists of the inequality which would be observed if the inequality between groups did not exist (as ifall regions had the same mean), so that the within-group inequality is the sum of the existing inequality in each group weighted by the population or pollution share. Therefore, decomposing total inequality in terms of *between* and *within* may help us to understand where the major part of this inequality comes from. If it is found that most of the total inequality can be explained by the *within* component, then redistribution policies could be focused on reducing the inequality within those groups which exhibit high internal inequality. At the same time, in terms of environmental agreements, the higher the inequality within the regions, the harder it it will be to achieve regional sustainability policies. In contrast, if most of the total inequality can be explained using the *between* component, then redistribution should be driven in terms of those groups, rather than in terms of individual countries. In this latter case, it is interesting to consider what these groups have in common since they are the ones driving the distribution of natural resources[63].

To the best of our knowledge, only two papers have used this technique to decompose inequality in terms of regional groups; the first, however, focuses on the EF inequality of Heihe River Basin of Northwestern China (Wu and Xu, 2010) and so its results are not comparable; the second paper deals with the subgroup decomposition of international EF inequality, while at the same time performing multiplicative decomposition (Duro and Teixidó-Figueras, 2013)[64]. The results of the latter are consistent with those presented in this paper, however for the sake of this thesis a longer period is considered.

4.1.1 METHODOLOGICAL ASPECTS

Technically, subgroup decomposition of EF inequality takes the form

$$I = I(e)_w + I(e)_B = \sum_{g}^{G} \omega_g I(e)_g + I(e)_B \qquad (1)$$

[63] Chapter 6 deals with cluster analyses of the EF distribution by means of the polarisation approach.
[64] This paper was actually derived from section 4 of the present chapter of this thesis.

where $\omega_g = \omega_g(p_g, e_g)$ are the weights for each *within* inequality, being the groups $g=1,2,...,G$ and where p_g and e_g are the relative population and the relative EF, respectively.

As already mentioned in the previous chapter, not all indices satisfy the decomposability axiom (See table 2 in Chapter 3). For this reason, only the family of generalised entropy measures (GE) can be decomposed by their subgroups (Shorrocks 1980, Shorrocks 1984, Cowell 1980)[65]. Hence, by translating that expression (1) to *GE* indices, we obtain:

$$GE(\beta) = \sum_{g}^{G} \omega_g GE_g(\beta) + GE_B(\beta) \tag{2}$$

where $\omega_g = p_g^{1-\beta} e_g^{\beta}$. So, only for $\beta = 1$ or $\beta = 0$ the weights can be read as population proportions ($\beta = 0 \Rightarrow \omega_g = p_g$) or EF proportions ($\beta = 1 \Rightarrow \omega_g = e_g$). Therefore, in the former the resulting inequality gives more importance to the more populated countries, while the latter, are the countries with higher relative EF per capita who weigh more in the inequality. In contrast, in the case of $\beta \neq 0, 1$ leads to a problem of interpretation since the weights in this case would be a non-linear combination of population and pollution shares, and so, the interpretation is cumbersome. Furthermore, those weights are not consistent since they do not add to one. The problems involved in interpreting results of the calculation restrict the subgroup decomposition to GE(0) and GE(1), and consequently, subgroup decomposition usually works with two indices.

However, GE(1) deserves further mention: recall that the *between* inequality has been defined as the inequality that would exist if all of the countries in the group had the

[65] Interestingly, both A. Shorrocks and F. Cowell independently developed the family of Generalized Entropy measures (which includes the Theil measures) in the 1980s.

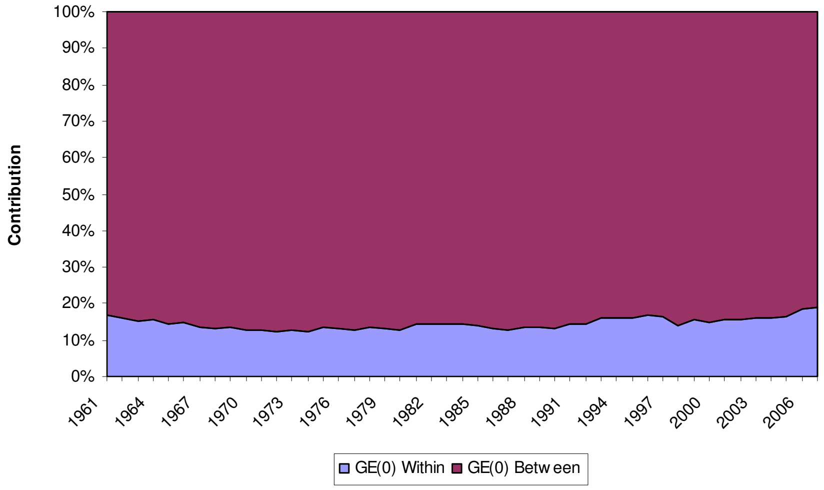
mean of their own group (so that $I(e)_w=0$) and that the *within* inequality would exist if the only source of inequality was the weighted inequality within those groups (so that $I(e)_B=0$). Thus, understanding the information given requires, in a conceptual way, a transfer to be made between regions in order to eliminate the *between* inequality and to properly interpret the *within* inequality. Given that the decomposition for $\beta=1$ corresponds to weighting observations by relative EF per capita (*e*) instead of by relative population (*p*), the weights ω_g of expression (2) are not independent of those conceptual transfers. Hence, only when $\beta=0$, the weights of the *within* component ω_g is independent of the subgroup mean e_g. For this reason, the GE measure with $\beta=0$ (GE(0)) is the most unambiguous solution according to the specialised literature (see Shorrocks 1980; Goerlich 1998). In any case though, our empirical analysis provides the subgroup decomposition of the three GE measures treated up to now: GE(0), which is the most unambiguous solution from an interpretation point of view, GE(1), which is consistently decomposable and is popular in decomposition inequality analyses despite its shortcomings, and finally, GE(2), which despite its problems of weighting consistency and interpretation, enjoys neutral sensitivity to the different parts of the distribution.

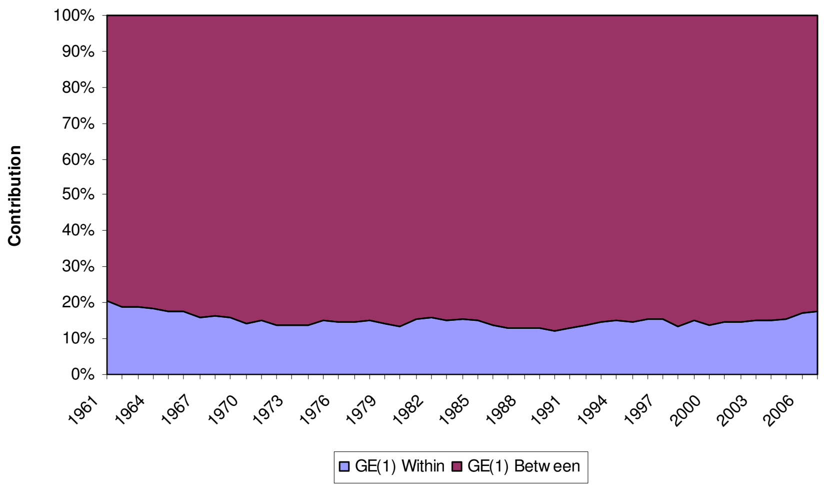
Subgroup decomposition has been performed using exogenous groups of countries such as those defined by the Regional classification of the World Bank. This World Bank classification consists in grouping low and middle income countries according to their region while grouping all of the high income economies together irrespective of their region. This particular definition of groups must be considered when interpreting the results obtained. The groups are; East-Asia and the Pacific, Europe and Central Asia; South Asia, Latin America and the Caribbean; the Middle East and North Africa, Sub-Saharan Africa and lastly, Industrial countries. Appendix A1 shows the specific countries in each group. Hence, subgroup decomposition will show us to what extent the EF inequality observed in the previous chapter, is driven by the differences between these groups and to what extent it is driven by the inequality within them.

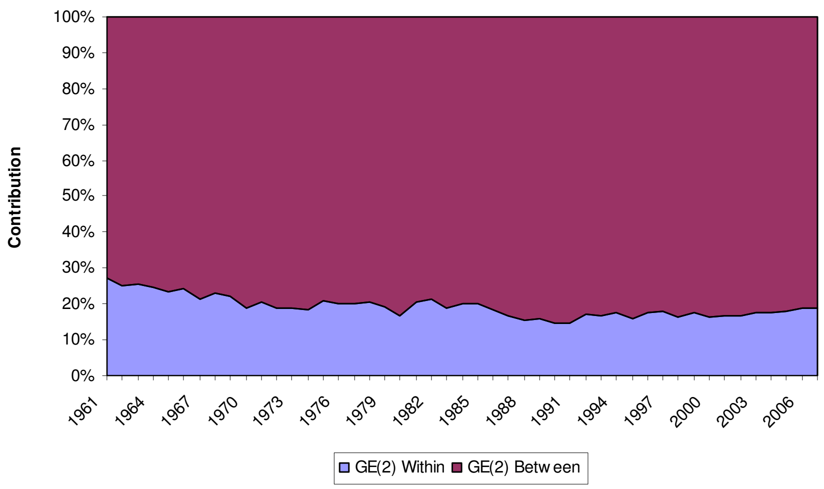
4.1.2 MAIN EMPIRICAL RESULTS

Figure 1 illustrates this decomposition using the three GE indices considered in this work: the main result is that the bulk of the inequality that was found during the analysed period is largely and persistently explainable using the *between* inequality component regardless of the inequity index used. According to the decomposition of GE(0), discussed as the less unambiguous subgroup decomposition, the *between* inequality component is responsible for 81%-88% of the whole EF inequality in the course of the period (see the table containing the indices in the appendix A2). Therefore, it could be said that the inequality in EF would be drastically reduced (the 81%-88%) if differences among these groups were eliminated, or equivalently, if the inequalities *within* groups were null, there would be no significant reduction in global inequality. Such an empirical finding could have important policy implications in terms of achieving international agreements if EF were the indicator used for international commitments. In the light of these results, the probability of achieving a 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 (provided that there are no other political issues on the table within these regions). This is because inequality within these groups is not so marked.

Figure 1. Subgroup decomposition of EF inequality according to regional classification of World Bank by GE(0), GE(1) and GE(2).







Source: Present Author's derivation from (Global Footprint Network).

Looking in more detail at the subgroup decomposition of GE(0) (Table A2, left), we see that the between-group component displays an inverted U-shape over 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 overall inequality in 2007. On the other hand, also in Table A2 (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 might be explained, on the one hand, by a sensitivity of the index 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 (*e*) where *GE(0)* does this by population (*p*). In contrast, despite this *GE(2)* cannot be interpreted in the manner of logical weights (the weights are neither population shares nor EF share), it is a neutral index and so it does not benefit from any particular part of the distribution. 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.

From a methodological perspective, it must be noted that *GE(2)* is the inequality index which, because of its neutrality property, is the most appropriate index for this subject, ecological inequalities (as discussed in Chapter 3). However, we have also shown that, in terms of interpretation, the best choice for decomposing such an inequality by subgroups is *GE(0)*. As a result, our analysis leads us to believe that, insofar as environmental inequalities are being measured, the three indices used in this analysis should be considered for their particularities as described previously, while paying attention to the minutiae of each index when interpreting results. Nevertheless, as far as our empirical results are concerned, the three subgroup decompositions performed by the EF are robust in the sense that all of them point to the same conclusion of an EF inequality being significantly driven by the differences between regional groups of World Bank.

Finally, it is remarkable that during the 46-year period analysed, the EF asymmetries have been conspicuously and persistently determined by the world region to which the country belongs (according to World Bank classification). Taking into account both the particularities of such World Bank regional classification, where the world is divided between high income countries and the rest of world regions (see A1), and the persistence in the time of inequality being driven by differences between those groups, it becomes pertinent to recall those approaches that point to a World structural inequality (Hornborg, 2011), concerned with revealing world asymmetries as a by-product of structural relations between core countries and peripheral countries. In other words, this result suggests that the natural resource consumption (as measured by EF) of any country tends to be highly determined by the world region to which it belongs.

4.2 THE SOURCE DECOMPOSITION

Again, the observed inequality in the international distribution of EF is the result of the international differences in fishing ground, cropland, grazing, forest, carbon footprints and built-up areas as far as this footprints constitute the EF. Hence, disentangling the contributions of each of the EF to its international inequality might reveal the principal building blocks of such inequality.

This decomposition aims to quantify how much EF inequality can be attributed to those EF sources. However, the contribution of an EF source to overall inequality can adopt different forms which are not always consistent (see Shorrocks 1982, Shorrocks 1988).

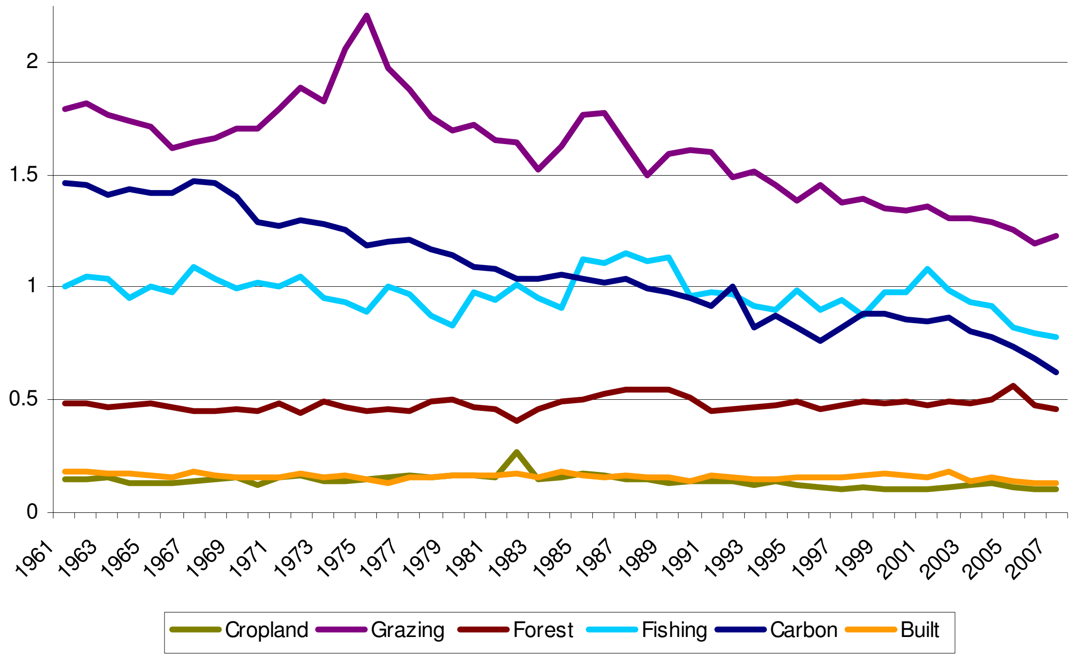
To deal with this, we will consider the three main ingredients necessary to build the component's contribution to total inequality. It can be stated thus that the contribution of source *k* to the overall inequality (e.g. the contribution of cropland footprint to EF inequality) is three-fold: firstly, the source's inequality itself, i.e. the more unequally distributed the EF source is, the higher its contribution to overall EF inequality must be, secondly, the component's share in whole EF; the greater that its share in the EF is, the more its inequality will weigh and so, the higher its contribution will be. And thirdly, the correlation between EF sources must be considered to obtain unambiguous contributions; the contribution of a certain EF component to total inequality might be the result of its own inequality and its own share to EF, but also could be due to indirect effects from the interaction of another correlated component.

It may be instructive to begin by considering first the inequality of each EF source. Indeed, this may be regarded as a component's contribution to overall EF inequality[66]. Figure 2 shows the inequality evolution according to GE(2) for each EF source (see the table A3 in the appendix for the specific index values). 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 is of particular interest since the cropland footprint could be linked with the special status of some of the biomass consumption (food and fibre for human consumption) which is an integral part of a human's basic needs (Steinberger et al., 2010). Consequently, the low level of inequality in cropland footprint can be seen as an objective itself. In contrast, the inequality in grazing

[66] It is a common practice in empirical literature to use each component's inequality as a contribution to the overall inequality (see Shorrocks 1988). Actually, it provides critical information: 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). Dongjing et al. (2010) analysed the international inequality of ecological footprint and also the inequality of two aggregated subcomponents: Renewable Resources Footprint and Energy Footprint.

footprint, despite also registering a reduction during the course of the period, is the most unequal in its distribution when compared to the rest of EF sources. The explanation of such a high inequality may be found in the meat-intensive diets of industrialised countries not being affordable for poor countries (White 2000). Finally, the carbon footprint inequality displays a significant reduction during the period - this is consistent with the findings of (Duro and Padilla 2006, Padilla and Serrano 2006, Ezcurra 2007, Heil and Wodon 1997, 2000) among others, who have analysed CO_2 emissions inequality[67].

. **Figure 2. Inequality of EF components 1961-2007 according to GE(2)**



Source: Own elaboration from (Global Footprint Network).

[67] Steineberger et al. (2010) estimated the Gini index of Domestic Material Consumption (DMC) and 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 dealt with different research questions and so were constructed differently. EF focuses mainly on biomass consumption. However, 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” (this is EF without Carbon footprint and built up land), 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. (2010). Therefore, our analysis is in complementary to that of Steinberger et al. 2010 (calculations are available on request).

In 1961, the most unequal distributions of footprint were for grazing, followed by carbon and then fishing. However, by the end of 2007, the ranking shows grazing remained 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 first-step interpretation, were diet-related issues followed by a decreasing energy-related issue

Despite providing critical information as depicted above, the approach of defining contributions to EF inequality cannot be considered from the formal perspective of a proper decomposition analysis since it is not consistent with the total EF inequality calculated in the previous chapter. This approach does not distinguish the relative importance of having high inequality in a source which, say, accounts for 99% share of EF versus having high inequality in the component which accounts for 1% of the share of EF. It also does not take into account the effects of interaction between sources which might shape the inequality of those sources. The next section deals with the consistent source decomposition methodology which will consist of complementing the independent analyses of the different sources inequalities, firstly with their EF share, and secondly with their correlation. In other words, source decomposition of inequality consists in relating the sources internal inequality with the total EF inequality.

4.2.1 METHODOLOGICAL ASPECTS

The EF sources' inequality thus does not take into account the weight of each EF source and so it cannot be directly connected to the whole EF inequality estimated in the previous chapter. Hence, the second issue after the source inequality itself which must be considered in accounting for source *k* contribution is its weight (importance) in EF accounting.

Therefore, let us consider in the following the contribution to inequality when the source's weights are taken into account. By definition, EF can be broken down into the sum of its components, i.e.

$$EF_i = \sum_{k=1}^{K} EF_{ki} \,, \tag{3}$$

where subindex k indicates each EF source (cropland, grazing land, fishing ground, forest land, carbon land, built-up land) and subindex i indicates the country. Therefore, expression (4) in per capita terms would be:

$$e_i = \frac{EF_i}{P_i} = \frac{\sum_{k=1}^{K} EF_{ki}}{P_i} = \sum_{k=1}^{K} e_{ki} \tag{4}$$

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 natural source decomposition will have the form

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

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

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

As the Gini index is the most popular inequality index, its natural decomposition is widely applied to such an index, first proposed by (Fei et al. 1978), and performed by White (2007) for the EF sources. However, the natural decomposition of the Gini index has several technical problems, whose description will allow us to deal with the third issue of source decomposition; the role of correlations among sources. Actually, the natural decomposition of the Gini index will only lead to non-trivial result (as will be explained later on in this chapter) provided that there is no correlation among sources, which hardly happens in empirical applications.

The natural decomposition of the Gini index consists thus of performing expression (5) with the Gini formula (see Chapter 3). However, if we did that with the EF data we would find that the sum of the weighted Ginis of the sources is greater than the Gini of the EF[68]. Since the Gini index depends on the ranking of the observations, to solve this shortcoming, Fei, et al. (1978) proposed to rank the distribution of sources according to the ranking of the aggregate variable, and then calculate the Gini indices of the sources: these ranked source Ginis are known as Pseudo-Ginis or Concentration indices[69] in specialised literature. As a result, expression (5) becomes consistent because in doing the ranking of sources according to the total variable, correlations among sources have been allocated by the procedure of ranking source's distribution. Therefore, the necessity of calculating the pseudo Gini indices (and make expression (5) consistent) stems from the existence of correlations among sources.

Shorrocks (1982) demonstrated that such an approach makes the contribution of source k independent of its own distribution and dependent on the aggregate variable distribution (here e) by the pseudo-Ginis procedure. The reason is in the fact that in

[68] This is given for the mathematical theorem of Triangle Inequality $|a+b| \leq |a|+|b|$ in the Gini decomposition. See Goerlich, 1998, Shorrocks 1982, 1983; Cowell 2000

[69] The pseudo Gini or Concentration index is the Gini index when it is calculated over a distribution which has been ordered according to the ranking performed by another variable (usually the aggregate variable).

calculating the pseudo-Ginis, the existing correlations among sources are being allocated implicitly by the ranking procedure in the different factor's contributions in an arbitrary way. This is what a pseudo-Gini actually is: a way of allocating the correlations to the contributions. As a result, the source 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[70], the contribution to the whole inequality turns out to be the component's share to EF λ_k. A more sensible strategy would be to allocate the interaction effects (correlations) in a explicit and non-arbitrary way. This is why available literature does not consider Gini to be a decomposable index (see (Shorrocks 1982, Bourguignon 1979, Cowell 2000, Cowell 2011, Goerlich 1998, Shorrocks 1983). However, the natural decomposition of the Gini index is still performed in some fields (as in White, 2007).

As a result, the contribution of a source to an overall inequality is not only about its inequality and its weight, but also it is about the correlations among the sources, the last piece of the source contribution jigsaw. Nonetheless, such correlations are often neglected despite their significance in empirical results obtained[71].

The correlations involve interaction effects among sources and so their distribution might be affected by those interactions; for instance, having a higher carbon footprint (due to the higher energy demands of colder countries) might require a higher demand of wool and so of grazing footprint (see the correlation's table in appendix A4). Accordingly, the inequality contribution of, say, a grazing footprint would be a combination of its weighted direct effects to the overall EF-inequality and its weighted

[70] Yitzhaki (1998) lists more than 12 alternative ways of defining Gini index
[71] In Duro and Teixidó-Figueras (2013), which corresponds to section 4 of this chapter, there is an example how neglecting the correlations among factors (multiplicative decomposition) may have empirical implications.

indirect effects, i.e. the correlations. So that each EF source will contribute to total EF inequality twofold: its direct effect plus its indirect effect (through some other source). Those indirect effects thus must be allocated to the different contributions. In the natural decomposition of the Gini index, the indirect effects are implicitly assigned by ordering EF sources according to total EF ranking (pseudo-Ginis procedure) and arbitrarily (depending on the functional form of Gini[72]). Specialised literature wants the natural decomposition of the Variance to overcome this issue independently of the inequality index used to measure the inequality level. The natural decomposition of the Variance (and thus the natural decomposition of the CV^2), in contrast to the Gini's decomposition, shows clearly what the interaction effects are and also allows an explicit and non-arbitrary allocation of them:

$$Var_{\omega}(e) = Var_{\omega}(\sum_{k=1}^{K} e_k) = \sum_{k=1}^{K} \lambda_k Var_{\omega}(e_k) + \sum_{k}^{K}\sum_{j\neq k}^{K} \lambda_k \operatorname{cov}_{\omega}(e_k, e_j) \qquad (7)$$

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 of 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 a 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

[72] See Shorrocks (1983) for an empirical example

distributed: $S_k^a = I(e_k + \mu - \mu_k)$

b) All of 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: $S_k^b = I(e) - I(e - e_k + \mu_k)$

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

$$S_k^a(CV^2) = CV_\omega(e_k + \mu - \mu_k)^2 = \lambda_k \frac{\text{var}_\omega(e_k)}{\mu^2} \tag{8}$$

$$S_k^b(CV^2) = CV_\omega(e)^2 - CV_\omega(e - e_k + \mu_k)^2 = \frac{\lambda_k Var_\omega(e_k) + 2\sum_{j\neq k} \lambda_k \text{cov}_\omega(e_j, e_k)}{\mu^2} \tag{9}$$

According to Shorrocks (1982), 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 it total inequality, plus one half of its weighted indirect effects. In doing so, we obtain the "natural decomposition of CV^2" proposed by the same author:

$$S_k^*(CV^2) = \frac{1}{2}(S_k^a + S_k^b) = \lambda_k \frac{\text{cov}_\omega(e_k, e)}{\mu^2} \tag{10}$$

Shorrocks (1982) proves that, under some very plausible axioms[73], the natural decomposition of the variance or what is equivalent, of the CV^2, is the only unambiguous decomposition method independent of the index used to measure the

[73] 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 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.

whole inequality[74]. Thus, if the researcher asserts that the best way to analyse the inequality in his specific topic is, for instance, the Atkinson index A(0.5) or any other index, 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 due to an arbitrary allocation of interaction effects. This result is very opportune in environmental analyses, since CV^2 benefits from the neutrality property defended in Chapter 3 as an appealing property to analyse ecological inequality.

Although specialised 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 many cases (Shorrocks 1999; Chantreuil and Trannoy 2013).

One possible solution is to use the Shapley value decomposition, which has its origins in game theory[75] (Shapley 1953) and which can be understood as a generalisation of the natural decomposition of the CV^2 (Rodriguez-Hernadez 2004)[76]. 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 equalising each *k* component, Shapley decomposes the averages of all these impacts over all possible sequences of component's *k*

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

[75] 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.

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

inequality elimination[77] (Sastre and Trannoy, 2002). So, the Shapley contribution will be $S_k^{ShD} = I(Se) - I(Se - \{e_K\} + \mu_k)$ where Se is a Subset of EF`s components $(Se \subseteq e, k \in Se)$. It takes the form:

$$S_k^{SD}(K,I) = \sum_{\substack{S \subseteq K \\ j \in S}} \frac{(k-se)!(se-1)!}{k!} \left[I(Se) - I(Se - \{e_k\} + \mu_k) \right] \tag{11}$$

The main advantages of using the Shapley methods are that consistent and unambiguous decompositions can be performed using any inequality index, provided the method is sensitive to the index chosen (in contrast to the natural decomposition rule described). One major shortcoming, however, is that the contributions obtained are not independent from the level of disaggregation[78]. 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, the CV^2, is used to measure inequality[79] (Shorrocks 1999). Hence, CV^2 has been stated above as one of the most suitable indices to measure environmental inequalities because of its neutrality and decomposition properties, this result also allows us to interpret the same contributions obtained by the Shorrocks' natural decomposition in a marginal way[80].

[77] Shapley Value Decomposition can also be performed by completely removing the source instead of equalising it – this is the 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).

[78] 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.

[79] If the variance is used, the Zero Shapley procedure (see footnote 15) also yields the natural decomposition of CV^2. Any other index used will not yield that result (Shorrocks, 1999)

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

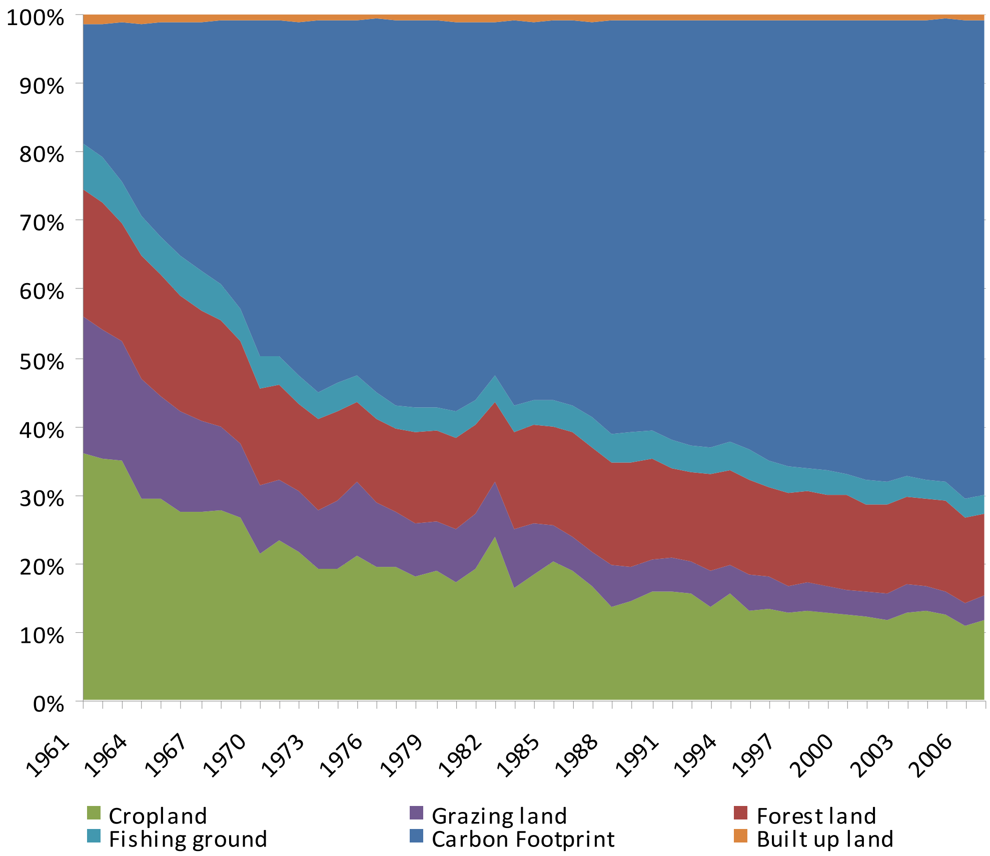
4.2.2 MAIN EMPIRICAL RESULTS

Figure 3 (see the specific values in the Table A5 of the appendix) shows the changes in contribution of EF components during the period, as estimated by the natural CV^2 decomposition (and coincides with the Shapley Value decomposition). In the first place, the result 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[81].

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 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 decrease their inequality contribution in the trend (from 20% to 4% in the former and a smaller reduction in the latter, from 7% to 3%).

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

Figure 3: Relative contributions of EF components estimated by Natural decomposition of CV^2 (1961-2007)



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

It is interesting to notice that the contributions of a source to the overall EF inequality differ from that component's inequality indices as shown in figure 2. It has been shown that all of these inequalities decreased in the course of the period, however, some contributions, have not decreased in the same proportion, the carbon footprint contribution increased quite 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 of that 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 Chapter 2, section 2.3.3). 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. Indeed, what we are observing in the period analysed (1961 to 2007) is the shift from cropland based societies to carbon based societies. So in terms of EF share, cropland and carbon footprints have swapped their relative weights over that period. However, also to be considered is the fact that the low inequality joint with important EF share of cropland footprint stems from its strong link with the basic needs of humanity. This is that at the end of the day, all countries require cropland to live.

Different implications were understood from these results, for example climate change negotiations now are mainly focused on the carbon emissions of different countries. However, the fact is these negotiations are one dimensionally based which can be counterproductive: for instance, as EF source decomposition points out, converting cropland to bio-fuel land in order to reduce CO_2 emissions[82] will lead unavoidably to an increase in the cropland footprint share at the same time. Thus the low inequality of cropland footprint would be seriously compromised and this in turn could have serious implications, not only for international agreements, but also in terms of social unrest in many countries due to the strong link between cropland and basic human needs. In this way, complementing international CO_2 emissions based negotiations with other ecological indicators (such as EF or other physical indicators) is of extreme importance since only then can some future errors be avoided. Furthermore, the fact that some indicators were production based (as they are currently) and other were consumption

[82] Assuming that land use change does not increase CO_2 emissions.

based might allow us to deal with sustainability and equity in more comprehensive way. Actually, the use of multiple indicators in multilateral agreements points to the possible benefits of extending the idea of multi-criteria analyses of sustainability assessment[83]. In this context, and as White (2007) also suggests, 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. However, in order to do so, other environmental and social dimensions need to be taken into account.

4.3 MULTIPLICATIVE DECOMPOSITION OF INEQUALITY

In earlier sections we dealt with inequality decomposition by sources and by population sub-groups, which allowed us to decompose the observed inequality according to the sum of sources or groups. Here we address the contributions of factors instead of sums to EF inequality. Multiplicative decomposition stems from the fact that the variable of interest can be also expressed in terms of a multiplication. In ecological economics literature such decomposition can be performed by the IPAT identity, which is a widely recognised formula for analysing the effects of human activities on the environment. IPAT emerged out of the Ehrlich-Holdren/Commoner debate in the early 1970s about the principle driving forces of anthropogenic environmental impacts (Ehrlich and Holdren 1971, Commoner 1972) and it continues to be widely utilised as a framework for analysing the driving forces of environmental change (see York et al. 2003; Chertow 2000). IPAT specifies that environmental impacts are the multiplicative product of three key driving forces: population, affluence (per capita consumption or production) and technology (impact per unit of consumption or production), hence I=PAT. Affluence is

[83] See Martinez-Alier et al. (1998)

typically approximated by GDP per capita and Technology, by definition, is the impact per unit of economic activity, which also is often defined as environmental Intensity (or its inverse, environmental productivity):

$$I = P \cdot A \cdot T = P \cdot \frac{GDP}{P} \cdot \frac{I}{GDP} \qquad (12)$$

In particular, an interesting analysis in the context of an international distributive analysis of the EF, would be one that evaluates the role of environmental intensity (measured here as EF/GDP and identified as EF intensity hereafter), and level of affluence as explanatory factors of global inequalities in EF, following in the wake of the IPAT model. In particular, intensity is seen as an indicator of environmental efficiency, by relating the volume of productive and human activity with the associated need for resources. The lower the intensity, the more decoupled the economy. Thus, refinements in efficiency of production are required to counterbalance the expected growth of population and affluence over this century. Otherwise, the negative impact on the environment will continue to increase (Chertow 2000, York, et al. 2004)[84]. Since EF per capita is the product of both affluence and intensity, international inequality in EF per capita is consequently also explained by both factors. In this context, (White, 2007) suggested decomposing an index such as Atkinson's with an inequality aversion parameter equal to 1 (Atkinson 1970) in the multiplication of individual factorial indices (hence associated with EF intensity and average income) and a component that

[84] It should be taken into account that a greater efficiency of resources does not necessarily involve greater sustainability since it might be accompanied by an absolute increase of resources. This is the well-known rebound effect. Indeed, several high income countries, despite being more efficient (less intensive in resources), have largest EF per capita. Furthermore, GDP per capita is conventionally used as a measure of society's welfare. However, it only measures the total *monetary* value of goods and services produced within country borders in a given year. It does not take into account nor the depletion of natural resources nor the ecological productions. Indeed, GDP may increase with further use of fossil fuels. In this same line, those defensive expenditures that aim at avoiding or correcting impacts caused by GDP growth, are also positively added in GDP accounts. There are many other dimensions that GDP per capita does not capture properly in order to measure social welfare (such as wealth distribution, domestic work, quality of goods and services, etc). Therefore, some caution must be taken in interpreting both EF intensity and GDP per capita.

covers factorial averages. Hence, among other aspects worth noting, this decomposition does not precisely consider the role that might be played by the probable correlation between the two factors, which has already been clearly documented by York et al (2004). In this way, the factors included in White's (2007) exercise, or one of them, appear as a type of black box that can contain both the partial impacts and the indirect impacts arising from the interactions between them and, consequently, the decomposition seems rather ambiguous.

In view of these circumstances, this section proposes the usefulness of alternatively decomposing an index such as the GE(0), also known as the Theil index (Theil 1967), which is cardinally equivalent to the Atkinson index mentioned earlier, which can, indeed, be decomposed (in an additive way, furthermore) in the partial contribution of both factors (intensity and GDP per capita) plus a factorial interaction component. This decomposition can be immediately extended with the aim of analysing the group inequality components by performing the subgroup decomposition already explained in the previous section (Shorrocks 1980).

4.3.1 METHODOLOGICAL ASPECTS

One of the most interesting approaches designed to investigate the explanatory factors behind the Ecological Footprint of a country consists in breaking down, through multiplication, the level of intensity of the use of resources and the average income in a country (York et al. 2004):

$$e_i = \frac{E_i}{P_i} = \frac{E_i}{Y_i} \cdot \frac{Y_i}{P_i} = I_i \cdot y_i \tag{13}$$

where E_i is the Ecological Footprint of country i; P_i is its population and Y_i is its GDP;

e_i is the Ecological Footprint per capita; I_i is the EF intensity factor, and y_i is the GDP per capita.

Thus the use of resources per capita would be broken down in the part associated with intensity of resource use and global economic activity per capita (i.e. the scale effect). In the first case, its importance would be associated with factors such as environmental efficiency.

In this respect, and with the aim of evaluating the inequalities in EF and the role of the two previous multiplicative components, White (2007) used the Atkinson index (Atkinson 1970), with an inequality aversion parameter equal to 1[85]. Specifically, the aversion parameter used would indicate the presence of a progressive-type inequality index (sensitive to changes in the lower part of the distributive ranking by countries) but not extreme (Atkinson 1970). To be specific, this index would be expressed as follows (already adapted to the analysis of the ecological footprint per capita in its notation):

$$A(e) = 1\text{-}\Pi_i \left(\frac{e_i}{\mu_e} \right)^{p_i} \tag{14}$$

where μ_e is the global average of e; and p_i is the relative population of country i

Replacing (13) with (14) and manipulating the equation, we find that:

$$1 - A_e = \left(\frac{\mu_i \cdot \mu_y}{\mu_e} \right) \cdot \Pi_i \left(\frac{y_i}{\mu^y} \right)^{p_i} \cdot \Pi_i \left(\frac{I_i}{\mu^I} \right)^{p_i} \tag{15}$$

And thus White (2007) established that:

[85] The use of an index from the Atkinson family is slightly surprising, given the objective difficulties in decomposing it in parts (Bourguignon 1979).

$$1-A_e=\left(\frac{\mu_I\cdot\mu_y}{\mu_e}\right)\cdot(1-A_y)\cdot(1-A_I) \tag{16}$$

where *1-A_e* would be an equality index (according to the author); μ_I global average of EF intensities and μ_y the average GDP per capita.

However, if we analyse this in detail, it is not difficult to see that the last multiplication of (15) is not exactly an Atkinson index. Indeed, if it were, the weight vector would have to be consistent with the actual variable analysed, in this case the EF intensity. This is indeed the case for *1-A_y*, where the weighting in the expression (15) comes from population-shares. In the case of *1-A_I* the weightings of the differences across countries should, if we are talking about the Atkinson index in the strictest sense, be done based on GDP-shares. This is not a trivial difference. Indeed, it is plausible that, on an empirical level, the value of this pseudo-Atkinson index could reach negative signs, which would indicate that it contains factorial correlation components. In this way, therefore, one of the components detailed in the decomposition, i.e. *1-A_i*, is not strictly speaking an Atkinson index and, moreover, the factorial correlation is not individualised.

In this respect, it would be interesting to have a decomposition which: firstly, decomposes the global index in a series of strict inequality indices (or partial factorial contributions) for each of the factors; secondly, it would be interesting if the decomposition were to include, separately, the role of the factorial correlation; thirdly, it would be good for the decomposition of inequality to be additive, as is the case with other more familiar decompositions of inequality indices[86].

In these circumstances, we suggest the usefulness of using an alternative decomposition

[86] This would be the case of decomposition by groups (Shorrocks 1980) or by sources (Shorrocks 1982).

technique for an index such as Theil's second measure, or GE(*β=0*) (Theil 1967), which is easier to decompose than the Atkinson index mentioned earlier and, in fact, would achieve analogue distributive rankings to the Atkinson index with a sensitivity parameter equal to 1[87]. In particular, as is well known, this Theil index (*β=0*) (hereinafter referred to as T to simplify notation, however notice that T corresponds to GE(0) in the rest of this thesis) would be calculated based on the following formula (now adapted to the analysis of inequalities in the Ecological Footprint per capita):

$$T_e = \sum_{i=1}^{n} p_i \ln\left(\frac{\mu_e}{e_i}\right) \tag{17}$$

where p_i is the relative population of country *i*; μ_e would represent the world ecological footprint per capita; e_i denotes the ecological footprint per capita of country *i*.

This index could demonstrate that it is a growing monotonic transformation of the Atkinson index with *ε=1* (i.e., A(1)), used referentially by White (2007) in the following form:

$$T = -\ln(1 - A(1)) \tag{18}$$

The minimum value that this Theil index could hypothetically reach is zero, a circumstance that would describe a scenario of absolute equality. The maximum value is not uniformly defined but depends on the specific details of each case. However, a figure close to one could be understood as high inequality. Meanwhile, you can see that this measure is not defined by values equal to zero, a circumstance which, however, is unlikely for the analysis in question.

The decomposition of the inequalities in Ecological Footprint per capita measured by this index would start with the initial factorial decomposition expressed in (13). We

[87] Duro and Padilla (2006) applied a similar methodology to analyse international inequalities in per capita carbon emissions but in a three-factor scenario.

now need to define two fictitious national ecological footprint vectors. According to Duro and Padilla (2006), in each case we allow only one of the factors to vary, setting the other at the global average. We would then find that:

$$e^I = I_i \cdot y \tag{19}$$

$$e^y = I \cdot y_i \tag{20}$$

If we apply the Theil index, according to formula (17) for each of the fictitious factors above, we would be measuring the partial role of each of these factors.

This being the case, we would find that:

$$T\left(e^I\right) = \sum_i p_i \ln\left(\frac{\mu(e^I)}{e_i^I}\right) \tag{21}$$

$$T\left(e^y\right) = \sum_i p_i \ln\left(\frac{\mu(e^y)}{e_i^y}\right) \tag{22}$$

If we add both factors, we find that:

$$\begin{aligned} T\left(e^I\right) + T\left(e^y\right) &= \sum_i p_i \ln\left(\frac{\mu(e^I)}{e_i^I} \cdot \frac{\mu(e^y)}{e_i^y}\right) = \sum_i p_i \ln\left(\frac{\mu(e^I)}{y \cdot I_i} \cdot \frac{I \sum_i p_i \cdot y_i}{I \cdot y_i}\right) = \\ &= \sum_i p_i \ln\left(\frac{\mu(e^I)}{I_i} \cdot \frac{y}{y_i}\right) \end{aligned} \tag{23}$$

if we add the term $\ln\left(\frac{\mu}{\mu(e^I)}\right)$ to the previous total and group them, we find that:

$$\begin{aligned} T(e^I) + T(e^y) + \ln\left(\frac{\mu}{\mu(e^I)}\right) &= \sum_i p_i \ln\left(\frac{\mu(e^I)}{I_i} \cdot \frac{y}{y_i}\right) + \ln\left(\frac{\mu}{\mu(e^I)}\right) = \\ &= \sum_i p_i \ln\left(\frac{\mu(e^I)}{I_i} \cdot \frac{y}{y_i} \cdot \frac{\mu}{\mu(e^I)}\right) = \sum_i p_i \ln\left(\frac{e}{e_i}\right) = T(e) \end{aligned} \tag{24}$$

It is easy to corroborate that, indeed, this added component can be rewritten in terms of a covariance component term between both homogenized factors. Thus, it can be easily demonstrate that:

$$\ln\left(\frac{\mu}{\mu(e^I)}\right) = \ln(1+\frac{\sigma_{I,y}}{\mu(e^I)}) \approx \frac{\sigma_{I,y}}{\mu(e^I)} \tag{25}$$

This being the case, the final outcome would be that the international inequalities in Ecological Footprint per capita could be decomposed strictly in terms of the sum of the partial factors' contribution and the correlation factor:

$$T(e) = T(e^I) + T(e^y) + \ln\left(1+\frac{\sigma_{I,y}}{\mu(e^I)}\right) \qquad (26)^{88}$$

This decomposition is interesting in political terms as well as for its analytical implications. Thus, the first two factors of the previous decomposition would capture the partial role of energy intensities and affluence as explanations for global inequality. If it is the first factor that is most relevant, the measures aimed at fostering equality should prioritise, for example, disseminating international economic models that consume resources less intensively. If, on the other hand, affluence is the principal determining factor for inequalities in per capita consumption of resources between different countries, the main weapon to use as an equalizer would be to encourage real convergence and, consequently, taking action over the factors that lie behind growth

[88] Thus, one could consider decomposing, analogously, the first Theil measure, or *GE(β=1)* (Theil (1967)). This measurement is characterised by weighting the differences based on the share dictated by the numerator, in this case the EF-share per country. Given that the only difference between this index and the GE*(β=0)*, which has been proposed in the main text, is also the weighting vector and the position of variables within the logarithm we would immediately seem to be trying to decompose this measure too. However, in this case the decomposition is much less natural and attractive than that of the *GE(0)*, expressed in (26). In particular, the problem is that the term we have called 'factorial interaction' is, in this case, a type of adjustment component with a much less attractive meaning than that of the GE*(0)*. In particular, it can be demonstrated that:

$$T_1(e) = T_1(e^I) + T_1(e^y) + \ln\left(\frac{\sum_i \alpha_i * e_i - \sigma_{I,y}}{\mu}\right)$$

where αi is the EF-share.
In this way, the additional term depends inversely on the covariance as well as an element that reflects a pseudo-global EF per capita average when using the EF-share instead of the population-share.

processes. Finally, the interaction component, the third term of the expression (27), takes the complementary or substitutive features of both factors and thereby helps to understand the global role of each of them. For example, a significant negative interaction factor would imply that a process of differential economic growth, such as in the emerging countries, would not only have a direct balancing effect through the affluence factor, but that this effect would see itself reinforced through intensities.

Likewise, this decomposition can be easily extended to the analysis of the intra- and inter-group components of the global international inequality (see subgroup decomposition in previous section). These components, as we know, emerge from the capacity of this index to break down the inequalities into a weighted average within the subgroups under observation (intra-group or internal component) and the inequality shown between the subgroups (inter-group or external component) (Shorrocks 1980; Bourguignon, 1979). We would thus need to select a criterion to demarcate the groups of countries which would be intuitive and, a priori, relevant. In this instance, the use of the International Energy Agency aggregations which identify nine main regions will be examined. The implications that emerge from this analysis by groups could be interesting. For example, in terms of environmental policy, the findings would offer clues as to the suitability of implementing re-balancing policies in terms of a global regional design. On the other hand, from a more academic point of view, the results might be used to test the informative value of the aggregations themselves. Thus a high value in the intergroup component (or a small one in the intragroup one) would be perceived as an endorsement of the proposed regional grouping.

In algebraic terms, and recalling the subgroup decomposition formula (2) of the previous section, the groups decomposition by GE(0) (here noted as T measure) would be expressed as:

$$T(e) = T(e)_w + T(e)_B = \sum_{i=1}^{G} p_g T_g(e) + \sum_{g=1}^{G} p_g \ln\left(\frac{\mu^e}{e_g}\right) = \sum_{i=1}^{G} p_g T_g(e) + T(e_g) \qquad (27)$$

where $T(e)_w$ is the intragroup component and $T(e)_B$ is the intergroup component; g refers to country groups; p_g and e_g are the relative population and the average EF corresponding to the g group, respectively, and $T_g(e)$ is the inequality between countries in the g group.

This being the case, and given the expression that takes both components, it is worth looking at breaking them down immediately in the form suggested in (26). Note that the intergroup component is none other than a Theil index (or GE(0)), in this case applied to the groups of countries as basic units of the study. The intragroup component, meanwhile, is a weighted average of regional Theil indices which, in turn, can be decomposed using the multiplicative form above.

Up to now, two studies have been conducted in the international sphere to examine inequalities in EF per capita. White (2007), for example, examined them using the Gini coefficient and the Atkinson index, but only for 2003, and also decomposed the latter, as we have seen, by multiplication factors. Dongjing et al (2010), meanwhile, analysed these inequalities by taking the Gini coefficient as a benchmark measurement of inequality for selected years during the 1996-2005 period. In our particular case, therefore, we are focusing on a specific methodological aspect, the decomposition of inequalities, by multiplication and by groups, and undertaking an empirical analysis over a longer period of time.

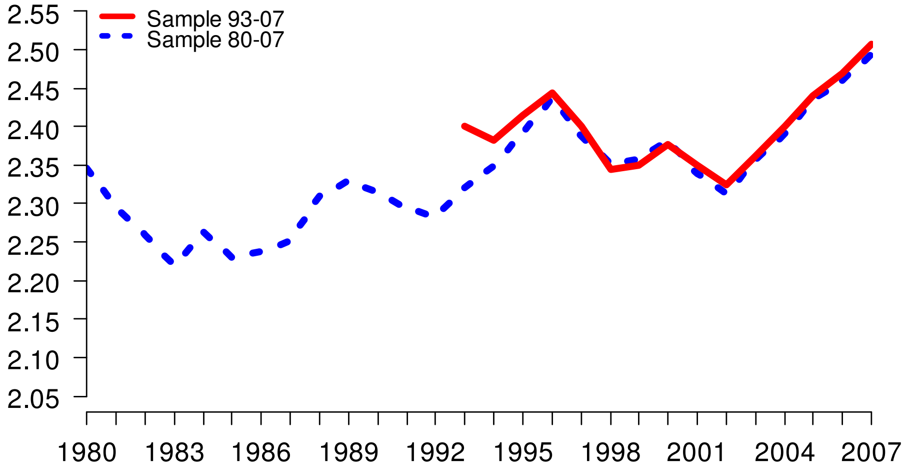
4.3.2 MAIN EMPIRICAL RESULTS

The data used in this section also came from the Global Footprint Network in the case of the Ecological Footprint of a country, and from the World Bank (World Bank Indicators) based on the GDP and population factors. The joint analysis of the available variables made it advisable to differentiate two periods of time for the samples. The first included 105 countries during the 1980-2007 period, which together accounted for almost 80% of the world ecological footprint generated in 2007. In the second, the analysis was restricted to the period of 1993-2007, which allowed us to use data for 136 countries generating 89% of the world ecological footprint of 2007.

We see, initially, the global data in relation to world EF per capita. Figure 4 illustrates the development of the two sample countries used. Thus, in the contextual period there has been a gradual increase in the EF per capita on a global level, rising from 2.23 in 1985 to 2.49 in 2007, i.e. an increase of just over 10%. There was a slight drop between 1980 and 1985 and a global tendency to rise since then, with ups and downs. The use of the 1993-2007 sample did not produce any significant changes either in the time pattern or the overall level of the world EF per capita[89].

[89] Because of the merging datasets between Global Footprint Network and World Bank data, it was not possible to keep working with exactly the same dataset as previous sections. However, the sample is still representative.

Figure 4. Evolution of the world EF per capita, 1980-2007



Source: Drawn up by the authors using Global Footprint Network and World Bank data

Table 1 and 2 present some statistical summaries of regional groups (according to International Energy Agency-IEA) as an illustration of what is underlying international differences. Table 1 shows average EF per capita of the different regions through time and its world population share, which plays as the weighting role in inequality measures applied thereafter. In table 2 we can see which share of world EF is appropriated by each group of countries given its GDP and population shares. Additionally, the average EF per capita, intensity and income of each group are presented as relative to the world mean. In doing so a convenient reference point is provided (the world mean) to assess the value of any country group relative to others.

Table 1: Summary statistics by groups of Countries according to IEA criterion

	1980		1990		2000		2007	
Region	**EF per capita**	**World Pop.**	**EF per capita**	**World Pop. %**	**EF per capita**	**World Pop. %**	**EF per capita**	**World Pop. %**
OECD-Europe	4.83	11.1%	4.79	9.77%	4.75	8.9%	4.84	8.5%
OECD-North America	6.44	8.4%	6.66	7.98%	7.01	7.9%	6.87	7.7%
OECD-Pacific	3.92	4.5%	4.62	4.14%	5.03	3.8%	4.96	3.5%
Non-OECD Europe	4.29	0.9%	3.79	0.78%	2.32	0.6%	2.94	0.6%
Africa	1.67	10.0%	1.52	11.06%	1.46	12.2%	1.45	13.1%
Latin America	2.87	7.2%	2.47	7.39%	2.60	7.5%	2.56	7.6%
Middle East	1.75	1.7%	1.99	2.10%	2.60	2.3%	3.54	2.4%
Asia	1.00	30.3%	1.01	31.67%	1.06	32.8%	1.12	33.5%
China	1.34	25.8%	1.51	25.12%	1.76	24.1%	2.25	23.1%
World	**2.35**	**100.0%**	**2.31**	**100.00%**	**2.38**	**100.0%**	**2.49**	**100.0%**

Source: Drawn up by the authors using Global Footprint Network and World Bank data

It can be observed that those groups with higher GDP per capita (*y*) are the countries with higher relative EF per capita and lower relative intensity. After all, the allocation of resource is determined by the dominance of market mechanisms. Hence, wealthy nations may pay for having greater amounts of land embodied in its consumption. They can consume a lot of meat, bananas, coffee, tea, wear cotton clothes, etc. (Røpke 2001). Lower intensity (greater efficiency) is often related to the better technologies available in rich countries.

Table 2: Summary statistics by groups of Countries according to IEA criterion in relative terms

1980	EF %	GDP %	Pop %	Relative *e*	Relative *I*	Relative *y*
OECD-Europe	22.89%	32.47%	11.12%	2.06	0.70	2.92
OECD-North America	23.10%	30.80%	8.41%	2.75	0.75	3.66
OECD-Pacific	7.61%	11.99%	4.55%	1.67	0.63	2.64
Non-OECD Europe	1.62%	0.95%	0.89%	1.83	1.71	1.07
Africa	7.11%	3.84%	9.98%	0.71	1.85	0.38
Latin America	8.76%	8.40%	7.15%	1.22	1.04	1.17
Middle East	1.30%	3.55%	1.74%	0.75	0.36	2.04
Asia	12.90%	5.76%	30.33%	0.43	2.24	0.19
China	14.72%	2.24%	25.84%	0.57	6.58	0.09
World	**100.00%**	**100.00%**	**100.00%**	**1.00**	**1.00**	**1.00**
1990	**EF %**	**GDP %**	**Pop %**	**Relative *e***	**Relative *I***	**Relative *y***
OECD-Europe	20.26%	30.57%	9.77%	2.07	0.66	3.13
OECD-North America	22.98%	30.56%	7.98%	2.88	0.75	3.83
OECD-Pacific	8.26%	13.38%	4.14%	2.00	0.62	3.24
Non-OECD Europe	1.28%	0.78%	0.78%	1.64	1.63	1.00
Africa	7.25%	3.63%	11.06%	0.66	2.00	0.33
Latin America	7.90%	6.91%	7.39%	1.07	1.14	0.94
Middle East	1.81%	2.89%	2.10%	0.86	0.62	1.38
Asia	13.84%	7.28%	31.67%	0.44	1.90	0.23
China	16.43%	3.99%	25.12%	0.65	4.12	0.16
World	**100.00%**	**100.00%**	**100.00%**	**1.00**	**1.00**	**1.00**
2000	**EF %**	**GDP %**	**Pop %**	**Relative *e***	**Relative *I***	**Relative *y***
OECD-Europe	17.72%	27.67%	8.88%	2.00	0.64	3.12
OECD-North America	23.11%	30.41%	7.85%	2.94	0.76	3.87
OECD-Pacific	7.94%	11.94%	3.76%	2.11	0.66	3.17
Non-OECD Europe	0.62%	0.48%	0.64%	0.97	1.30	0.75
Africa	7.44%	3.40%	12.18%	0.61	2.19	0.28
Latin America	8.22%	6.77%	7.53%	1.09	1.21	0.90
Middle East	2.45%	3.01%	2.25%	1.09	0.82	1.34
Asia	14.62%	8.57%	32.79%	0.45	1.71	0.26
China	17.87%	7.74%	24.13%	0.74	2.31	0.32
World	**100.00%**	**100.00%**	**100.00%**	**1.00**	**1.00**	**1.00**
2007	**EF %**	**GDP %**	**Pop %**	**Relative *e***	**Relative *I***	**Relative *y***
OECD-Europe	16.54%	24.94%	8.53%	1.94	0.66	2.92
OECD-North America	21.24%	27.71%	7.71%	2.76	0.77	3.60
OECD-Pacific	7.02%	10.88%	3.53%	1.99	0.65	3.08
Non-OECD Europe	0.67%	0.56%	0.57%	1.18	1.20	0.98
Africa	7.61%	3.63%	13.09%	0.58	2.09	0.28
Latin America	7.77%	6.87%	7.59%	1.02	1.13	0.90
Middle East	3.36%	3.27%	2.37%	1.42	1.03	1.38
Asia	14.99%	10.21%	33.51%	0.45	1.47	0.30
China	20.80%	11.93%	23.10%	0.90	1.74	0.52
World	**100.00%**	**100.00%**	**100.00%**	**1.00**	**1.00**	**1.00**

Source: Drawn up by the authors using Global Footprint Network and World Bank data

Table 3 shows the main results obtained after decomposing the international inequalities in EF per capita, taking the Theil index (GE(0)) as a reference and for selected years in the different periods. In this sense, we have focused on the evidence provided by the Theil index because this section wants to focus on the investigation of the role of environmental intensity and affluence as explanatory factors and, therefore, in a context of multiplicative decomposition. This being the case, it does not reflect the results obtained from using other inequality indices which are not easy to decompose in this context. In any event, the calculation of indices such as the Gini and the Atkinson or the Coefficient of Variation (following Duro (2012)) does not throw up any particularly significant changes to the time pattern of international inequalities in EF per capita[90]. In this respect, the main results can be summed up as follows:

For the subperiod considered here the international inequalities would have dropped, especially up to 1995. Between 1995 and 2007 there is barely any variation. Indeed, we cannot conclude that there is a substantial variation in an almost thirty-year period (plus or minus 10%)[91]. This finding, for example, is lower than the reduction experienced in international inequalities in CO_2 per capita, which over the 1971-2006 period was 38%, or those reflected by energy intensities, whose inequalities were mitigated by 45% since 1971 (Duro 2012). Such differences may be occurring because the EF is a consumption-based indicator[92] whereas emissions indicators are rather production-based. Thus, such stable/slight decline may suggest that international distribution of production and international distribution of consumption are not spatially linked. Indeed, since we are dealing with the inequality of embodied land in consumption, its contrasting non-decreasing inequality points, again, towards an ecological Prebisch thesis and its

[90] See Chapter 3.
[91] See Chapter 3 to see the longer period analyses of the Inequality.
[92] See Chapter 2.

international structural heterogeneity (Pérez-Rincón 2006).

Table 3: International inequalities in the Ecological Footprint per capita and its decomposition by multiplication factors, 1980-2007

	T(*e*)	T(e^I)	T(e^y)	Interaction term
Sample 80-07				
1980	0.2764	0.3714 (134%)	1.0261 (371%)	-1.1212 (-406%)
1985	0.2726	0.2869 (105%)	0.9309 (341%)	-0.9452 (-347%)
1990	0.2676	0.2493 (93%)	0.8838 (330%)	-0.8655 (-323%)
1995	0.2459	0.2197 (89%)	0.7769 (316%)	-0.7507 (-305%)
2000	0.2591	0.2043 (79%)	0.7378 (285%)	-0.6829 (-264%)
2005	0.2622	0.2057 (78%)	0.6470 (247%)	-0.5905 (-225%)
2007	0.2445	0.2056 (84%)	0.6043 (247%)	-0.5654 (-231%)
Sample 93-07				
1993	0.2433	0.2457 (101%)	0.7896 (325%)	-0.7920 (-326%)
1995	0.2398	0.2313 (96%)	0.7576 (316%)	-0.7490 (-312%)
2000	0.2485	0.2144 (86%)	0.7259 (292%)	-0.6918 (-278%)
2005	0.2522	0.2179 (86%)	0.6428 (255%)	-0.6084 (-241%)
2007	0.2387	0.2128 (89%)	0.6038 (253%)	-0.5779 (-242%)

Source: Drawn up by the authors using Global Footprint Network and World Bank data

However, both the partial contribution to global inequality attributable to the intensity factor and to the affluence factor (which is the most important factor) drop significantly, especially the second one, thus leading to a broad reduction in global EF inequalities per capita: the partial disparities attributable to the intensity factor drop from 0.37 in 1980 to almost 0.21 in 2007 (a reduction of almost 50%). The income factor, meanwhile, while it maintains a relatively larger contribution, sees its contribution reduced from 1.03 in 1980 to 0.60 in 2007 (a reduction of almost 40%). The decrease in the intensity factor takes place essentially up to 2000, after which it becomes stable. However, the income factor drops throughout the whole period. Therefore, in spite of everything, the international differences in EF per capita are more a matter of affluence rather than the supposed compensating effect on the scale of EF intensity. Consequently, according to this result, further equity might be achieved more by redistributing income (i.e. real convergence) than by redistributing efficient technologies.

Given the significantly equalising contribution of the abovementioned factors, the interaction factor is the one which, in effect, explains the less clear-cut result seen in the evolution of international inequalities in EF per capita. Thus factorial interaction plays a significant role, with a negative sign[93]. Indeed, its value is similar to that of affluence, with a changed sign. And it is the significant drop in the value of this component (in absolute terms), which explains the lower drop in global inequalities. This being the case, two things can be interpreted from this result. First, the negative correlation between GDP per capita and intensity favours the equalisation of EF per capita throughout countries. Thus, an increase in the GDP per capita in any country would increase its EF per capita to a greater level if the intensity were not less. In this context, given that, overall, the emerging economies are in a process of growth, their consumption of resources would not grow so much due to the effect of the intensity of use. Interestingly this effect has reduced, which has diminished the individual equalising effect of the real convergence factor. For this reason, the reduction in the equaliser factor associated with the interaction element would indicate a diminishing in the income-consumption trade-off relative to resources. These difficulties in reducing the consumption of resources are to do with the growth of the emerging nations. In fact, we see how the disparity in the intensity of use has hardly reduced since 2000, when real convergence was important. Without this development in the interaction component, and supposing a zero value, the international inequalities in EF per capita would have dropped from an imaginary 1.4 in 1980 to 0.81 in 2007.

[93] The factorial correlation coefficient typically moves between -0.37 and -0.48 in the case of the 1980-2007 sample, and between -0.43 and -0.49 in the case of the 1993-2007 sample. More detailed information is available on request.

Meanwhile, we have taken advantage of the decomposition facilities of GE(0) to decompose by multiplication the global inequalities by group components (Shorrocks 1980). In other words, we have initially decomposed the global inequality in EF per capita into two parts[94]: the first is attributed to the differences between groups of countries when these are regional, and the second attributed to the scale of the internal heterogeneities of the groups in accordance with the regionalisation criteria used by the IEA (International Energy Agency)[95]. The point is that each of these synthetic components are thus decomposable based on the previous multiplicative format. Table 4 shows the results associated with the between-groups component, and Table 5 shows those associated with the within-groups component.

Table 4: Between-groups Inequalities in Ecological Footprint per capita and their decomposition by multiplication factors, 1980-2007

	$T(e)_B$	$T(e^I)_B$	$T(e^y)_B$	Interaction term
Sample 80-07				
1980	0.2350 (85%)	0.3411 (145%)	0.9341 (397%)	-1.0402 (-443%)
1985	0.2313 (85%)	0.2313 (100%)	0.8365 (362%)	-0.8365 (-362%)
1990	0.2255 (84%)	0.1942 (86%)	0.7821 (347%)	-0.7508 (-333%)
1995	0.1972 (80%)	0.1285 (65%)	0.6588 (334%)	-0.5901 (-299%)
2000	0.2146 (83%)	0.0886 (41%)	0.6221 (290%)	-0.4961 (-231%)
2005	0.2143 (82%)	0.0666 (31%)	0.5316 (248%)	-0.3838 (-179%)
2007	0.1950 (80%)	0.0598 (31%)	0.4889 (251%)	-0.3537 (-181%)
Sample 93-07				
1993	0.1960 (81%)	0.1478 (75%)	0.6647 (339%)	-0.6166 (-315%)
1995	0.1892 (79%)	0.1199 (63%)	0.6261 (331%)	-0.5568 (-294%)
2000	0.2031 (82%)	0.0865 (43%)	0.5975 (294%)	-0.4808 (-237%)
2005	0.2041 (81%)	0.0685 (34%)	0.5158 (253%)	-0.3802 (-186%)
2007	0.1886 (79%)	0.0615 (33%)	0.4774 (253%)	-0.3503 (-186%)

Source: Drawn up by the authors using Global Footprint Network and World Bank data

[94] See section 4.1 of this Chapter
[95] On this occasion the groups are purely regional (see appendix A)

Table 5: Within-groups Inequalities in Ecological Footprint per capita and their decomposition by multiplication factors, 1980-2007

	$T(e)_W$	$T(e^I)_W$	$T(e^y)_W$	Interaction term
Sample 80-07				
1980	0.0414 (15%)	0.0624 (151%)	0.0920 (222%)	-0.1130 (-273%)
1985	0.0413 (15%)	0.0627 (152%)	0.0945 (229%)	-0.1158 (-280%)
1990	0.0421 (16%)	0.0607 (144%)	0.1017 (242%)	-0.1203 (-286%)
1995	0.0487 (20%)	0.0648 (133%)	0.1182 (243%)	-0.1343 (-276%)
2000	0.0446 (17%)	0.0676 (152%)	0.1157 (260%)	-0.1388 (-311%)
2005	0.0479 (18%)	0.0747 (156%)	0.1155 (241%)	-0.1423 (-297%)
2007	0.0495 (20%)	0.0766 (155%)	0.1153 (233%)	-0.1424 (-288%)
Sample 93-07				
1993	0.0473 (19%)	0.0769 (163%)	0.1249 (264%)	-0.1545 (-327%)
1995	0.0506 (21%)	0.0757 (150%)	0.1315 (260%)	-0.1566 (-310%)
2000	0.0454 (18%)	0.0703 (155%)	0.1284 (283%)	-0.1534 (-338%)
2005	0.0482 (19%)	0.0764 (159%)	0.1270 (264%)	-0.1553 (-322%)
2007	0.0501 (21%)	0.0774 (155%)	0.1264 (252%)	-0.1537 (-307%)

Source: Drawn up by the authors using Global Footprint Network and World Bank data

With regard to the between-groups inequality, we can see the following basic results: firstly, it is the between component which has the greater explanatory power of global inequalities in EF per capita. In fact, its weight is typically close to 80% of the total, when not exceeding it. This weight illustrates, amongst other aspects, the explanatory capacity of these exogenous groups for the EF per capita inequalities as well (Duro and Padilla 2006). Secondly, it also confirms the not very substantial drop in global inequalities accompanied by the larger drop in individual factorial inequalities, especially in the affluence factor. Thirdly, it confirms the high incidence of the interaction component and its particular influence on the apparent stability of the between component of global inequality. Indeed, the interaction component, with a negative sign, declines significantly, which considerably contributes to offsetting the drop in individual factorial inequalities. Therefore, as the patterns of international inequality are mainly captured by these regional groups, a country's EF (expressed as income and intensity) appears to be mainly determined by the group to which it belongs, which strengthens the idea of a geopolitical structural heterogeneity: less developed countries, dependent on manufactured exports to high-consuming countries reduce consumption-based impacts. Dependence on high exports makes exporting countries more vulnerable to world market forces, such as depletion of raw materials, concentration of pollution due to mono-cropping or unhealthy production of commodities (Niccolucci et al. 2012). Consequently, ecological distribution, like sustainability, is a global geopolitical problem.

Finally, with regard to the *within* component, this has a lower overall weight in the explanation of global inequalities, reaching maximum explanatory values of around 20% of the total. In this case, the pattern outlined is different to that of the between component. For example, in this case the inequalities increased during the period, explained by the evolution in both factors. In contrast, the interactive component now increases its negative value in the 1980-2007 sample, contributing to reducing the inequalities, and remains stable in the sample that starts in 1993.

4.4 CONCLUSIONS

In this chapter, we have dealt with inequality additive decomposition methodologies; by subgroup, by EF sources and by multiplicative factors.

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 weighs 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 contribute 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%) for the whole period analysed (1961-2007). 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. Additionally, the persistence in time of the high *between* inequality suggests structural world inequality and so it is in line with Ecological Unequal exchange theories which points that certain subgroups historically have borne a disproportionate share of environmental burdens because of its position in the resource flow in a World system economy. 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 also 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.

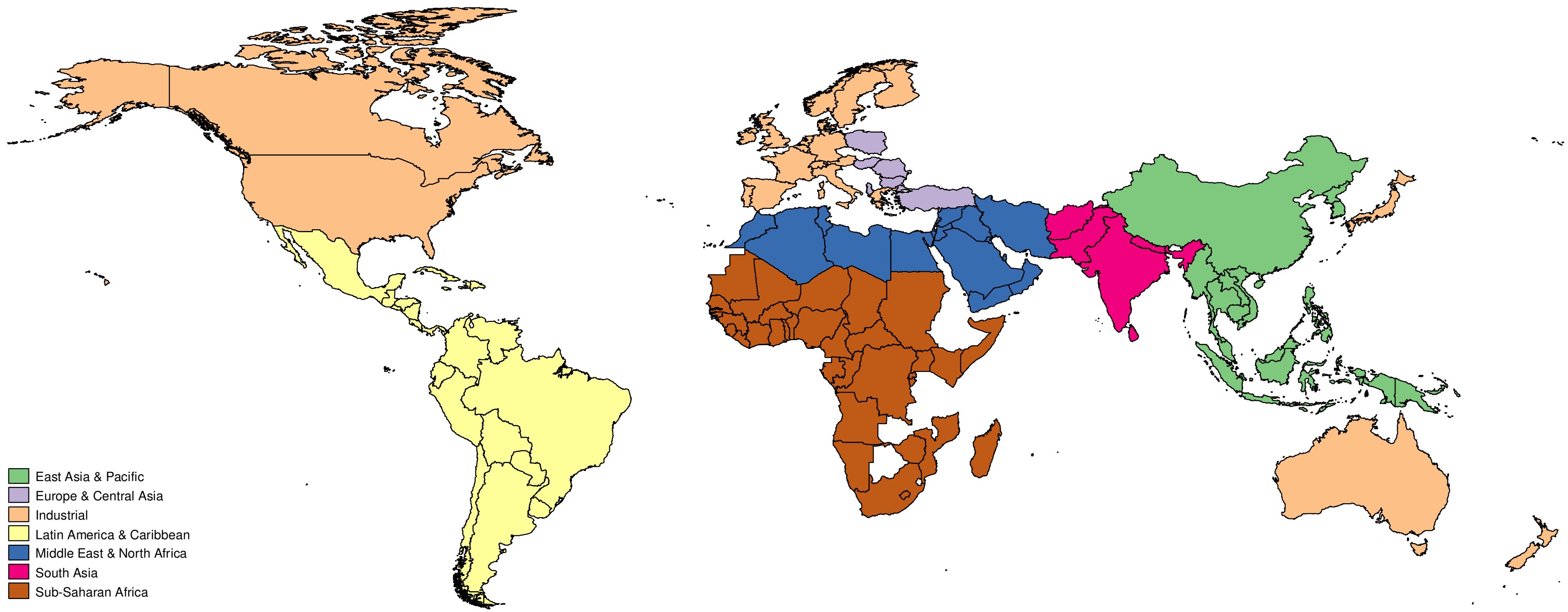
Regarding source decomposition, we have noted the inappropriateness of the widely used Gini coefficient decomposition since its resulting contributions are non-unique and the interaction effects are allocated in an implicit and arbitrary way. The only non-ambiguous way of decomposing inequality by sources is the natural decomposition of CV^2, which allows, besides, interpreting contributions in marginal terms. The empirical results point out that, although all EF sources' inequalities have reduced, the contribution to total EF inequality has not necessarily followed the same movement. This is due to changes in sources' shares 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 provides 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. However, the results also suggest that policies aimed at converting typical cropland utilities into commercial energy (bio-fuels), could threaten basic human needs due to the expected increase of Cropland Footprint Inequality. In order to protect these needs in international agreements, the use of EF jointly with other ecological indicators would be highly recommendable to complement the carbon emissions indicator (in the line of multi-criteria analyses).

Finally, the multiplicative decomposition makes two essential contributions, one methodological and the other empirical. Firstly, it proposes a decomposition of international inequality (in this indicator) by multiplicative factors, i.e. by separating the effect of intensity of use and affluence, which provides additional and more crucial information than the methodology used in the decomposition proposed for an index such as the Atkinson index by White (2007). In particular, the proposed decomposition not only allows us to identify the partial role played by each factor individually, but also to include an interaction factor, already referred to as significant by York et al (2004) though not contemplated by White (2007). Furthermore, the proposed decomposition (for the Theil index) can be extended to the group inequality components (Shorrocks 1980). Secondly, the paper makes an empirical implementation of the proposed analysis in order to examine the international inequalities in EF per capita for the 1980-2007 period. The evidence suggests that the apparent stability of, or lower reduction in, the international inequalities in EF per capita in this period considered is attributed, to a large extent, to the role of the interaction factor between affluence and EF Intensity (that is, a lesser negative sign); the individual contribution of the intensity factor and, above all, of the affluence factor has clearly reduced, so that the reduced correlation component (negative) would explain the apparent stability in global inequality. Therefore, the dwindling of the trade-off between PIB per capita and the intensity of resource consumption, especially in the case of emerging countries, would have slowed down the reduction in disparities and clearly poses new questions for future environmental sustainability. Thus the basic strategy, in this context, would be fundamentally to promote the process of real convergence and, hence, reduce the contribution of the affluence factor in global inequality, but with significant advances in the intensity of use in those countries that converge, which would serve to increase the negative interaction value. Only in this way can advances be achieved in international EF equality per capita that can be, furthermore, compatible with a reduction in global levels. On the other hand, an analysis of the inequality by groups of countries suggests that it is the inequality component between groups (regional) of countries that primarily explains the global results and also that the nine regions considered (now according to International Energy Agency classification) can be a good reference unit for addressing global measures for environmental sustainability.

APPENDIX

A1. World Bank Regional Grouping of countries

East Asia and Pacific	Europe and Central Asia	Industrial	Latin America and Carib.	Middle East and North Africa	South Asia	Sub-Saharan Africa
Cambodia	Albania	Australia	Argentina	Algeria	Afghanistan	Angola
China	Bulgaria	Austria	Bolivia	Egypt	India	Benin
Indonesia	Hungary	Belgium	Brazil	Iran	Nepal	Burkina Faso
Korea, DPR	Poland	Canada	Chile	Iraq	Pakistan	Burundi
Korea, Rep	Romania	Denmark	Colombia	Israel	Sri Lanka	Cameroon
Lao PDR	Turkey	Finland	Costa Rica	Jordan		Central African R
Malaysia		France	Cuba	Kuwait		Chad
Myanmar		Germany	Dominican Republic	Lebanon		Congo
Papua New Guinea		Greece	Ecuador	Libyan AJ		Congo, DR
Philippines		Ireland	El Salvador	Morocco		Côte d'Ivoire
Singapore		Italy	Guatemala	Oman		Gabon
Thailand		Japan	Haiti	Qatar		Gambia
Timor-Leste		Luxembourg	Honduras	Saudi Arabia		Ghana
Vietnam		Netherlands	Jamaica	Syrian AR		Guinea
		New Zealand	Mexico	Tunisia		Guinea-Bissau
		Norway	Nicaragua	Yemen		Kenya
		Portugal	Panama			Liberia
		Spain	Paraguay			Madagascar
		Sweden	Peru			Mali
		Switzerland	Trinidad and Tobago			Mauritania
		United Kingdom	Uruguay			Mauritius
		United States of A	Venezuela, BR			Mozambique
						Namibia
						Niger
						Nigeria
						Rwanda
						Senegal
						Sierra Leone
						Somalia
						South Africa
						Sudan
						Togo
						Uganda
						Zimbabwe



Source: Own elaboration from (World Bank).

A2. Decomposition by country subgroups using World Bank geographical groups. GE(0), GE(1) and GE(2).

	$\beta=0$					$\beta=1$					$\beta=2$				
year	$I(e)_W$	%	$I(e)_B$	%	GE(0)	$I(e)_W$	%	$I(e)_B$	%	GE(1)	$I(e)_W$	%	$I(e)_B$	%	GE(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: Own elaboration from (Global Footprint Network).

A3. Inequality of per capita EF components according to GE(2) indices, 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: Own elaboration from (Global Footprint Network).

A4. Correlations of EF per capita and its sources

	EF per capita	Cropland	Grazing	Forest	Fishing	Carbon	Built-up
EF per capita	1						
Cropland	0.0628	1					
Grazing	0.134	0.6267	1				
Forest	0.2057	0.7957	0.5811	1			
Fishing	0.1335	0.6984	0.494	0.6025	1		
Carbon	0.2497	0.6784	0.4512	0.8731	0.6706	1	
Built	-0.0083	0.91	0.6215	0.6086	0.7096	0.5766	1

Source: Own elaboration from (Global Footprint Network).

A5. EF Source contribution to total EF per capita inequality according to the Natural decomposition of CV^2 (values in %)

Year	Fishing	Cropland	Grazing	Forest	Carbon	Built	Total
1961	6.54	35.93	20.07	18.53	17.51	1.46	100
1962	6.46	35.13	18.90	18.71	19.34	1.50	100
1963	6.10	34.94	17.33	17.17	23.08	1.24	100
1964	5.91	29.49	17.39	17.90	28.07	1.37	100
1965	5.76	29.46	15.01	17.51	31.14	1.16	100
1966	5.58	27.37	14.68	17.03	34.25	1.02	100
1967	5.76	27.44	13.33	16.13	36.20	1.18	100
1968	5.26	27.59	12.43	15.32	38.56	0.91	100
1969	4.69	26.65	10.86	14.90	42.09	0.85	100
1970	4.81	21.46	9.80	14.18	48.92	0.84	100
1971	4.18	23.25	8.99	13.82	48.81	0.90	100
1972	4.16	21.65	8.72	12.69	51.76	0.99	100
1973	3.93	19.22	8.60	13.16	54.24	0.83	100
1974	4.13	19.16	9.99	13.02	53.10	0.80	100
1975	3.83	21.03	10.91	11.79	51.84	0.83	100
1976	3.95	19.37	9.29	12.35	54.37	0.61	100
1977	3.50	19.36	8.02	12.21	56.14	0.86	100
1978	3.54	17.92	7.96	13.13	56.63	0.78	100
1979	3.50	18.74	7.36	13.12	56.55	0.76	100
1980	3.90	17.09	7.79	13.28	57.10	0.99	100
1981	3.51	19.26	8.04	13.02	55.29	1.00	100
1982	3.80	23.85	7.99	11.69	51.50	1.15	100
1983	4.04	16.24	8.54	14.07	56.02	0.85	100
1984	3.63	18.31	7.38	14.33	55.17	1.05	100
1985	3.93	20.15	5.25	14.29	55.23	0.96	100
1986	3.93	18.99	4.75	15.26	56.20	0.96	100
1987	4.39	16.73	4.78	15.39	57.89	0.98	100
1988	4.28	13.68	6.03	14.88	60.38	0.84	100
1989	4.40	14.46	5.00	15.17	60.11	0.84	100
1990	4.03	15.84	4.54	14.81	59.98	0.80	100
1991	4.10	15.71	5.13	12.87	61.08	0.89	100
1992	3.99	15.46	4.78	12.97	61.97	0.84	100
1993	4.01	13.55	5.34	13.92	62.30	0.77	100
1994	4.22	15.40	4.27	13.77	61.39	0.83	100
1995	4.41	12.96	5.20	13.85	62.67	0.81	100
1996	3.82	13.32	4.62	13.07	64.32	0.87	100
1997	3.88	12.73	4.00	13.37	65.30	0.78	100
1998	3.34	13.11	3.98	13.47	65.29	0.84	100
1999	3.50	12.76	3.79	13.54	65.70	0.85	100
2000	3.26	12.41	3.73	13.64	66.10	0.85	100
2001	3.52	12.04	3.75	12.84	66.98	0.77	100
2002	3.39	11.54	3.98	13.05	67.35	0.86	100
2003	3.08	12.62	4.24	12.69	66.52	0.69	100
2004	2.91	13.05	3.45	12.84	66.91	0.82	100
2005	2.76	12.33	3.52	13.32	67.25	0.69	100
2006	2.94	10.74	3.53	12.27	69.86	0.71	100
2007	2.92	11.63	3.70	11.72	69.23	0.73	100

Source: Own elaboration from (Global Footprint Network).

A6. International Energy Agency (IEA) Regional Grouping of countries

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

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CHAPTER 5

THE CAUSAL CONTRIBUTORS OF EF INEQUALITY: A REGRESSION-BASED DECOMPOSITION

The study of the driving forces behind the demand for natural resources (or pollution) has been of widespread interest to researchers and policy makers in recent decades because, apart from the boundaries of the earth, they are highly important as they spread concern for future generations. One common framework was suggested by Ehrlich and Holdren (1971) who first proposed the so-called IPAT identity, where environmental impact (I) is related to Population (P), Affluence (A) and Technology (T). Hence I=PAT. The strength of this identity stems from capturing the key driving forces of the environmental impact.[96] Further research developed this accounting equation into a stochastic regression model (York, et al. 2003b). It allowed both for making a test hypothesis and also introducing further factors that may have some environmental impact. As a result there is a vast amount of knowledge about the driving forces of

[96] See Chapter 2 for a brief introduction and contextualisation of the IPAT identity. Chapter 4 performs a multiplicative decomposition of International Inequality of EF as assessed by IPAT identity.

natural resource consumption (Caviglia-Harris et al., 2009, Dietz et al. 2007, Fischer-Kowalski and Amann 2001, Rosa et al., 2004). These empirical analyses tell us about the effect (elasticity) that a rise in affluence, population or technology (or temperature or urban population share, etc.) would have on a particular environmental impact scale of natural resource demand.[97] However, and this is the main contribution of the present chapter, they do not reveal the effect these causal factors will have on the international environmental impact distribution, i.e. influence on *intra*generational inequality.

Methodologically, we can go one step further in these two by merging topics of ecological economics: the ecological inequality measurement (studied in previous chapters) and the estimation of the impact of driving forces. To do so, we will apply the Regression-Based Inequality Decomposition (RBID hereafter),[98] which to the best of our knowledge has never been adopted in any of the main strands of ecological economics.

The RBID allows, once the STRIPAT model has been assessed by the usual procedures, us to determine to what extent the typical ecological impact drivers contribute towards international inequality. In this chapter, we will therefore determine the causal contributions to International Inequality in natural resource consumption (as measured by per capita EF). In doing so, we will significantly extend the results obtained so far in terms of environmental equity, allowing at the same time for a wider discussion of its connection to sustainability.

The remainder of this chapter is organised as follows. Section 5.1 describes the methodology applied to decompose the EF inequality observed into the explanatory variables of the regression model used; the so called regression-based Inequality

[97] But also literacy rate, income inequality, growth rate, country institutional framework, etc.
[98] See Fields (2003).

Decomposition. Section 5.2 presents the results of the estimation of driving forces of the ecological footprint and its contribution to international inequality in the ecological footprint. Section 5.3 concludes the chapter.

5.1 METHODOLOGY OF RBID ACCORDING TO FIELDS (2003)

In contrast to the traditional analytical method of decomposing inequality by sources (Shorrocks 1982, 1983), which is based purely on mathematical properties (see Chapter 4 of this thesis), RBID allows, not only for inequality accounting, but also for causal analysis. Actually, the main advantage of such relatively new methodology is that it does not require the variable of interest, here the EF, to be broken down into its components (which in EF framework would consist of decomposing inequality according to the contributions of carbon, cropland, grazing, fishing, forest and built-up footprints).[99] On the contrary, RBID permits accounting for the inequality contribution of any significant explanatory factor. Hence, all that is needed is the auxiliary regression of pollution generating functions estimated within the framework of environmental economics, which are an expanded environmental Kuznets curve or STRIPAT model:

$$EF = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon_i \qquad (1)$$

There is a large amount of empirical literature in environmental economics which estimates such functions, i.e. an environmental Kuznets curve (Caviglia-Harris et al.,

[99] White (2007) and Chapter 4 of this thesis decompose the International Ecological Footprint Inequality according to the contribution of EF components. The main results indicate that the most important contribution to EF inequality became the carbon footprint because of its rising share in total EF rather than because of its inequality, which actually decreased. In contrast, grazing and fishing footprints (related to the diets of industrialised countries) exhibited relatively high levels of inequality despite contributing modestly to total EF inequality because of their low share to total EF. Finally the cropland footprint contribution to EF inequality 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.

2009; Dinda 2004, Grossman and Krueger, 1991; Torras and Boyce, 1998) or stochastic estimations of IPAT identity, also known as STRIPAT for Stochastic Regression of IPAT (York et al., 2003b, Dietz et al., 2007, Rosa et al., 2004, York et al., 2003a). But, to the best of our knowledge, such results have never been used to analyse international differences among countries.

By construction, in expression (1) EF is presented as the sum of its *k* explanatory variables plus a typical error term and constant term, so it can be expressed as

$$EF = \sum_{k}^{K+2} \beta_k X_k \tag{2}$$

The RBID is based on considering the product of estimated coefficients and its variable as a composite variable, where the β-coefficients play the role of weighting the importance of the component *k* in contributing to whole EF. As a result, a consistent identity is obtained in line with those required by traditional decomposition methods, so that the rule of natural decomposition of the variance can be performed in an analogous way and benefit from its persuasive axioms.[100] Under this decomposition rule, the contribution of each component corresponds to the cov(X_k, EF) and its relative contribution is defined as cov(X_k, EF)/var(EF).

Although there are other methods to decompose inequality, for example regression-based techniques, we use the Fields method here (Fields, 2003) because of its simplicity

[100] According to Shorrocks (1982, 1983) the natural decomposition of the variance is the only non-ambiguous decomposition of inequality by sources independently of the inequality measure used. The main reason is that correlation among components is allocated in an explicit and rational way without violating the basic axioms of inequality measurement (1: the inequality index and the sources are continuous and symmetric. 2: The contributions do not depend on the aggregation level. 3: The contributions of the factors add up to the global inequality. 4: The contribution of source *k* is zero if factor *k* is evenly distributed. 5: With only two factors, where one of them is a permutation of the other, the contributions must be equal.)

and analogy to Natural Source Decomposition described in Chapter 4 of this thesis.[101] In this RBID approach, the model is restricted to a semi-log linear function:[102]

$$\ln EF = \sum_{k}^{K+2} \beta_k X_k \tag{3}$$

Once the semi-log model is estimated, variances on both sides of the equation must be taken:

$$\text{var}(\ln EF) = \text{var}\left(\sum_{k}^{K+2} \beta_k X_k \right) \tag{4}$$

Notice that the right-hand side is already an inequality measure, the variance of logarithms (Var-Log). Rearranging the expression (4), we obtain

$$\text{var}(\ln EF) = \sum_{k}^{K+2} \text{cov}(\beta_k X_k, \ln EF) = \sum_{k}^{K+2} \text{cov}(\beta_k X_k, \ln EF) \tag{5}$$

which is an analogue of the expression of the natural decomposition rule of the variance (Shorrocks, 1982). Therefore, according to this method, the contribution of the EF's explanatory factors, x_k, to total EF inequality is defined by

$$s_k(\ln EF) = \frac{\text{cov}[\beta_k X_k, \ln EF]}{\text{var}(\ln EF)} \tag{6}$$

Notice that $\sum_{k=1}^{K+2} s_k(\ln EF) = 100\%$ so that s_k answers the question of how much EF

[101] There are several empirical applications to income comparing different methods. An appealing one is (Gunatilaka and Chotikapanich, 2009)

[102] The semi-log model $Ln(EFpc) = \beta_0 + \beta_1 F_1 + \beta_2 F_2 + ... + \beta_k F_k + \varepsilon_i$ is equivalent to $EFpc = \exp(\beta_0 + \beta_1 F_1 + \beta_2 F_2 + ... + \beta_k F_k + \varepsilon_i) = \exp(\beta_0) \cdot \prod_{k=1}^{k} \exp(\beta_k F_k) \cdot \exp(\varepsilon_i)$. Then, the contribution β_0 is null since it is a constant in each observation.

inequality is accounted for by the factor *k*. If we remove the residual term, then what we will get is the R^2 of the regression $\sum_{k=1}^{K+1} s_k (\ln EF) = R^2 (\ln EF)$

Since the coefficients of the regression play a weighting role, it may be interesting to know whether the different changes of s_k are caused by a change in the dispersion of factor *k*, or by a change in its importance in the function measured by β. Expression (7) provides a decomposition of just such a change of the s_k contribution

$$s_{kt} - s_{kt-1} = \frac{\mathrm{cov}(\beta_t^k x_t^k, \ln e_t)}{\mathrm{var}(\ln e_t)} - \frac{\mathrm{cov}(\beta_{t-1}^k x_{t-1}^k, \ln e_{t-1})}{\mathrm{var}(\ln e_{t-1})} = \left[\frac{\mathrm{cov}(\beta_{t-1}^k x_t^k, \ln e_t)}{\mathrm{var}(\ln e_t)} - \frac{\mathrm{cov}(\beta_{t-1}^k x_{t-1}^k, \ln e_{t-1})}{\mathrm{var}(\ln e_{t-1})}\right] + \left[\frac{\mathrm{cov}(\beta_t^k x_t^k, \ln e_t)}{\mathrm{var}(\ln e_t)} - \frac{\mathrm{cov}(\beta_{t-1}^k x_t^k, \ln e_t)}{\mathrm{var}(\ln e_t)}\right] \quad (7)$$

The first term depicts the dispersion effect since the coefficients are not allowed to vary (and so only the dispersion changes between *t-1* and *t*) and the second term represents the coefficient effect since the dispersion of vector x is not allowed to vary (and so only the coefficient changes between the two periods).

Additionally, we may be interested in knowing to what extent the *k* factor contributed to the change in the EF inequality level between two periods. This inequality change contribution is expressed as:

$$\delta_k \equiv \frac{s_{kt} I(.)_t - s_{kt-1} I(.)_{t-1}}{I(.)_t - I(.)_{t-1}} \quad (8)$$

Notice that expression (8) is not restricted to the use of any particular inequality index. However, unlike the previous decompositions described, its results do depend on the inequality measure chosen.

5.2 Main Empirical Results

The method developed in the previous subsection (Fields, 2003) is performed in order to quantify the contribution of various factors in accounting for the amount of international EF inequality at a point in time (equation 6), their change over time, its functional decomposition (equation 7) and, finally, the role they played in the increase of the EF inequality observed (equation 8).

The data used comes from the World Bank and from the Ecological Footprint Network and covers the period from 1993 to 2007, biannually.[103] As it is shown in Table 1, each year uses at least 87% of the world EF (at least 94% of the world population and, at least 96% of world GDP).

Table 1. World Ecological Footprint data

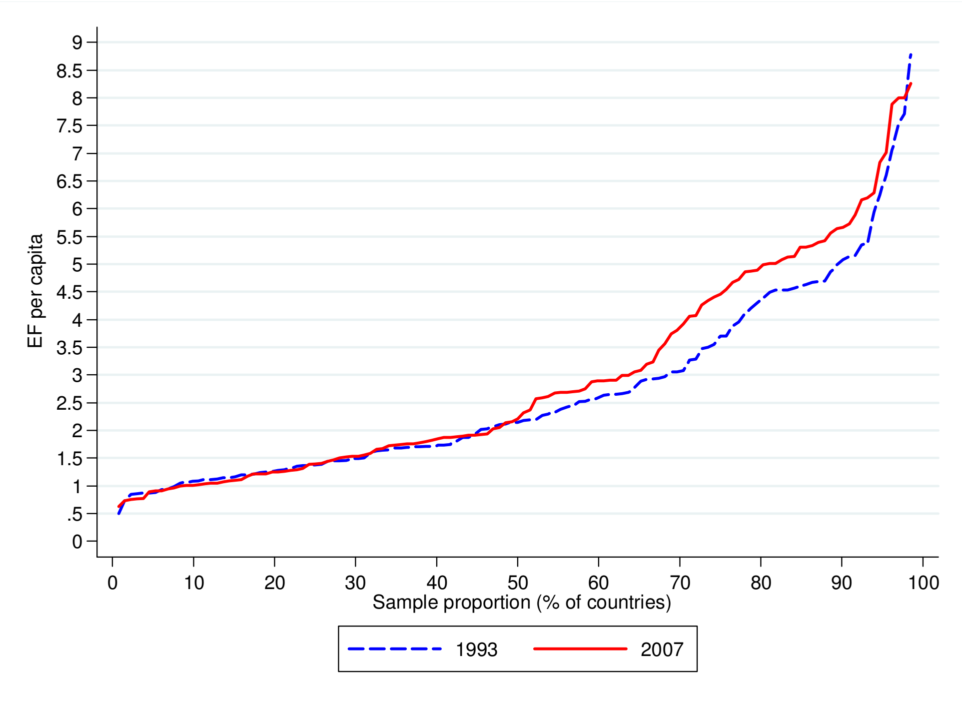
	World EF		Sample data		% EF sample over world EF
Year	Total EF (billion gha)	EF per capita	Total EF (billion gha)	EF per capita	
1993	14.35	2.59	12.50	2.38	87%
1995	14.85	2.60	13.00	2.40	88%
1997	15.12	2.57	13.30	2.38	88%
1999	15.25	2.53	13.40	2.33	88%
2001	15.54	2.51	13.80	2.34	89%
2003	16.28	2.56	14.40	2.32	88%
2005	17.29	2.66	15.10	2.39	87%
2007	17.99	2.70	15.80	2.46	88%

In 2007 the human race's total Ecological Footprint worldwide was 18 billion *gha*. The population was 6.7 billion, so the average Ecological Footprint per capita was 2.7*gha*. Nonetheless, according to Ecological Footprint National Atlas (Ewing et al. 2010), that year there was only 11.9 billion *gha* of biocapacity available (1.8*gha* per capita), which

[103] This is because the RBD decomposition requires further data (for anthropogenic drivers) of different sources (mainly from World Bank) and we lose some observations in the merging process. The sample proposed is the one that allows longer period (1993 to 2007 biannually) with a significant sample of countries.

means that at least 6.1 billion of the *gha* consumed was charged to future generations.[104] Hence at least 33% of the EF per capita of the present generation was appropriated from future generations. On the other hand, the *gha* was consumed in an equitable way. Figure 1 is the Pen's Parade diagram of the distribution of EF per capita of 1993 and 2007. The Pen's Parade consists of ordering countries from low to high EF per capita so that in the horizontal axis we see the deciles and the vertical axis shows the EF per capita. It is easy to see that some countries had much greater EF per capita than others (see Chapter 3). Besides, if we compare both years, we observe that the higher deciles significantly increased their EF per capita while the lower ones did not, their deciles actually decreasing slightly. As a result, world EF per capita growth shown in Table 1 was mainly caused by higher deciles.

Figure 1: Pen's Parade Diagram of EF per capita for year 1993 and 2007



Note: own elaboration

[104] In spite of the growing world population trend, the per capita EF has also been increasing each year, and since 1975, it has been consuming more Global Hectares each year than those available.

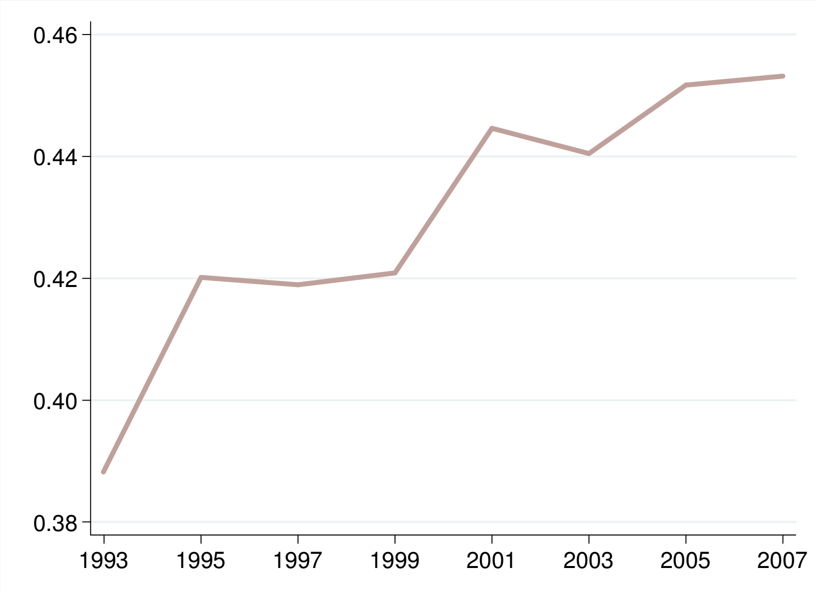
This visual aid may give us an idea of the international inequality trend in terms of EF per capita. Figure 2 shows the EF inequality observed in the analysed period according to the variance of logarithms (Var-log hereafter).[105] Notice that in this section the inequality is not weighted by population, so that the trend is different to that described in the previous chapters of this thesis.[106]In this instance we are interested in all observations weighting the same so that the explanatory power of the independent variables is not excessively determined by the performances of the highly populated countries. Besides the non-weighted regressions are more appropriate for the econometric model used. According to this index, the inequality between countries increased, and so not only was the intergenerational equity (sustainability) threatened but also the *intra*generational equity. Regression-based decomposition unravels the factors that were the main drivers in the rise in international EF per capita inequality and to what extent.

The explanatory variables used as factors are those typically regressed in STRIPAT models and extended EKC curves and are listed in Table 2 (see York et al. 2003a, b). Notice that Table 2 provides, apart from the typical descriptive statistics, the ratio between the standard deviation and the mean of the variables (Coefficient of Variation), which may allow comparisons among internal inequalities of each variable. Nonetheless, we need to keep in mind that the contribution of each variable to global inequality is given by the particular combination of internal inequality, its weight, and its indirect effects.

[105] In this work, inequality is measured by the variance of Logarithms mainly because this index is methodologically linked to the Regression-Based Inequality Decomposition proposed by Fields (2003). Such an index is a common inequality index which satisfies the scale-independence property and the population principle (Goerlich 1998) but it does not satisfy the Pigou-Dalton transfers principle as long as the observations are greater than *e* times the geometric mean of the distribution in question, what only affects the very high values of the distribution with no significant effect on our analysis (Foster, Ok 1999, Cowell 2011).

[106] See Appendix A1 to see the inequality evolution according to main indices analysed in section 3.2 without weighting countries by its population share.

Figure 2. International EF-Inequality according to variance of logarithms



Note: Present authors from Global Footprint Network

Table 2. Descriptive statistics

Variable (1993)	Obs	Mean	Std. Dev.	CV	Min	Max
EF per cap.: global hectares per capita	132	2.782	1.933	0.695	0.497	11.115
Per capita GDP (constant 2000 US$)	132	4963.830	7985.772	1.609	79.581	35963.800
Industrial GDP share (%)	132	30.377	10.196	0.336	8.825	63.996
Urban population share (%)	132	49.891	23.014	0.461	6.840	100.000
Non-dependent population share (aged 15 to 65)	132	58.940	6.717	0.114	45.528	72.130
Average daily min temperature	132	12.132	8.098	0.667	-10.100	23.300
Variable (2007)	**Obs**	**Mean**	**Std. Dev.**	**CV**	**Min**	**Max**
EF pc: global hectares per capita	132	3.018	2.070	0.686	0.62	10.68
Per capita GDP (constant 2000 US$)	132	7313.431	11217.280	1.534	96.25	56388.99
Industrial GDP share (%)	132	32.881	12.610	0.384	13.27	76.42
Urban population share (%)	132	55.797	21.664	0.388	12.56	100.00
Non-dependent population share (aged 15 to 65)	132	63.024	6.597	0.105	48.81	81.44
Average daily min temperature	132	11.981	8.006	0.668	-10.10	23.30

Note: Present authors, based on Global Footprint Network and World Bank. Further descriptive data is available upon request. CV refers to the Coefficient of Variation, a normalized inequality index (the mean divided by the standard deviation).

5.2.1 AUXILIARY REGRESSION RESULTS

The first step in decomposition analysis commences with equation (3). Since the model is a semi-log model, the dependent variable is the EF per capita in log scale and it consists of a linear function of GDP per capita (and its square and cubic terms), industrial GDP share, urban population share, non-dependent population share and the climate control variable. The results obtained by an OLS are shown in Table 3. The most striking thing to notice is that high values are registered in R^2. Considering that high values in the adjusted R^2 in the cross-sections are accompanied by high significance in the variables, collinearity is not a problem in the model estimated (Pindyck 1998). We calculated quadratic partial correlations between exogenous variables and dependent variables and low values were obtained indicating, once more, that collinearity is not a problem in our estimation.[107]

Since this is a semi-log model, we must interpret the significant coefficients as semi-elasticities, i.e. an increase (decrease) of one unit in an explanatory variable yields a β% increase (decrease) in the dependent variable. Hence, an increase in one dollar of per capita GDP yields an increase of EF per capita of 0.01%, and so on (in low income countries).

[107] Other models have been estimated with different regressors, including models where cubic GDP per capita is removed and the results obtained are virtually equivalent. Actually, as can be expected, the higher correlation belongs to this variable. It must be taken into account, however, that the non-collinearity assumption is about linear relationships among regressors, and despite its high correlation with GDP per capita, the cubic GDP per capita is a non-linear relationship. Hence, it does not violate the basic assumption (Gujarati and Porter 2009).

Table 3. OLS coefficients predicting the National Ecological Footprint per capita.

Variable	1993	1995	1997	1999	2001	2003	2005	2007
Affluence								
Per capita GDP	.00010702***	.00013775***	.00011086***	.00012868***	.00013551***	.00014331***	.00011793***	.00012602***
pc GDP 2	-5.647e-09**	-6.272e-09**	-4.822e-09**	-5.300e-09***	-5.502e-09***	-5.911e-09***	-4.244e-09***	-4.387e-09***
pc GDP3	9.325e-14*	9.135e-14*	6.840e-14*	6.930e-14**	7.051e-14***	7.646e-14***	4.887e-14***	4.657e-14***
Sectorial Composition								
Indust. GDP share (%)	-.00567775*	-0.0053	-.00749226**	-.00715216**	-.00599264**	-.00534894**	-0.00342	-0.00111
Population Structure								
Urban population sh	.0051429**	.0042*	.00510013**	.00468959**	.00413376**	.00439423**	.00514963***	.00410505**
Non-dependent pop	.02001067**	.01562846**	.02191975***	.01635892**	.01656801**	.01459613**	.01706415***	.0180932***
Climate								
Avg. min temperature	-.0198924***	-.01331806***	-.0131226***	-.00912717*	-.01044084**	-.00897584**	-.01148746***	-.01165549***
Constant	4.1722791***	4.2730793***	3.9271276***	4.148702***	4.1207606***	4.163932***	3.9771418***	3.8762283***
Countries	132	136	137	137	139	141	137	132
R- Squared	0.71	0.71	0.73	0.71	0.73	0.75	0.77	0.77
Adjusted R- Squared	0.69	0.70	0.71	0.70	0.72	0.74	0.76	0.75
Log-likelihood	-42.6265	-48.1674	-45.6984	-49.3509	-48.4103	-44.3009	-38.6825	-38.5654

*, **, *** significant at the 10%, 5% and 1% level, respectively

The coefficient signs are consistent with results obtained by other authors: firstly, the affluence factor, here approximated by GDP per capita (which should not be confused with welfare but with economic activity),[108] indicates the existence of a non-monotonic relationship given the negative sign in the quadratic term of GDP, pointing to an Environmental Kuznets Curve (EKC) relationship. However, the significant positive cubic term of GDP per capita rejects such a hypothesis. This has an N-shape pattern and so, the rejection of the EKC hypothesis is obtained in all of the studies of the sample years.[109] Therefore, all other things being equal, GDP per capita raises EF per capita. The more affluent the country, the more resources it requires and so the lower the sustainability. In this regard, the strictly economic degrowth theories may solve the distributional problems with future generations as environmental pressure would, however, slow down at the cost of aggravating resource distribution conflict between people of the same generation since, despite huge inequalities, growth can make everybody at least a bit better off (despite the huge inequality in how the growth is shared).[110] On the other hand, decoupling GDP growth from resource demand would obviously help in both directions, however, in some point this decoupling will clash with the physical laws of thermodynamics; and so complete decoupling is not feasible.

The economic structure, approximated here by the industrial share of GDP, appears with a negative sign that is not always significant. Thus, as long as the environmental impact is measured using EF, a greater share of industry involves lower EF per capita in comparison to non-industrial sectors (services and agriculture). Such a result is quite

[108] GDP per capita is conventionally used as a measure of society's welfare. However, it only measures the total *monetary* value of goods and services produced within a country's borders in a given year. It does not necessarily correlate with access to healthcare, wealth distribution and literacy. Indeed, those defensive expenditures that aim at avoiding or correcting social or ecological impacts caused by GDP growth, are also positively added into GDP accounts.

[109] Other studies finding this N-pattern relationship between GDP per capita and environmental pressure are (Friedl and Getzner, 2003; Sengupta, 1996; Taskin and Zaim, 2000).

[110] For each 100$ of growth only 60 cents go to the poorest people of the World (Dietz and O'Neil, 2013).

different to results obtained when the ecological impact is measured with some more production-based indicators. Nonetheless, it is consistent with estimate made using EF (York et al., 2003a, b). EF is a consumption-based indicator, therefore having a more industrial-based GDP does not necessarily imply consuming more resources (countries may be exporting their products and global hectares exported are subtracted from a country's EF). In fact, for several years, the coefficient is not statistically different from zero.

The more the population lives in urban areas, the more EF per capita is exposed. The rationale stems from the fact that the migration of rural workers to urban areas in search of better jobs yields a sprawl of growing cities with large suburbs and thus more roads, wires and infrastructures per capita are required. Additionally, in urban zones, the need to commute every day by private transport becomes more pressing. Therefore, the EF per capita tends to be higher as the urban population is also higher. In effect, although the impact of urban development is often perceived as local or regional, cities have become entropic black holes drawing in energy and matter from all over the ecosphere (Alberti, 1999; Rees and Wackernagel, 1996). Nonetheless, the coefficient is quite low (a 1% rise yields a 0.5% rise in EF per capita) and registered a slight shrinkage over the period analysed. Actually, in this direction, some evidence points to significant reduction potentials from better urban structures (Weisz and Steinberger, 2010)

Still, in demographic terms, the share of non-dependent population (this is the population aged between 15 and 65, and so of working age) raises the demand of resources per capita by around 2% for each additional percentage point in such a variable. This is caused because the ages of 15 to 65 are the most productive and also consumes the most and so the EF per capita of a country with high share of this adult population will tend, naturally, to be higher. In other words, children may consume substantially less natural resources than adults but, as they grow, they will consume further cars, flights, tobacco, clothes, furniture, etc., so increasing their EF. However, as they reach the later stages of life they may moderate some of this consumption (Zagheni, 2011). [111] In this regard, we may expect that, as populations of the low fertility nations of the world grow older, resource consumption patterns may shift radically (Dietz and Rosa 1994). *Ceteris paribus*, this is what the regression coefficient is indeed capturing.

Lastly, climate plays a role in influencing patterns of ecological impact. Here, we used a climatic normal,[112] instead of a dummy variable, to take advantage of its greater variability.[113] Concretely, the daily minimum average temperature is used as a control for such a role. The negative sign obtained thus indicates that the colder (the hotter) the weather, the higher (the lower) the environmental impact – this might be due to higher energy demands.

5.2.2 REGRESSION-BASED CONTRIBUTIONS OF FACTORS

The regression results are used to calculate each factor's weight which, together with the variable vector dispersion (its inequality), will yield the contributions to overall EF per capita inequality observed.[114] Table 4 presents, on the left, the relative factor contributions to inequality (expression 6) for each year sampled from 1993 to 2007 and on its right, the contribution change registered throughout the whole period analysed

[111] Zagheni's (2011) results point out that per capita CO_2 emissions in the US increase with age until the individual is in his or her 60s, and then emissions tend to decrease.
[112] Climatologists define a climatic normal as the arithmetic average of a climatic element (such as temperature) over a prescribed 30-year interval in order to filter out many of the short-term fluctuations and other anomalies that are not truly representational of the real climate. The last climatic normal available is for the period 1971-2000.
[113] Many studies used dummy variables coded into three categories based on the latitude of a country: arctic, tropical, temperate. See York et al. 2003a, b.
[114] The non-linear effect of GDP per capita (say quadratic and cubic) is grouped into the affluence factor, following Fields' (2003) methodology.

(1993-2007) is decomposed in order to quantify the extent to which that change is due to changes in a factor's dispersion or to its coefficients (expression 7). Lastly, Table 5 quantifies the contribution of each factor to the rise observed in international EF inequality as measured by Log-Variance (expression 8).

As can be seen, despite the bulk of the variables being statistically significant determinants of EF per capita, not all of them share the same importance in accounting for cross-country inequality in EF per capita. These differences in relative importance could not have been seen from standard regression output alone (Fields, 2003).

Table 4. Decomposition of Inequality, Contribution Level and Decomposition of Contribution Change by the dispersion-coefficient effect

	Contribution level								Dispersion and Coefficient effect in contribution changes 1993 - 2007				
Factors	**1993**	**1995**	**1997**	**1999**	**2001**	**2003**	**2005**	**2007**	**Change 1993 - 2007**	**Disp. Effect**	**(%)**	**Coeff. effect**	**(%)**
Affluence													
GDP per capita	28.26	42.89	36.62	44.11	47.2	50.36	46.8	48.93	+20.40%	13.3%	(65%)	7.20%	(35%)
Sectorial Composition													
Indust. GDP share (%)	-1.75	-1.46	-1.15	-0.61	-0.55	-0.38	-0.02	-0.04	+1.70%	1.5%	(90%)	0.20%	(10%)
Population Structure													
Urban population sh	13.3	10.39	12.47	11.23	9.58	10.13	11.77	8.86	-4.40%	-2.2%	(50%)	-2.20%	(50%)
Non-dependent pop.	15.9	11.32	16.13	11.16	11.17	9.74	11.29	11.83	-4.00%	-2.8%	(69%)	-1.20%	(31%)
Climate	15.29	8.35	8.49	5.31	5.99	5.06	7.19	7.07	-8.20%	-3.2%	(39%)	-5.00%	(61%)
Residual	28.99	28.51	27.43	28.8	26.62	25.09	22.97	23.35	-3.90%	-3.9%	(100%)	0.00%	(0%)
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**					

Note: Present authors, based on (Global Footprint Network) and (World Bank)

Table 5. Contribution of that factor to the change in inequality measured by Log-Var and GE(2):

	Log-Variance	GE(2)
Factors	**1993-2007**	**1993-2007**
Affluence	172.39	730.52
Sectorial Composition		
Indust. GDP share (%)	10.14	56.18
Population Structure		
Urban population sh	-17.66	-137.53
Non-dependent pop.	-12.52	-122.58
Climate	-42.02	-263.97
Residual	-10.33	-162.62
Total	**100.00**	**100.00**
Total Inequality change	**17%**	**3%**

Note: Present authors, based on (Global Footprint Network) and (World Bank)

The affluence factor accounted for the largest share of total EF inequality throughout the whole period. In 1993 it already accounted for the 28.26% and registered a sharp increase over the period, finally accounting for 50% of the EF inequality. Consequently, it can be stated that the most important factor in determining the international EF inequality level was the affluence factor, especially in the final years of the sample taken where it accounted for half of the total EF inequality. Furthermore, taking into account that in the period analysed, as Figure 2 shows, international EF inequality increased (according to log-variance), the fact that the contribution of affluence registered such an increase inevitably means that its covariance with the EF increased faster than EF inequality (see equation 6).[115] As Table 4 (right) shows, this increase in affluence contribution was not entirely driven by an increase in

[115] The cov(x,y) corresponds to the contribution of source decomposition which is the direct contribution of the variable x (through its own dispersion) and the half of all its indirect effects through the interaction of x with other factors (See Chapter 4 expressions 7 to 11).

its own dispersion: a sizeable 35% of that increase between 1993 and 2007 was due to changes in the regression coefficient (the remaining 65% being a result of the dispersion effect). Finally, as Table 5 shows, the rise of EF inequality observed in the period was mainly due to the contribution of the affluence factor. What we see then, is that the affluence factor is not only the main contributor to EF inequality but also the main (if not the only) driver which spurred international inequality in terms of natural resource consumption (176% of the increase in log variance). Hence, in terms of *intra*generational inequality, what determines the direction of resource flows in the world's system is essentially the purchasing power of countries.

Considering the remarkable importance of the affluence factor in determining and in raising EF inequality, this finding expands the typical regression result qualitatively, since, all other things being equal, as countries get richer, they tend to require a larger EF per capita (regression result) but in doing so, international inequality in the EF per capita is also encouraged (RBID result). Therefore, decoupling policies will undoubtedly improve sustainability as many papers point out;[116] however, the results shown indicate that neglecting GDP per capita convergence will still lead to a high EF inequality (a sustainable but inequitable world system) and will probably hinder the achievement of sustainability; for instance, the more unequal the per capita income is, the more difficult it will be to reach multilateral environmental agreements, since poor countries will have more pressing concerns to prioritise, and as a result, they will be more reluctant to engage in costly commitments. Rich countries, which could compensate them through transfers, do not have enough guarantees that those transfers will be used to achieve environmental objectives

[116] Decoupling policies are those policies that are aimed at reducing the relationship between certain variables, which in this case is GDP growth, and its associated environmental pressure, in this case EF. This relationship is quantified here by the auxiliary regression coefficient β. Nonetheless, despite decoupling policies being highly desirable, complete decoupling of GDP growth is not feasible from a physical point of view; any economic activity involves the thermodynamics' laws.

(Neumayer, 2011). Indeed, there is some evidence from field experiments demonstrating that the more inequality exists among individuals, the greater the concern about the fairness of the outcome rather than the achievement of the objective itself, which in this case is sustainability (Tavoni et al. 2011). Therefore, international policies should have two objectives: first, decoupling GDP and the demand for natural resources and second, fostering economic convergence to benefit its plausible positive synergies (for instance, those compensating transfers from rich to poor countries would help in the right direction). In the light of the results, then, such policies (decoupling policies and relative transfers from rich to poor) will clearly be the most effective ones in achieving an equitable, sustainable world.

Furthermore, there is some evidence that shows that, even assuming an increase in GDP per capita improves the standard of living in a country, once a certain threshold of affluence is reached, this no longer remains true. Therefore, since GDP growth is (still) dependent of natural resource consumption, when such resources are mainly being consumed by rich countries in order to achieve even greater GDP (which likely will not result in greater living standards), poor countries are losing ecological space which may improve their quality of life (Dietz and O'Neil 2013).

The sectorial composition factor, approximated here by the industrial share of GDP, appears with a negative contribution to EF inequality (Table 4 right). This means that this factor not only does not contribute to inequality but lowers EF inequality. The reason for this particular behaviour is twofold: firstly, the factor registers relatively low inequality among countries (compared to EF per capita inequality; see Table 2), and secondly, its coefficient (weight) is also relatively low in explaining EF per capita (a 1% increase in industrial share lowers the EF per capita by 0.5-0.7% as long as the statistical significance holds). However, since the still low inequality in industrial share increased modestly during the period, 90% of the change in that factor's contribution to EF inequality was due to a dispersion effect (Table 4, right). Given the increasing EF inequality scenario, the modest change in the unequalising direction of the factor makes the contribution to EF inequality significant (10% of log-variance increase in Table 5). In any case, inasmuch as the coefficient is not statistically different from zero over several years, we may conclude that industrial share is not an important factor due to its causality and its international inequality provided that EF is the ecological indicator used.

Urban population share, related to the additional resources per capita used by those living in urban areas, exhibits a sizeable although decreasing contribution to international EF inequality. At first, urban share was responsible for 13.3% of international differences but at the end of the period it decreased to just 8.86% of the differences (Table 4). This is caused, on the one hand, by a decrease in the internal dispersion of the factor (Table 2), and, on the other hand, to the slight decline in its regression coefficient (Table 3). Such a change in urban factor contribution was thus driven equally by both dispersion and coefficient effect (50% and 50%), since both the factor's inequality and coefficient reduced equally throughout the period. The changes registered explain the negative contribution (equalising) of the factor to rising EF inequality (Table 5). In this regard, it could be stated that the urban factor avoids greater EF inequality. This is, however, is not necessarily good: what we are observing in this factor is that humanity assembles in urban environments (and so the factor's inequality is low and declining) but, since its coefficient is still positive in explaining EF per capita, as more people live in cities, the urban convergence of humanity has a greater impact. According to UN-Habitat (2012) urban areas around the world are becoming the dominant form of habitat for humankind.[117] Therefore, in terms of sustainability, it becomes critical to continue lowering that coefficient. In this regard, the low coefficient with its slight reduction in our results may suggest that some potential advantages of urban settlements play a minor role in

[117] According this report, only one century ago, two out of ten people in the world were living in urban areas, in 1990 less than 40%, and since 2010, more than half the world population is settled in a city (UN Habitat, 2012).

decoupling urban population from EF per capita; for instance, urbanisation involves lower demand for occupied land because of high population density and it also provides great potential for economies of scale (in recycling and material re-use, co-generation, providing running, treated water, waste collection and other public amenities) and for reducing energy consumption through walking, cycling or public transport (Rees and Wackernagel, 1996). Hence, given this urban convergence trend, such potentialities must be fostered in order to completely decouple cities from their environmental impact in order to ensure sustainability.[118]

In contrasting, the second demographic factor captured, the non-dependent population (a country's age structure) exhibits a relatively high coefficient (Table 3) and a relatively low international inequality (compare its CV with EF per capita CV in Table 2). Consequently, its sizeable contribution to EF inequality is mainly due to its contribution to EF per capita rather than in exhibiting internal inequality. Hence the non-dependent population factor's contribution is a factor mainly driven by its high coefficient, which is its weight in explaining EF per capita. However, as shown in Table 4, this contribution reduced from 15.9% to 11.8%, and it was due mainly to the dispersion effect (69%), rather than a coefficient effect (31%). Therefore, on average, it was mainly due to the fact that countries became more equal in terms of their demographic pyramid structure that in the factor's contribution reduced. This equalising movement in turn led to the age structure contributing negatively to the rise in EF inequality (Table 5). As a result, focusing on the non-dependent population share, the only possible policy recommendations which would ensure both a fairer distribution of natural resources and higher sustainability rates, would be those that make the factor's coefficient shrink so that the working age population is decoupled from its higher ecological impact This

[118] There is vast literature focused on the study of how different urban patterns can affect ecological systems. See Alberti (1999) and Weisz and Steinberger (2010) for two appealing reviews or Muñiz and Galindo (2005) in the case of Barcelona.

may have deep political implications since the stability of capitalism is highly dependent on consumerism and productive capacity.

The differences of climate in each country significantly contributed towards international EF inequality. Since the climate factor does not change throughout the period (it is a climatic normal), its reduction must have been caused by the statistical effect produced by the increase of log variance in EF per capita and the changes registered in regression. Nonetheless, it is worth highlighting the fact that the climate factor is the only non-anthropogenic factor of the empirical model considered, so that its change over time reinforces the idea that the international inequality of resource consumption is mainly and increasingly a matter of human societies. Otherwise, if inequality in EF per capita stemmed only from climatic differences, such inequality would not be unfair; we would be facing just inequalities.

Finally, residual contribution corresponds to that part of EF per capita variance that is not explained by regressors. From a statistical point of view, the reduction of the residual's contribution is more appropriate for the model used (as R^2 points out in Table 4). However, focusing on these kinds of environmental economics models, which stem from IPAT identities, the T of Technology is usually included in the residual term rather than estimated separately as a measure of resource efficiency (see York et al. 2003b, p. 354). Therefore, in a very cautious way, and insofar as we assume that the residual is mainly capturing the technological capacities of the countries, it may involve the technological differences among countries contributing a significant 28% to international EF inequality in the initial years, reducing to a still significant 23.35% in 2007.

5.3 CONCLUSIONS

This chapter aims to contribute to the literature that deals with ecological inequalities. In particular, we estimate the influence of the anthropogenic driving forces of environmental impact on the international inequality of natural resources. In doing so, we extend the empirical analyses which, adopting regression techniques, estimate the elasticities of the drivers' ecological impact. As a result, the analysis performed shows and discusses not only the intergenerational equity (a future generation's rights) but also the often neglected *intra*generational equity. We use Ecological Footprint data to measure a country's demand for natural resources.

From a technical point of view we have applied a relatively new methodology, the Regression Based Inequality Decomposition (Fields 2003), in order to obtain the building blocks of international EF inequality. The empirical literature on this issue was limited to the use of additive sources of the environmental indicator as contributors to its inequality. In the case of Ecological Footprint inequality, for instance, the contributors to total EF inequality were limited to the contributions of its additive components (carbon, cropland, grazing, forest, fishing and built-up footprints) by applying traditional inequality decomposition tools. However, the regression-based approach allows us to decompose inequality into explanatory variables typical of environmental threats such as climate, technology, per capita GDP, sectorial composition, population structure. As a result, the analysis performed is critical to understanding the main determinants of international EF inequality per capita.

The main results demonstrate that economic growth not only increased ecological impact per capita but also the ecological inequality within countries. Such a finding expands the typical growth-environmental damage trade-off: as countries became more affluent, it led not only to a more unsustainable level but also to a less fair allocation of natural resources, which may yield a circle of unsustainability and inequity, given the potential interactions between them.

Indeed, economic convergence may yield a more equitable distribution of natural resources within and between generations. Hence, decoupling policies should be combined with economic convergence policies, such as relative transfers from rich to poor.

On the other hand, demographic variables also play a critical role in EF inequality. Firstly, we observed that world population is migrating from rural to urban environments and, according to international studies, it is not expected to end in the coming decades. Hence, it becomes of paramount importance to keep lowering the still positive link between cities and greater EF per capita by redesigning cities in a rationally ecological way, i.e. taking advantage of a city's potential given its economies of scale and its high population densities: co-generation, public mobility, material recycling and re-use, etc. Such policies may prevent future generations from ecological overshoot and at the same time yield a more just distribution of natural resources within present generations. More ambitiously, policies aimed at preserving rural population share will also work towards the same objective. Secondly, the demographic pyramid shape also plays a significant role in explaining EF differences among countries, mainly because of the greater consumption of working age population. Hence, it may become critical to foster policies that detach a population group from its ecological impact; this may create both more ecological equality among countries and greater sustainability.

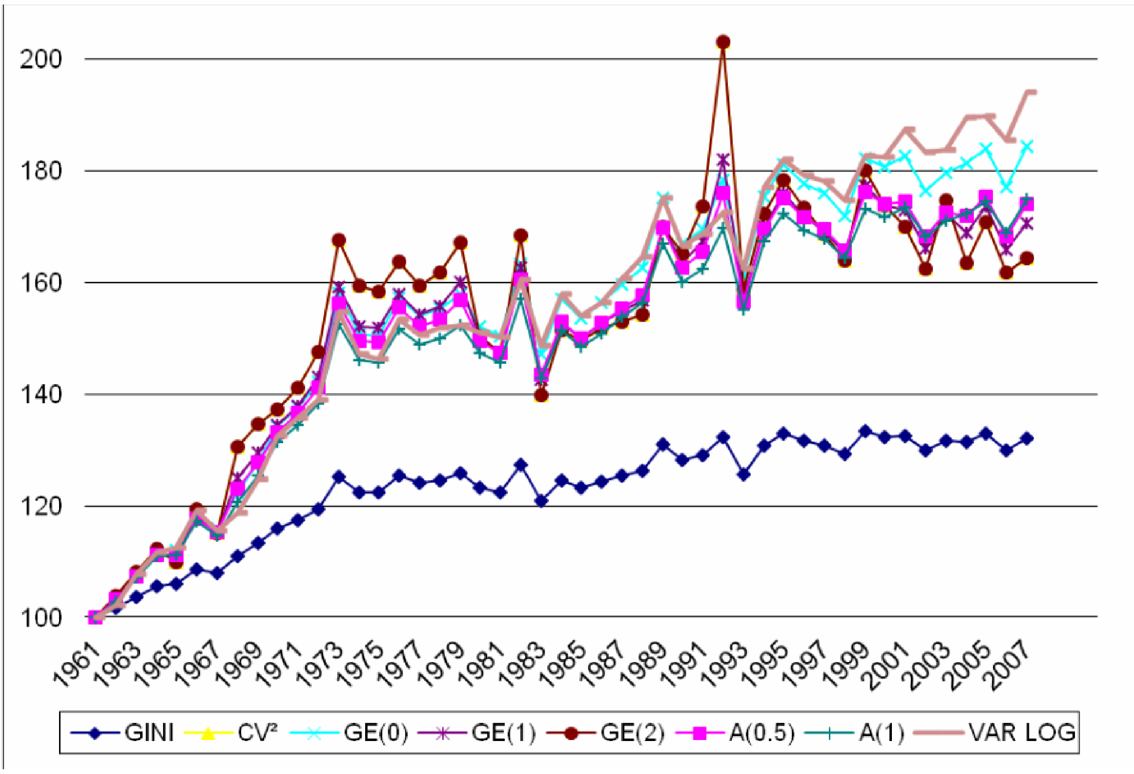
In contrast, the structural composition of economies does not contribute to EF inequality not only because of a low number of differences among countries, but also because of its weight (regression coefficient) in explaining EF per capita, which actually is not always not statistically different from zero.. Finally, we observed that climatic characteristics of countries did not play an important role in the latter years, proving that EF inequality is mainly a matter of social relationships among countries.

On balance, this chapter wishes to encourage global governance to simultaneously meet the needs of both future and present generations' claims; in doing so, some positive synergies may help achieve both equity and sustainability. In the same vein, the main policy recommendations highlighted in this paper are: firstly, to decouple economic growth from its environmental impact without neglecting the economic convergence of different countries; secondly, that given the urban convergence of humankind, policies oriented at reducing the ecological impact of urban environments are critical to ensure sustainability; and thirdly, the ecological impact of the working age population should also be reduced to make the use of natural resources more sustainable and equitable. Therefore, at the end of the day, policies aimed at decoupling the link between the anthropogenic driver and the ecological impact (the coefficient) will have dual consequences: it will improve future generations' chances and consequently environmental sustainability and, secondly, it will reduce *intra*generational inequality in resource consumption. However, complete decoupling is impossible because of the thermodynamics' law, so then convergence policies need to be taken into account.

With this chapter we finalise the EF distributional analyses from the perspective of inequality. We have analysed its trends and decomposed it using different techniques. The next chapter further develops analysis distribution using a different approach, that of polarisation, in a way which complements the results obtained so far. This, as will be shown, is a different, although closely linked, concept from inequality.

APPENDIX

A1. Inequality trends in EF according to the main (non-population weighted) inequality indices (1961 – 2007)



Note: 1961=100 for all indices.

Source: present authors

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CHAPTER 6
POLARIZATION ANALYSIS IN INTERNATIONAL EF DISTRIBUTION

Up to now the distributional analysis has focused on the inequality approach, which is typically identified by the axioms defined in Chapter 3 of this thesis and particularly by the Pigou-Dalton principle. Broadly speaking, inequality captures the degree of dispersion of the observations in a given distribution. The polarization approach, however, captures different features of the distribution, which the inequality approach does not identify, and is conceptually linked with potentially conflicting tensions. In fact polarization and inequality can move in opposite directions, and for this reason we will only deal with the polarization approach.

The basic feature measured by polarization is that of the distribution converging in different and distanced poles, which results in a clustering process; for instance, suppose a distribution where, *ceteris paribus*, the richer (countries or individuals) become more homogenous (so that there is less inequality amongst them) and so do the poorer; so that the resulting distribution is formed by two distinct and highly homogenous groups. In such a situation, Lorenz-based inequality measures might register a decrease in value since the distribution could be becoming more homogeneous around both poles (rich and poor). However, the more sharply defined and the more distinct those poles are, the more polarised the distribution will be and, despite lower overall inequality (resulting from the homogenisation process), the distribution is not more just but entails more inherent conflict. Indeed, the appealing particularity of analysing distributions from the polarization perspective is the capacity to approximate the degree of latent conflict present in a distribution.

The underlying idea of polarization measurement is that groups rather than individuals are the decisive actors in large-scale conflicts (Esteban and Schneider, 2008). A group of countries sharing common interests which conflict with the interests of another group (a polarised distribution) is potentially more conflictive than a situation in which all countries have different interests (an unequal distribution). In the context of natural resource distribution, which is what we are interested in throughout this thesis, such latent conflict might manifest itself in groups of countries that consume the most resources and at the same time in countries that scarcely consume them (the Ecological Unequal Exchange hypothesis). A situation like this could create a distribution instability since inequalities would be driven by different groups of countries rather than by the individual countries themselves. Groups of countries have a greater possibility of developing their common interests than individual ones. Also, in the context of international negotiations in multilateral environmental agreements, the polarization of the level of emissions could determine the commitments reached by the parties.[119] Indeed, as Esteban and Ray (1994) suggested, there might be some economic and social phenomena for which the knowledge of the degree of clustering or polarization would be more telling than any measurement of inequality. In our particular analysis of the EF distribution, the polarization approach will complement the distributional analyses performed prior to this chapter (inequality) to see whether the inequality trends

[119] Duro and Padilla (2008) showed how the analysis of CO2 emissions distribution from a polarization approach led to notable conclusions about the emergence of the two groups Annex B countries and non-Annex B countries and in the Kyoto protocol.

observed underlie a clustering process of countries in terms of EF, in other words, a polarization process.

Thus, in this chapter, we will measure the polarization of the international EF distribution by applying some of the different polarization indices developed in recent years in the specialized literature on income distribution (Duclos et al., 2004; Esteban et al., 1999; Esteban and Ray, 1994; Foster and Wolfson, 2010; Zhang and Kanbur, 2001).[120] Such indices, despite sharing the same spirit, are based on different methodologies and assumptions. For instance, the polarization indices developed by Esteban and Ray (1994), Esteban et al. (1999) which are defined for multi-pole cases,[121] generate the distributional groups endogenously from the main distribution, while in the index developed by Zhang and Kanbur (2001) the groups are derived exogenously. Finally, the indices proposed by Duclos et al. (2004), are based on continuous distributions and so there are no discontinuities in the groups generation (groups are individual perceptions of each country). By performing these three main polarization approaches, we intend to capture those patterns that might be not captured by the inequality approach methodology used so far. This thesis will argue that polarization measurement may well be particularly revealing in the context of international EF distribution.

The polarization concept has previously been applied to the analysis of environmental distribution by (Duro and Padilla, 2008, 2013; Duro, 2010; Ezcurra, 2007), who analyse the polarization of international distribution of CO_2 emissions, highlighting the discussions in global environmental governance and the probabilities of achieving agreements for climate

[120] As in the income inequality and the economic convergence literatures, the polarization of a distribution can also be tackled from the literature of Convergence Clubs (Quah, 1996, 1997).
[121] The polarization indices proposed by Wolfson (1997) and Foster and Wolfson (2010) are defined only for the bi-polarization approach and are a particular case of the index proposed by Esteban and Ray (1994). However, such indices are particularly interesting because they can be derived from the Lorenz Curve diagram.

change mitigation.[122] This chapter will measure polarization in the international distribution of the EF, which to the best of our knowledge has never been carried out. Using EF to discover whether ecological distribution is polarised or not, the results are particularly interesting when they are framed within the context of world-system analysis; the main hypothesis being driven by the relationship between core countries (which take advantage of most of the natural resources), and peripheral countries (whose consumption per capita is much lower).[123]

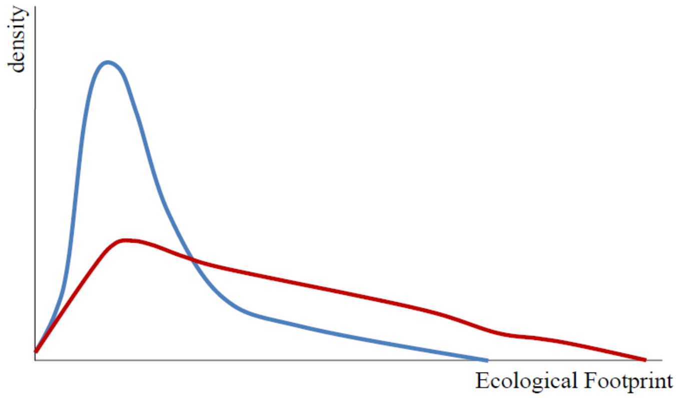
This chapter is organised as follows: the first section (6.1) investigates, in an intuitive way, the main differences between polarization and inequality. The second section (6.2) deals with the methodological aspects of polarization by presenting the different polarization indices used. The third section of this chapter (6.3) discusses the main empirical results for those indices. Finally, section four (6.4) concludes the chapter.

6.1 POLARIZATION VERSUS INEQUALITY

One of the basic axioms of inequality measurement is the Pigou-Dalton principle (see Chapter 3) which states that the inequality index should decrease when there is a progressive transfer.[124] Such equalising transfers would appear in the form of a concentration of the EF density function (Figure 1 represents a hypothetical distribution). We could say that the blue distribution is the outcome of Pigou-Dalton transfers occurring in the red distribution.

[122] Excurra (2007), Duro and Padilla (2008) calculate the indices based on Esteban et al. (1999). Duro (2010) and Duro and Padilla (2013) extend the analysis by calculating the indices proposed by Zhang and Kanbur (2001) and decomposing them by their factors. Their results point to a reduction of polarization, regardless of the number of groups considered.
[123] See Chapter 1, sections 1.3 and 1.4
[124] *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.

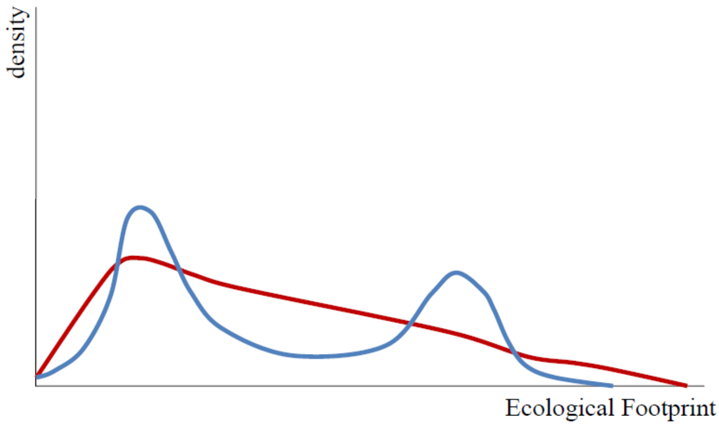
Figure 1. A global distribution concentration lowers Inequality



Source: Present authors.

According to the theory of second-order stochastic dominance (Lorenz Dominance), the concentration of the EF as represented in Figure 1 will reflect a decrease in all Lorenz-based Inequality indices (see Chapter 3). In this sense, it should be easy to see that the red density function exhibits a higher inequality than the blue one, which is far more compact. However, if we now consider the same behaviour in the distribution, but occurring at different local points instead of globally (i.e. the same Lorenz contraction of Figure 1 but in different parts of the distribution), we will see that inequality will be lower again (because of the Pigou-Dalton principle), and it appears that the new distribution may entail a higher degree of clustering between observations and so a more 'tense' distribution (Figure 2). In the aforementioned distribution, the antagonistic groups are clearly defined, each with a clear sense of itself and of one other. This is the result of the combination of two different and contradictory processes; on the one hand, there is an *identification* process, which entails an equalisation process through the local convergence of observations of the group and on the other hand, there is an *alienation* process which, in contrast, captures the inequality between those identified groups. Indeed, the inequality approach actually captures one part of the polarization framework, that of alienation, however it is not considering the sense of identification, and that makes all the difference. Obviously, there may be some changes that could be branded as both inequality and polarization enhancing, for instance, if the two groups represented in Figure 2 increased their distance (without changing the within-group cohesion), inequality and polarization would presumably both increase.

Figure 2. Local distribution concentrations lower inequality and increase polarization



Source: Present authors.

Therefore, the crucial difference between inequality and polarization is that polarization takes into account the Lorenz contractions in a global sense (Figure 1) or in a local sense (Figure 2), or in other words, the underlying axioms of the inequality measurement (or equivalently, second-order stochastic dominance for mean-normalised distributions) fail to adequately distinguish between "convergence" to the global mean and "clustering" around "local means" (Esteban and Ray, 1994). Polarization thus captures the feeling of *identification* within a group and, at the same time, the feeling of *alienation* with other groups. Therefore, this particular combination of equality (identification) and inequality (alienation) is what Esteban and Ray (1994, 1999) and Duclos et al. (2004) axiomatised in order to formally characterise the Polarization concept.

Focusing on the international distribution of natural resource consumption, as measured by EF per capita, the distributional analyses conducted up to this point have been formulated from the inequality approach. In this chapter, we will extend such analyses by dealing with the polarization approach.[125] Since a decrease (increase) in inequality may entail an increase (decrease) in polarization, the results obtained up to now may be considered as just a part of the whole story of the distributional dynamics of the EF. As previously mentioned, according to Esteban and Ray, a polarised distribution is a distribution with a higher potentiality of conflict – this may be very straightforward to visualise when the concept is applied to societies, social classes, races, etc. In the present context, an extreme case of a polarised distribution would be a distribution where a group of countries produce a very small EF per capita which does not even satisfy basic human necessities together with a second group of countries whose EF per capita is very large in comparison with their national boundaries and also with planetary boundaries (so that they are using global hectares from other countries and from future generations). There is a large inter-group distance, but the groups are at the same time internally very homogenous (which is what creates the notion of a group). In such a world, the inequality approach will not capture the groups' antagonism or the implicit tension in the distribution. International conflicts stemming from natural resource distribution can emerge in different forms and situations: for instance, as discussed by Duro and Padilla (2008, 2013), Duro (2010) or Ezcurra (2007), the inequality in CO_2 emissions may have blocked international Environmental Agreements from making deeper commitments The polarization of CO_2 emissions, however, is what lies beneath different groups with different interests, as was the case for Annex B countries and non-Annex B countries in the Kyoto Protocol. Also the polarised distribution of natural resources may support the hypothesis of structural differences between groups of countries in a centre-periphery international frame (as in ecological unequal exchanges theories), where the resource flows are driven from the peripheral countries towards core countries – picture a rich North, consuming most of the

[125] The same balanced sample of Chapter 3 and Chapter 4, sections 4.1 and 4.2 is used as data for the empirical analyses.

resources available and a poor South providing such resources while, at the same time, having to face the consequences of environmental degradation. The polarization measurement of EF thus is an empirical strategy to test whether the sharing of natural resources among countries results in greater inherent conflict or not. When the inequality is between groups that cooperate to a greater extent with one another (i.e. polarization), the countries within those groups can work together to better achieve their common interests and as a result there is a real possibility of creating international tensions (consider, for example, of wars for natural resources and the international terrorism derived therefrom). Analysing the polarization tendencies is thus of paramount importance in completing the whole picture of the international EF distribution.

6.2 MEASURING POLARIZATION: INDICES

Since the initial work of Esteban and Ray (1994) and Foster and Wolfson (1992 [2010]), different statistical measures have been proposed to analyse polarization. We will focus on those that have recently received more attention in the empirical works, especially in analysing environmental outcomes. These are the EGR indices (J. Esteban et al., 1999) and the ZK index (Zhang and Kanbur, 2001) defined for discrete distributions.[126] We also calculate the DER indices (Duclos et al., 2004), which are designed for continuous distributions and to the best of our knowledge have never been applied to environmental outcomes.

Before introducing the particularities of these different families of indices, we will briefly describe the general features from which they are derived.[127] Doing so will allow us to have a

[126] Ezcurra (2007) and Duro and Padilla (2008) calculate EGR indices to analyse CO_2 emission distribution, while Duro and Padilla (2013) extended such analyses by also calculating Z-K indices.
[127] Insofar as single-dimensional approaches are considered, we are assuming that only one variable (here EF) defines the notion of the group, the notion of identification and the notion of alienation at the same time, in

clearer picture of what the indices proposed are actually measuring. According to Esteban and Ray (1994), the basic features of polarization are:

1. The issue is that of groups. An isolated observation should have little weight.
2. There must be a high degree of homogeneity within the groups, i.e. a great sense of feeling of identity.
3. There must be a high degree of heterogeneity between groups, i.e. a great sense of feeling of alienation.
4. There must a small number of significantly sized groups.[128]

In order to make this notion plausible, these authors axiomatised these features and proposed the family of ER indices (Esteban and Ray, 1994)[129] which formally sum all antagonisms between all countries of the different groups, where antagonism is viewed as a combination of inter-group alienation, and identification with the group itself:

$$ER(\alpha) = \sum_{i=1}^{n}\sum_{j=1}^{n} p_i^{1+\alpha} p_j \left| \frac{e_i}{e} - \frac{e_j}{e} \right|, 1 \le \alpha \le 1.6 \qquad (1)$$

where p_i and p_j are the relative populations of countries i and j; and e_i and e_j are the EF per capita of both countries, while e is the average EF per capita. Notice that if we removed the p_i^{α} of the expression (1), the result would be the Gini coefficient.[130] Indeed, it is precisely the fact that population weights are raised to a power greater than one which constitutes the

contrast to multidimensional approaches, in which other variables different from EF may define groups (ethnicity, religion, etc.) but not the identification and alienation.

[128] Therefore, maximum potential conflict according to polarization happens when there are two equally sized groups. Actually, there are some indices such as those proposed by Foster and Woflson (2010) that are limited to measuring bipolarization. Additionally, the literature of conflict also distinguishes Polarization from Fractionalization measures, which, in contrast, increase the level of conflict as the number of groups increase (see Esteban and Schneider, 2008).

[129] See Appendix A1 of this chapter to see the graphical axioms derived from the formalisation of ER indices. For a more detailed description, see the Esteban and Ray (1994).

[130] See Chapter 3.

real difference between inequality and polarization. The term p_i^α stands for the sense of identification and so accounts for the clustering effect by which each country identifies with its own group. The second term, meanwhile, captures the alienation between countries *i* and *j*. Hence, $p_i^\alpha \left| \frac{e_i}{e} - \frac{e_j}{e} \right|$ is the antagonism felt by each country of group *i* with respect to each country of group *j* (Esteban, 2002). Thus, α is a parameter measuring the degree of polarization sensitivity (or the polarization aversion), whose construction defined as $1<\alpha<1.6$.[131] The larger the value of α, the greater the importance we are giving to the clustering of groups of countries and so the greater the departure from inequality measurement will be.[132]

However, the ER indices presuppose that groups are already defined and so the only thing needed to be defined is the parameter α, so that we can measure the degree of polarization between the existing groups. But, in most of practical situations, such as the one discussed here, distributions are not grouped *ex ante*. Thus, in order to make the equation functional (1), it is necessary to choose a number of groups to work with and also a mechanism to define these groups. To address this technical problem, Esteban et al (1999) proposed the EGR indices, by which the groups are defined endogenously using the algorithm of Davies and Shorrocks (1989), which basically consists in delimiting the groups in such a way that the Gini index value of the original distribution *f* corresponding to the within group inequality is the minimum possible.[133] In other words, the groups are delimited in such a way that the

[131] For the derivation of the limits of α in the ER index, see Esteban and Ray (1994).
[132] In order to understand the role of α, suppose a situation where the population (or the countries) are divided into three groups, with the two higher groups being the same size. Then suppose that these two groups fused into only one group (so that the population is now formed by two groups). Then, we would expect the polarization measure to increase as long as the third group is considered large enough. However, if the third group is considered small, the polarization measure should decrease. The "size" of the third group depends on the parameter α, and so it measures our aversion to polarization.
[133] Such algorithms were designed in the context of income inequality analyses, where data from official publications were often grouped. However, it is important to bear in mind that there are no unanimous criteria to establish the precise demarcation between groups in a given distribution.

average within-group cohesion is maximal. In doing so, the algorithm yields an optimal simplified distribution ρ^* (simplified because data is grouped according to the n groups,[134] where the minimum loss of information is guaranteed with respect the original distribution f. However, simplifying the distribution to such an extent requires altering of the measurement of polarization ER (1) for the degree of cohesion within the defined groups. In accordance with existing literature, we will refer to this correction as the error term of the polarization index. Thus, the family of EGR indices is defined as:

$$EGR(\alpha) = \sum_{i=1}^{n}\sum_{j=1}^{n} p_i^{1+\alpha} p_j \left|\frac{e_i}{e} - \frac{e_j}{e}\right| - \beta\left[G(f) - G(\rho^*)\right], 1 \leq \alpha \leq 1.6 \qquad (2)$$

which consists of the ER index in the first term being corrected by the degree of cohesion of the defined groups in the second term, the error term.[135] *G(f)* is the Gini index of the original distribution and *G(ρ*)* is the Gini index of the optimal simplified distribution, or what would be the *between* inequality described in chapter 3 of this thesis.[136] Therefore, the difference between both Gini indices approximates the *within* inequality (the level of cohesion within groups), and so, the higher the within group dispersion, the lower the polarization of a given group configuration. Finally, β is a free parameter measuring the sensitivity of such within-group cohesion. Following Esteban et al. (1999), Ezcurra (2007) and Duro and Padilla (2008, 2013), the parameter will be fixed as $\beta=1$ in the empirical analyses.[137]

[134] Think of simplified distribution as the countries that have been grouped into a small number of categories such as the rich and the poor, or here, the high EF countries and the low EF countries (or the middle EF countries). Indeed, this simplification is what most people use informally when comparing distributions. Such informal descriptions can be seen as the simplified versions of the original distribution.
[135] The bipolarization measure proposed by Wolfson (1994) happens to be a particular case of the EGR index when α and β take the unitary value and the groups are defined by the median EF instead of the mean. Its main appeal however comes from its direct derivation from the Lorenz Curve, see Wolfson (1997).
[136] See Section 3.4.1.
[137] Besides as Duro and Padilla (2008) suggest, it seems more sensible, in terms of the internal scale of the measure, to establish $\beta=1$ since, at the end of the day, the definition of the three objects in EGR indices (*ER*, *G(f)* and *G(ρ*)*) are very similar.

In the empirical application of EGR indices, the number of groups is left to the discretion of the analyst. However, it should be understood that a high number of groups is meaningless in the context of polarization; empirical literature actually suggests up to four groups into which the distribution can be divided. Indeed, as we increase the number of groups, the simplified distribution becomes more accurate (so the error will be lower), but less sharp and useful. It should be taken into account that the decrease in error as the number of groups increases (the increase of the within cohesion) is non-linear; hence, the degree to which polarization decreases due to having a greater number of groups, is not compensated by the degree of greater cohesion within the groups. Therefore, the particular behaviour of the polarization measure taken together with its error term can be very useful in suggesting the number of groups that best define an appropriate representation of the distribution analysed in terms of groups (Esteban, 2002).

The main advantage of the EGR family of indices is that they were axiomatically derived from a behavioural model, and so their results are precise in what they are measuring. For this reason, an interesting particularity of these indices is the endogenous grouping of the distribution by which the polarization is estimated. Nonetheless, it might be also interesting to calculate another family of polarization indices whose main particularity is the exogenous grouping in the distribution. These are the ZK indices (Zhang and Kanbur, 2001). As these authors suggest, debates on polarization may be understood within a framework where recognised and accepted groups are not driven by the variable being analysed (here EF), but by some other issue which might be socially determined, for example, in income studies gender or race may be the driving factor and not income groups. This might be the case if we apply our analysis to the theoretical framework of world-system analyses (Hornborg, 2011)[138] in which some countries play a peripheral role in the world economy while others play a

[138] See Chapter 1 for a brief resumé of World System theories and Ecologically Unequal Exchange theories.

central role, independent of their EF distribution. Actually, the most typical division of countries in international debates is certainly is not along high EF and low EF lines but between developed, developing countries and, lastly, emergent countries. Therefore, it would be interesting to deal with these exogenous groupings by using the polarization approach and see whether there is a phenomenon of alienation between the common groups at the same time as an identification process within them.

Once the groups have been exogenously determined (e.g. North and South, rich, emergent and poor, etc.), the ZK index simply calculates the ratio between the between-inequality (the inequality of the simplified distribution, now determined by groups defined exogenously from the EF distribution) and the within-inequality (existent inequality within those groups)[139]

$$ZK = \frac{I(e)_B}{I(e)_w} \quad (3)$$

where $I(e)_B$ and $I(e)_W$ are the *between* inequality contribution and the *within* inequality contribution of the Inequality Subgroup decomposition proposed by (Shorrocks, 1980) and performed by EF inequality in Chapter 3 of this thesis. Hence, the *between* inequality defined by using Theil measure, GE(0), is

$$I(e)_B = \sum_{g}^{G} p_g \log\left(\frac{e}{e_g}\right) \quad (4)$$

Where g denotes the group, p_g is the population share of group g, e the average EF per capita and e_g the average EF per capita of group g. According to Shorrocks (1980), the between

[139] In Chapter 3 global inequality in EF is decomposed in terms of the between and within inequality when countries are grouped according to the regional World Bank classification. The *between* component is the inequality which would exist if each member of the group had the average EF of that group. On the other hand, the *within* component consists of the inequality that 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.

inequality accounts for the total inequality that would exist if each member of the group had the average EF of that group. In the polarization framework being treated here, this component accounts for the alienation between groups since it is the inequality that would exist if the only source of inequality came from the inequality between the groups. Hence, as the between inequality increases, so does the ZK measurement. On the other hand, the within inequality component consists of the group weighted inequality within each group (again with the GE(0) or Theil measure):

$$I(e)_W = \sum_{g}^{G} p_g \left[\sum_{i}^{n} p_i \log\left(\frac{e_g}{e_i} \right) \right] \tag{5}$$

The within Inequality accounts for the total inequality that would exist if all the groups had the same average. Within the polarization framework, however, it accounts for the within group cohesion. The greater the inequality within the groups is, the less the cohesion within the group and by construction, the lower the polarization.

It is important, however, to keep in mind that ZK indices are not as compelling as the EGR family since they do not satisfy some of the features described above for these last indices (and by extension, neither they do satisfy the basic axioms in Appendix A1). But, as can be intuitively seen in Expression (3), the features 2 (high degree of heterogeneity between groups) and 3 (high degree of cohesion) are properly satisfied. One of their drawbacks is that they may give unduly high values to isolated observations.

Finally, the last family of indices that will be considered in this analysis are the DER indices proposed by Duclos, Esteban and Ray (2004). DER family indices have been also derived axiomatically and share the same spirit of ER indices (see appendix A2 for the specific axioms). Actually, their particularity and main difference from ER indices is that DER indices are designed for continuous distributions while ER indices (and EGR indices by extension) are designed for discrete distributions. This basic difference leads to a slightly different interpretation of polarization.

DER indices are directly based on density functions, which in practical terms means that the discontinuities of the groupings (either endogenous or exogenous) disappear. By way of example, consider a case of bipolarization with EGR indices where the groups have been delimited by the mean,[140] –what sense of identification do the countries that are just above and beyond the mean (and still so close together) have? In fact the countries mentioned, despite being grouped separately, may actually be closer to a member of another group rather than to one of their own. DER indices correct these unwelcome discontinuities by using a "window of identification" for each observation (country). In fact, the empirical distribution itself, estimated non-parametrically and so free of the assumption of the true (but unknown) distribution, is the criterion by which group size is determined since a country is assigned to a particular group depending on its own particular distributional context. DER indices thus measure polarization from an *individual* alienation-identification perspective in which countries identify themselves only with those of similar EF, so that a country located in e_i experiences a sense of identification that depends on the density at e_i, $f(e_i)$. Hence identification and alienation are derived according to country's particular situation in the empirical distribution estimated.

Therefore, as in ER, DER indices are defined as the sum of all effective antagonism of e_i towards e_j, under f though:

$$DER = \iint f(e_i)^{1+\alpha} f(e_j) \left| e_i - e_j \right| de_j de_i, \text{ where } \alpha \in [0.25,\ 1] \qquad (6)$$

Where, again, the first part of the expression accounts for identification, while the second accounts for alienation. An interesting particularity of this index is that their authors provide

140 As actually is the case in the Davies and Shorrocks algorithm for two groups.

a decomposition of the measure in those same terms; i.e. identification, alienation and a third term capturing the correlation between the two.[141] Hence:

$$DER = a \cdot \iota \cdot [1+\rho] \tag{7}$$

Where a is the average alienation ($a = \iint |e_i - e_j| dF(e_i) dF(e_j)$), ι the α-identification[142] ($\iota_\alpha = \int f(e_j)^{1+\alpha} de_j$) and ρ the normalised covariance between a and ι ($\rho = \frac{\operatorname{cov}(\iota_\alpha, a)}{\iota_\alpha a}$). This last term accounts for the co-movement of alienation and identification: an increase in alienation is associated with an increase in e distances, at the same time, an increased identification can emerge when there is a convergence around a certain point of distribution that was already highly concentrated. These changes taken together may reinforce one other (alienation may be higher at observations that have experienced an increase in identification) or they may counterbalance each other (a decrease in identification may involve an increase in alienation). Therefore, it is not possible to move these three factors around independently. After all, density describes the distribution of EF and these three factors are by-products of that density (Duclos et al. 2004).

The above approach is interesting because it complements the previous polarization measures from a different perspective, in that the empirical distribution is used to define the phenomenon of identification-alienation. Furthermore, one could argue that in certain situations (including this one), where countries are the objects of analysis, polarization may stem from a more individual perception of distribution rather than from any arbitrary set of groups. In this way, as the authors have suggested, DER indices measure the ‘pure polarization’ of a distribution. Hence, it allows us to extend typical polarization analyses,

[141] Araar
[142] It is called α-identification because a depends on α. Notice also, that here a is twice the Gini coefficient (Duclos et al. 2004)

based on explicit group definitions (either exogenous or endogenous), by exploiting the notion of pure polarization, where the identification-alienation distances are determined by a "polarization window" for each country.

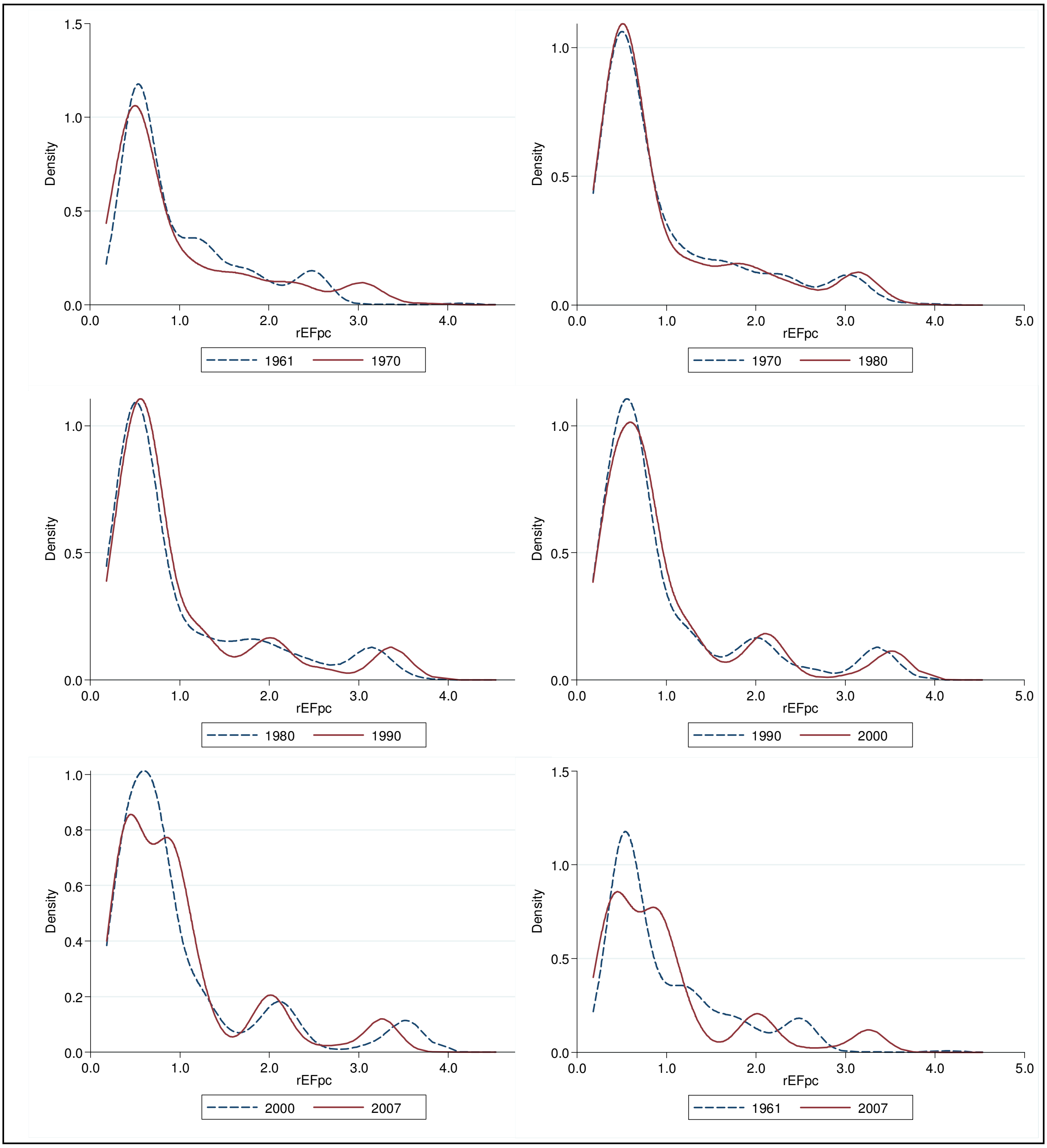
6.3 INTERNATIONAL POLARIZATION IN EF

The data used in this section comes from the Global Footprint Network (Global Footprint Network,) and covers 119 countries from the period 1961 to 2007, by using cross-country samples every ten years (1961, 1970, 1980, 1990, 2000, 2007). The countries in the sample amount to 90% of world population, 91% of the GDP and 82% of the World Ecological Footprint (according to 2007).[143] During this period, Ecological Footprint per capita increased by 14% and inequality also increased by 31% (according to neutral inequality indices.[144]. Let us now analyse the same distribution by considering the polarization approach.

Since graphical intuition regarding polarization has clearly been linked with its own multimodality, before properly estimating polarization measures, it might be useful to estimate the density functions of the per capita EF. However, it is important to keep in mind that is just one factor of several implications in polarization. For instance, distribution might become bimodal and still register lower polarization than a unimodal density. There is a *ceteris paribus* condition that might not hold for that density alteration. Indeed, the existence of more modes may also bring average alienation down (Duclos et al. 2004). Consequently, polarization indices happen are suitable due to containing a non-ambiguous criterion.

[143] The same samples were used in Chapter 3 to measure inequality.
[144] Neutral indices refer to indices that have neutral transfer-sensitivity i.e. do not weigh differently the transfers between observations depending on where they occur in the distribution. These indices are CV^2 and *GE(2)* and it has been argued that they are more appealing when environmental distributions are analysed. See chapter 3, section 3.2.

Figure 3. Comparison of density functions of relative EF per capita 1961—2007



Source: Present authors from Global Footprint Network.

Figure 3 reproduces the empirical density functions of the various years estimated non-parametrically using Gaussian Kernels.[145] Each graph includes the density functions of two consecutive periods in order to facilitate comparison and get an idea of the change in the distribution over the period. The last one compares 1961 to 2007 to see the global change for the period analysed. Following the common practice of spatial distribution of environmental outcomes (Duro and Padilla, 2013; Ezcurra, 2007) and of income (Quah, 1997), each country's EF per capita has been normalised according to the average of the annual distribution, so that the comparison between distributions is not influenced by the global changes in EF levels over time. Thus a year's average is 1 by definition.

The results show that majority of the population of the countries sampled here registered a below average EF per capita during the whole period analysed. In terms of the modes of the distribution, it can be seen that in 1961 there was a main pole with a peak situated at 0.55 of the year's average where the mass of the population was clearly concentrated but there was also a less defined and smaller pole (around 2.5 times the average) which in 1970 and 1980 became more clearly defined as it moved away from the main pole (alienation). Intuitively, such behaviour of the distribution should register an increase in polarization from 1961 to 1980 as two modes appeared and consequently distanced themselves from one other. In 1990, however, something interesting occurred; while the smaller mode continued to alienate itself from the main mode (now at 3.5 times the mean), a third mode develops between the two (at 2.0 times the mean). This pattern becomes even more pronounced in 2000 as the mass of the

[145] The estimates are based on Gaussian kernel functions (see Quah 1997) and have been used previously for the analysis of international distribution of CO_2 emissions by Padilla and Serrano (2006) and Ezcurra (2007). The estimation of the densitiy function performed assumes that each sampled observation gives some evidence of the underlying density within a 'window' around the observation (Cowell 2011). Then one can estimate density at EF value e, by specifying an appropriate Kernel function K (which itself has the properties of a density function) and a window width (or bandwidth) w and computing the function $\hat{f}(e) = \frac{1}{w}\sum_{i=1}^{n} K\left(\frac{e-e_i}{w}\right)$ where K here is the Gaussian kernel function and w has been determined endogenously from the method of Silverman (1986).

main mode is used to better define the smaller ones. In this case, again using intuition, polarization decreases since there are more modes (more groups imply less average alienation between them) but, on the other hand, there is a tendency towards better identification and alienation from the main pole which should make polarization increase. Finally, in 2007 one sees that the two small modes which have up to this point been alienating themselves from the main one, move back towards the distribution average, while the main mode seems to divide itself into two poles with a second main mode converging towards the distribution mean.[146]

Hence, it is clear that the distribution of the EF per capita has been experiencing different clustering over the period analysed and in some occasion intuition allows us to make predictions on the resulting polarization of the distribution, as is the case in the period from 1961 to 1980, where polarization should increase. However, on some occasions, it is not that clear whether polarization should increase or decrease, as, for example, in the periods 1980 to 2007. In these cases, the polarization indices can make a non-ambiguous calculation of the whole sum of antagonisms in the distribution which helps in understanding what really occurs during polarization. The number of groups considered, together with the way they have been defined, play a critical role in such evolution.

6.3.1 EGR INDICES

EGR indices, as have been described above, are axiomatically derived measures of polarization whose groups have been determined endogenously. Table 1 shows the results obtained for the distribution of EF per capita between 1961 and 2007 for two, three and four groups according to different values of α (sensitivity to polarization). The number of groups

[146] This fourth populated mode is, in fact, China.

has been determined from the observation of the empirical density functions described above. Table 1 also shows the error term of the EGR index as a percentage of the Gini index, this error thus approximates the level of internal cohesion within groups, so that it informs how well the groups are defined in the distribution. The greater the error is, the lower the intergroup cohesion (see equation 2).

Table 1. Polarization of EF per capita according to EGR family of indices

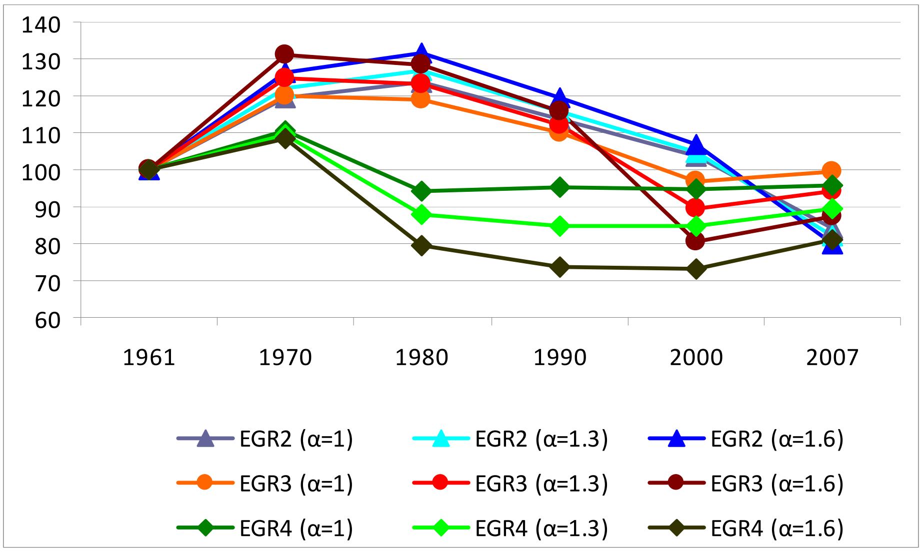
	2 groups				3 groups				4 groups			
	α=1	*α=1.3*	*α=1.6*	ε/Gini	*α=1*	*α=1.3*	*α=1.6*	ε/Gini	*α=1*	*α=1.3*	*α=1.6*	ε/Gini
1961	0.2065	0.1592	0.1213	18.88%	0.1947	0.1416	0.1033	6.50%	0.1782	0.1291	0.0952	3.46%
1970	0.2463	0.1942	0.1531	18.35%	0.2337	0.1766	0.1353	7.46%	0.1973	0.1414	0.1031	4.57%
1980	0.2549	0.2017	0.1599	18.51%	0.2318	0.1741	0.1324	9.26%	0.1682	0.1133	0.0759	9.17%
1990	0.2349	0.1845	0.1451	20.44%	0.2137	0.1589	0.1195	11.19%	0.1693	0.1096	0.0702	4.51%
2000	0.2138	0.1664	0.1294	22.71%	0.1884	0.1269	0.0833	9.53%	0.1690	0.1094	0.0698	4.81%
2007	0.1743	0.1311	0.0973	26.91%	0.1936	0.1332	0.0900	8.32%	0.1710	0.1154	0.0773	5.52%

Source: Present authors from Ecological Footprint Network.

Firstly, let us focus on the two EGR groups (or EGR2). Regardless of the *α* used, the change of bipolarization of the international EF in the course of the period results in an inverted U-shape. Hence, from 1961 to 1980 there is a clear increase of polarization according to this index, which clearly coincides with the change of the density functions –from 1980 onwards, the polarization decreases. Actually, as can be seen in the evolution of the error term, group cohesion diminishes along the period, and especially from 1990 onwards, yielding a decrease in the EGR index. Secondly, EGR3 registers relatively high values of polarization when compared with bipolarization levels, which clearly indicates that that simplification of the three groups is almost as informative as the two groups is (despite containing one extra group). In this case, again, the change of polarization appears as an inverted U-shape until the year 2000, although in 2007, the EGR3 registers a slight increase. Finally, the EGR4 displays a completely different pattern, an increase from 1961 to 1970 followed by a decrease in 1980, after which polarization, as measured by this index, remains relatively stable. Figure 4 shows the change in the different indices graphically (1961=100).

Observing this figure, it can be seen that, apart from the period 1961-1970 where all EGRs increase, there is a trade-off between them; in the period 1970-1980, EGR2 increases while all of the others decrease. Then, from 1980 to 2000 EGR2 and EGR3 decrease while the EGR4 remains relatively stable. So, in this period, the polarization for two and three groups of the distribution is clearly decreasing, although that is not clear when four groups are considered. The period 200-2007 is actually the most revealing period because, while EGR3 and EGR4 increase, EGR2 continues to decrease.

Figure 4. Change of polarization according to the EGR family indices (1961=100)



Source: Present authors from Ecological Footprint Network

Analysing the global change of the different polarization measures, and taking into account the non-linearity of the error reduction when adding groups as opposed to the compensation by higher within-group cohesion, it could be claimed that the most appropriate representation of the EF per capita distribution is the one which registers higher levels of polarization. For this reason, according to EGR indices, two-group polarization appears to be the best option during the initial years sampled. However, in 2007, the higher value of polarization is reached by the three-group measure (when α=1 or α=1.3). From this standpoint, from 1961 to 2000 the distribution of the EF is best described as essentially being made up of two groups (countries below EF average and countries above EF average). Nonetheless, in 2007 this converted to a three-pole distribution, which can be seen in the crossing trends between EGR2 and EGR3 in Figure 4.

Let us now consider the role played by the endogenous changes in the groups created in terms of both changes in population weights and relative EF per capita. Table 2 shows these changes for the different EGR endogenous groupings. Focusing on the bipolar case (EGR2) we can see that Group 1 increased its population proportion (from 0.64 to 0.72) at the expense of the smaller group (Group 2, which reduced its population weight from 0.37 to 0.28). This trend works against polarization since the small mass is transferring population to the greater one. At the same time, focusing on the average EF per capita of the groups, it can be seen that the Group 1 relative average shrunk from 1961 to 1980 at the same time as, in the same subperiod, Group 2 increased from an average of 1.7 to 2.1. Hence, this is clearly consistent with the increase obtained in the EGR2 for that subperiod. From 1980 on, however, it can be seen that both endogenous groups are converging to the average, which in addition to the general trend of the population proportion described, incurred a decrease in polarization. The specific groups of countries endogenously defined can be seen in appendix A3.

Table 2. Description of the endogenous groups' EGR indices: Average EF per capita (in relative terms) and relative population of each group.

	Group 1		Group 2		Group 3		Group 4	
	e_1/e	Rel. Pop.	e_2/e	Rel. Pop.	e_3/e	Rel. Pop.	e_4/e	Rel. Pop.
2 groups								
1961	0.577	0.637	1.741	0.363				
1970	0.541	0.692	2.032	0.308				
1980	0.53	0.702	2.107	0.298				
1990	0.554	0.709	2.088	0.291				
2000	0.579	0.72	2.079	0.28				
2007	0.616	0.719	1.981	0.281				
3 groups								
1961	0.522	0.526	1.076	0.274	2.152	0.2		
1970	0.488	0.597	1.18	0.231	2.544	0.171		
1980	0.484	0.606	1.169	0.223	2.605	0.171		
1990	0.52	0.616	1.061	0.21	2.624	0.174		
2000	0.439	0.407	0.87	0.413	2.566	0.18		
2007	0.436	0.428	0.953	0.391	2.428	0.182		
4 groups								
1961	0.52	0.517	0.902	0.166	1.438	0.186	2.391	0.131
1970	0.472	0.522	0.812	0.204	1.589	0.139	2.723	0.135
1980	0.378	0.258	0.709	0.517	1.79	0.093	2.808	0.131
1990	0.406	0.325	0.672	0.373	1.467	0.181	2.91	0.121
2000	0.412	0.354	0.732	0.349	1.318	0.151	2.742	0.146
2007	0.424	0.407	0.891	0.349	1.67	0.162	3.005	0.082

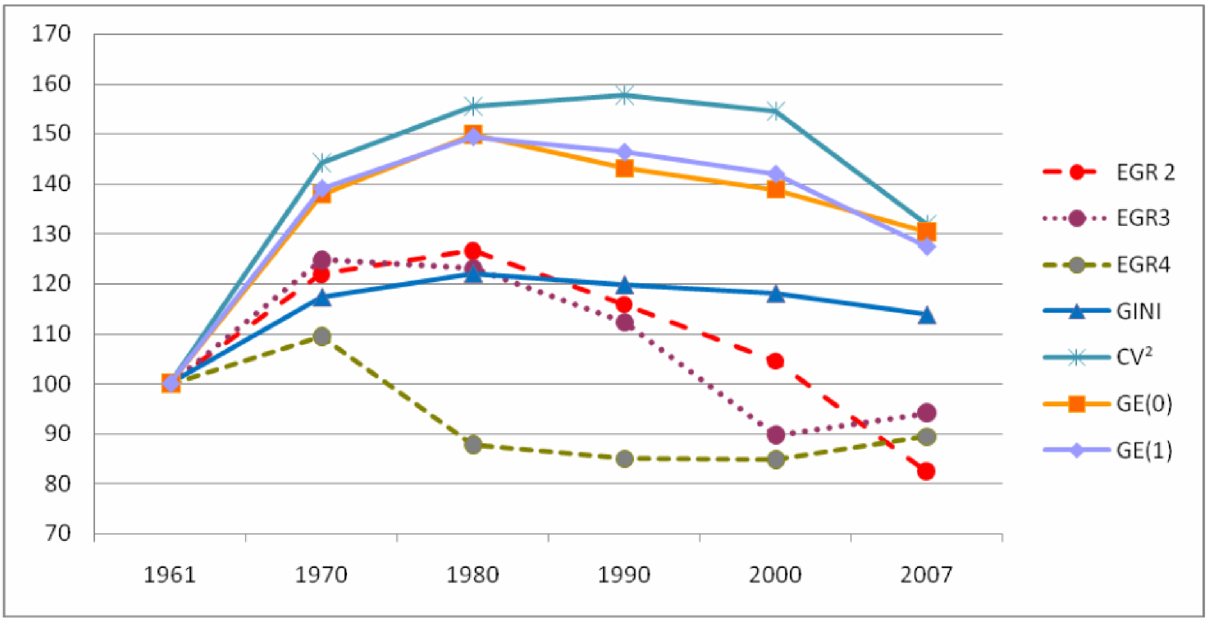
Source: Present authors from Ecological Footprint Network.

The three groups' simplification made by EGR3 follows a similar pattern to that of the two groups. However, as already stated in the EGR analysis trend, some remarkable differences must be taken into account. In this instance there is a big group, with almost half of the world's population percentage and two smaller groups. From 1970 on, the big group increases its already high proportion at the expense of the two smaller groups, a process which reaches its maximum in 1990 when the big group accumulates 62% of the world population while the small groups (21% and 17%) have equalised their weight with regards their initial population in 1961 (27% and 20%). This trend should, ceteris paribus, from an intuitive point of view, reduce the polarization index, and in fact it has if we look at EGR3 evolution. However, it is interesting to notice that, apart from the role played by the population as described above, the relative averages of the groups became more distant along the subperiod 1961-1990. Therefore it could be stated that the driving force of polarization reduction from an EGR3 perspective might be the population weighting role. However, in 2000 and in 2007, we can see that Group 1 and Group 2 are almost the same size while the third smaller group remains stable in terms of population proportion. Meanwhile the difference in averages between the two big groups creates distance between them, this makes the EGR3 increase in the last decade of the period analysed.

Finally, the four groups' simplification also shows how at the end of the period there are two big groups (Groups 1 and 2) whose population weight over the period is highly influenced by the performance of super-populated China In the first part of the period, China was in group one, but as its EF per capita increased it moved to Group 2, increasing its weight and thus its relevance in terms of polarization. Meanwhile, the smaller groups, in contrast to the bigger groups, continued increasing their EF per capita.

To sum up, let us consider the general trend of polarization according to EGR family compared with the inequality trend studied in the previous chapters. As stated above, according to these polarization family indices, when the distribution of EF per capita is approached from a polarization perspective, the distribution appears better explained in terms of bipolarization for most of the period analysed (1961-2007), however, in 2007 the distribution turned in to a three-pole(s) distribution. Hence, if we compare the EGR2 (Figure 5) trend with the Inequality trend studied in Chapter 3, we can see that general pattern is quite similar, creating an inverted U-shape. However, for the period 1980 to 1990, it can be seen that while the inequality trend is positive, polarization is negative. This opposing pattern between polarization and inequality happens again in the period 2000-2007 if now we consider EGR3 as the more representative. However, in latter period the opposite is true in that polarization increases while inequality decreases. These results are important because in some occurrences the appearance of a decreasing inequality in natural resource consumption may incur an increase in the polarization of distribution (as the case between 2000 and 2007), or the opposite may occur, polarization might decrease at the same time as inequality increases (as seen for the period 1980-1990 if we measure inequality by CV^2).

Figure 5. Evolution of cross-country Inequality and polarization (1961=100)



Note: EGR (α=1.3 and β=1)
Source: Present authors from Ecological Footprint Network

6.3.2 ZK INDICES

In addition to the EGR indices, where the groups of countries are formed endogenously, it might be worthwhile to look at polarization stemming from exogenous groups using ZK indices (Zhang and Kanbur, 2001). The interest of such an approach stems from the knowledge that, in many situations, debates on international issues divide countries in terms of their region or of their group of income, and not in terms of their EF per capita level. Tables 3 and 4 present the results for the ZK indices for groups defined, on the one hand on a regional basis according to the World Bank regional classification[147] and, on the other hand, on an income basis according to the classification also made by World Bank (see Appendix A4 to see the countries belonging to each group). Notice that the World Bank Regional classification groups countries according to world regions but the high income countries are grouped as “industrial countries”. Therefore, this particular administrative classification used by the World Bank considers that these high income countries, in some way belong to the artificial world region of “industrial countries”, which taking into account the results obtained in Chapter 4 is adequate.

Grouping countries according to the regional World Bank classification provides results (Table 3) which are quite consistent when compared to the results obtained by endogenous grouping of EGR indices: the highest levels of polarization are reached in 1970 and 1980, from which it begins to decline until reaching it minimum level in 2007. It is interesting to note that the simplification of the distribution in terms of the regional World Bank classification is representative of what was occurring for the whole distribution (as was already discussed in Chapter 4); the average differences between these groups of countries account for between 81% and 87% of the total inequality. Approaching the distribution from a polarization perspective, however, in contrast to the inequality approach, the increase in the within inequality reduces the polarization level (but increases inequality). In the sample analysed here, for instance, we can see how in the periods 1970-1980 and 1980-1990 inequality increased while polarization decreased (according to the CV^2, which as discussed in Chapter 3, its axioms of neutrality are appealing as far as environmental inequalities are concerned).

[147] The same classification has been used to decompose international EF inequality in subgroups in chapter 3, section 3.4.1.

Table 3. Exogenous polarization as measured by the ZK index for World Bank regional classification

year	Between Inequality	%	Within Inequality	%	Z-K index	T(0)	CV^2
1961	0.1487	83%	0.0305	17%	4.8746	0.1792	0.4436
1970	0.2158	87%	0.0312	13%	6.9076	0.2470	0.6398
1980	0.2342	87%	0.0343	13%	6.8198	0.2685	0.6896
1990	0.2225	87%	0.0338	13%	6.5784	0.2564	0.6998
2000	0.2116	85%	0.0372	15%	5.6927	0.2488	0.6853
2007	0.1896	81%	0.0440	19%	4.3074	0.2336	0.5849

Note: the World Bank groups are seven: 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.

Source: Present authors from Ecological Footprint Network.

Table 4. Decomposition of changes in the ZK indices for World Bank regional classification

Period	Z-K index	%	Between I.	%	Within I.	%
1961-1980	0.3358	100%	0.4541	135%	-0.118267	-35%
1980-2007	-0.4595	100%	-0.2113	46%	-0.2482	54%
1961-2007	-0.1237	100%	0.2427	-196%	-0.3664	296%

Source: Present authors from Ecological Footprint Network.

Table 4 shows the logarithmic differences of the ZK indices, where the ZK change has been decomposed in terms of the change of the *between* component and the change of the *within* component.[148] Dividing the period into two main subperiods 1961-1980 and 1980-2007: we can see that ZK polarization increased approximately by 33% in the first subperiod, driven by the increase of the between component (135% of the total ZK change) while the within component actually slowed it down. In the second subperiod, however, ZK polarization

[148] Since $ZK = b \cdot \frac{1}{w}$ where b is the between inequality and w the within inequality, the ZK change can be decomposed by the logarithmic differences as $\ln(ZK_t) - \ln(ZK_{t-1}) = (\ln(b_t) - \ln(b_{t-1})) + \left(\ln(\frac{1}{w_t}) - \ln(\frac{1}{w_{t-1}}) \right)$

decreased, 46% driven by the decrease in the between component and the remaining 54% in the within component.

In Table 5, the same exercise is performed but in this case the groups are delimited according to the World Bank income groups. These are low income countries, lower middle income countries, upper middle income countries and high income countries. According to this classification, different groupings have been proposed in order to capture the simplified distributions that are more common in the general picture. So we have calculated the ZK polarization indices for two groups (rich countries and poor countries), three groups (rich countries, emergent countries, and poor countries), and four groups (which coincide with the actual income classification of the World Bank). To see the countries belonging to each groups see Appendix A4.

The results obtained once more show the same inverted U-shape with the higher level of polarization occurring at some point between the decades 1980 and 1990. The most interesting fact in this exogenous group is, once again, the usefulness of income groups in explaining the distribution of EF. The results here are consistent with the results obtained for multiplicative decomposition (section 4.3) and also the Regression Based Decomposition (Chapter 5) since income determines the distribution of EF.

Focusing on the two groups in the ZK index (rich vs. poor countries) we can see that until 1990, the increase in the between group inequality pushes up polarization despite the within group inequality also increasing (so there is less group cohesion). However, from 1990 to 2007, the between group inequality also decreases which makes automatically polarization go down. Therefore, according to ZK(2) the rich and poor countries increased their distance in terms of EF from 1961 to 1980, and thus their polarization increased. However, during the whole period dispersion within each group increased constantly, which led to a decrease in polarization when from 1990 onwards the two groups of countries reduced their distance.

Table 5. Exogenous polarization as measured by ZK index for World Bank income classification.

year	Between Inequality	%	Within Inequality	%	T(0)	CV^2	Z-K index
ZK(2)*							
1961	0.1298	72%	0.0494	28%	0.1792	0.4436	2.6245
1970	0.1881	76%	0.0589	24%	0.2470	0.6398	3.1934
1980	0.2057	77%	0.0628	23%	0.2685	0.6896	3.2767
1990	0.1906	74%	0.0658	26%	0.2564	0.6998	2.8984
2000	0.1741	70%	0.0747	30%	0.2488	0.6853	2.3298
2007	0.1432	61%	0.0904	39%	0.2336	0.5849	1.5846
ZK(3)**							
1961	0.1340	75%	0.0452	25%	0.1792	0.4436	2.9611
1970	0.2021	82%	0.0449	18%	0.2470	0.6398	4.5020
1980	0.2188	81%	0.0498	19%	0.2685	0.6896	4.3965
1990	0.2112	82%	0.0451	18%	0.2564	0.6998	4.6820
2000	0.1971	79%	0.0517	21%	0.2488	0.6853	3.8083
2007	0.1636	70%	0.0700	30%	0.2336	0.5849	2.3382
ZK(4)***							
1961	0.1391	78%	0.0401	22%	0.1792	0.4436	3.4693
1970	0.2077	84%	0.0393	16%	0.2470	0.6398	5.2815
1980	0.2220	83%	0.0465	17%	0.2685	0.6896	4.7768
1990	0.2117	83%	0.0446	17%	0.2564	0.6998	4.7420
2000	0.1971	79%	0.0517	21%	0.2488	0.6853	3.8132
2007	0.1641	70%	0.0695	30%	0.2336	0.5849	2.3614

Notes: * Two exogenous groups: Group 1 is the lower income and low middle income countries; Group 2 is the upper middle and high Income countries. ** Three exogenous groups: Group 1 is the low and lower middle income countries; Group 2 is the upper middle income countries; Group 3 is the high income countries. *** Four Groups: Group 1 is the low income countries; Group 2 is the lower middle income countries; Group 3 is the upper middle income countries; Group 4 is the high income countries.

Source: Present authors from Ecological Footprint Network.

Regarding the three income groups classification, ZK(3), where the groupings correspond to the rich, the emergent and the poor, it becomes clear that despite the trend of the between group inequality following the same pattern as the one described for ZK(2), the within component does not increase along the whole period as much as ZK(2) does. In fact the within inequality depicts a less defined pattern, as it decreases and increases during the period, however, since from 1980 the between component decreases so does total polarization. Finally the ZK(4) follows almost identical behaviour to the ZK(3). Table 6 decomposes the ZK changes by logarithmic difference where it can be seen how the increase of ZK polarization in the first subperiod was driven by the increase of between inequality and the decrease of the second subperiod shared by both components.

Table 6. Decomposition of changes in the ZK indices for World Bank income classification

Period	Z-K index	%	Between I.	%	Within I.	%
ZK(2)*						
1961-1980	0.2220	100%	0.4608	208%	-0.2388	-108%
1980-2007	-0.7265	100%	-0.3623	50%	-0.3642	50%
1961-2007	-0.5046	100%	0.0985	-20%	-0.6030	120%
ZK(3)**						
1961-1980	0.3953	100%	0.4903	124%	-0.0951	-24%
1980-2007	-0.6314	100%	-0.2905	46%	-0.3409	54%
1961-2007	-0.2362	100%	0.1998	-85%	-0.4360	185%
ZK(4)***						
1961-1980	0.3198	100%	0.4675	146%	-0.1477	-46%
1980-2007	-0.7045	100%	-0.3024	43%	-0.4021	57%
1961-2007	-0.3847	100%	0.1651	-43%	-0.5498	143%

Notes: * Two exogenous groups: Group 1 is the lower income and low middle income countries; Group 2 is the upper middle and high income countries. ** Three exogenous groups: Group 1 is the low and lower middle income countries; Group 2 is the upper middle income countries; Group 3 is the high income countries. *** Four Groups: Group 1 is the low income countries; Group 2 is the lower middle income countries; Group 3 is the upper middle income countries; Group 4 is the high income countries.
Source: Present authors from Ecological Footprint Network.

A final thing to note is that the gain from adding more groups to the simplified distribution does not yield a significant increase in terms of explanatory power. In fact, the inequality explained by the two-groups simplification (the *between* inequality component) is quite close to that of three and four groups in the beginning of the period and as we advance in time it becomes less useful ; in 2007 the two-groups simplification clearly loses explanatory power relative of the three-groups simplification. This result thus points out that the first part of the analysed period, EF polarization was better captured by the two-groups distribution simplification of rich and poor countries, while for the final years of the sample, the analyses of the ZK indices indicates that the three-group simplification of rich, emergent and poor countries fits better in the real distribution. These results are consistent with those obtained by the EGR indices. Apparently both indices indicate that the distribution went from a two-pole to a three-pole distribution and also resulted in an inverted U-shape for the period mentioned. Therefore, it could be stated that those endogenous groups of EGR family were tied to the world income groups of rich-poor countries and to the rich-emergent-poor countries at the end of the period. The only difference, though, is that the latter ZK(3) does not increase in the final period while EGR(3) does.

6.3.3 DER INDICES

In Table 7 the results obtained by the estimation of DER indices (Duclos et al, 2004) are presented. It is easily seen that the pattern observed, once again, is consistent with the results obtained by previous polarization approaches, with an increase in polarization for the first few decades of the sample (until 1980) and a decrease thereafter.[149] However, it is important to keep in mind that the nature of DER indices is completely different to the previous indices due to the fact that polarization does not stem from defined groups (either exogenous or endogenous) but from the individual perspective of each country in the context of its particular empirical distribution context, so that group identification depends on the position of that country in the estimated distribution. More formally, a country located in e_i experiences a sense of identification that depends on the shape of the estimated density $f(e_i)$ at that point. Therefore, from this point of view, the polarization measured, despite sharing the

[149] The inverted U-shape pictured, however, is much more subtle than previous ones. This is a direct consequence of dealing with no discontinuities within groups.

same spirit as the previous calculations, allows a very different interpretation of the same phenomenon: the polarization of the EF distribution is a by-product of the alienation of countries fuelled by its own particular sense of identification within the distribution.

In Table 7 the decomposition of expression (7) is also performed so that polarization is the product of the average alienation, the average α-identification and (one plus) the normalised covariance between the two. Towards the bottom of Table 7, the logarithmic differences have been calculated in order to approximate the growth rates of DER and decompose them according to the evolution of these components. Notice that the polarization trend of the inverted U-shape is mainly driven by alienation rather than by identification. In fact, average identification appears to be quite stable along the period.

DER (0.25) increased approximately 15% from 1961 to 1980; of this, 132% was caused by the increase in alienation, with the other -32% being due to the compensatory role of identification and correlation in polarization growth. Similar patterns are found in the other DER indices. Therefore, it can be stated that the polarization growth from 1961 to 1980 was mainly driven by alienation rather than by the identification. Actually, the average identification appears to be quite stable along the period regardless of the α used.

Table 7. EF Polarization as measured by DER indices and its decomposition in Alienation

	DER (0.25)				DER (0.5)				DER (0.75)				DER (1)			
	DER	Alien.	Ident.	Corr.	DER	Alien.	Ident.	Corr.	DER	Alien.	Ident.	Corr.	DER	Alien.	Ident.	Corr.
1961	0.2646	0.3319	0.7983	-0.0014	0.2175	0.3319	0.6591	-0.0054	0.1837	0.3319	0.5554	-0.0032	0.1584	0.3319	0.4750	0.0047
1970	0.2971	0.3891	0.7930	-0.0372	0.2358	0.3891	0.6496	-0.0671	0.1937	0.3891	0.5430	-0.0834	0.1632	0.3891	0.4604	-0.0894
1980	0.3075	0.4048	0.7856	-0.0332	0.2422	0.4048	0.6384	-0.0628	0.1973	0.4048	0.5306	-0.0813	0.1649	0.4048	0.4480	-0.0907
1990	0.3013	0.3973	0.7971	-0.0487	0.2380	0.3973	0.6571	-0.0886	0.1949	0.3973	0.5539	-0.1145	0.1639	0.3973	0.4739	-0.1296
2000	0.2977	0.3917	0.7994	-0.0493	0.2354	0.3917	0.6594	-0.0887	0.1928	0.3917	0.5563	-0.1151	0.1621	0.3917	0.4765	-0.1318
2007	0.2898	0.3774	0.7888	-0.0268	0.2298	0.3774	0.6447	-0.0554	0.1879	0.3774	0.5394	-0.0771	0.1570	0.3774	0.4585	-0.0928
Logarithmic differences																
1961-1980	0.1503	0.1987	-0.0161	-0.0323	0.1074	0.1987	-0.0319	-0.0594	0.0714	0.1987	-0.0457	-0.0816	0.0405	0.1987	-0.0584	-0.0998
	100%	132%	-11%	-21%	100%	185%	-30%	-55%	100%	278%	-64%	-114%	100%	490%	-144%	-246%
1980-2007	-0.0593	-0.0700	0.0041	0.0066	-0.0524	-0.0700	0.0097	0.0078	-0.0491	-0.0700	0.0163	0.0045	-0.0492	-0.0700	0.0231	-0.0023
	100%	118%	-7%	-11%	100%	134%	-19%	-15%	100%	143%	-33%	-9%	100%	142%	-47%	5%
1961-2007	0.0910	0.1287	-0.0120	-0.0257	0.0550	0.1287	-0.0221	-0.0515	0.0223	0.1287	-0.0294	-0.0770	-0.0087	0.1287	-0.0353	-0.1021
	100%	141%	-13%	-28%	100%	234%	-40%	-94%	100%	578%	-132%	-346%	100%	-1479%	405%	1173%

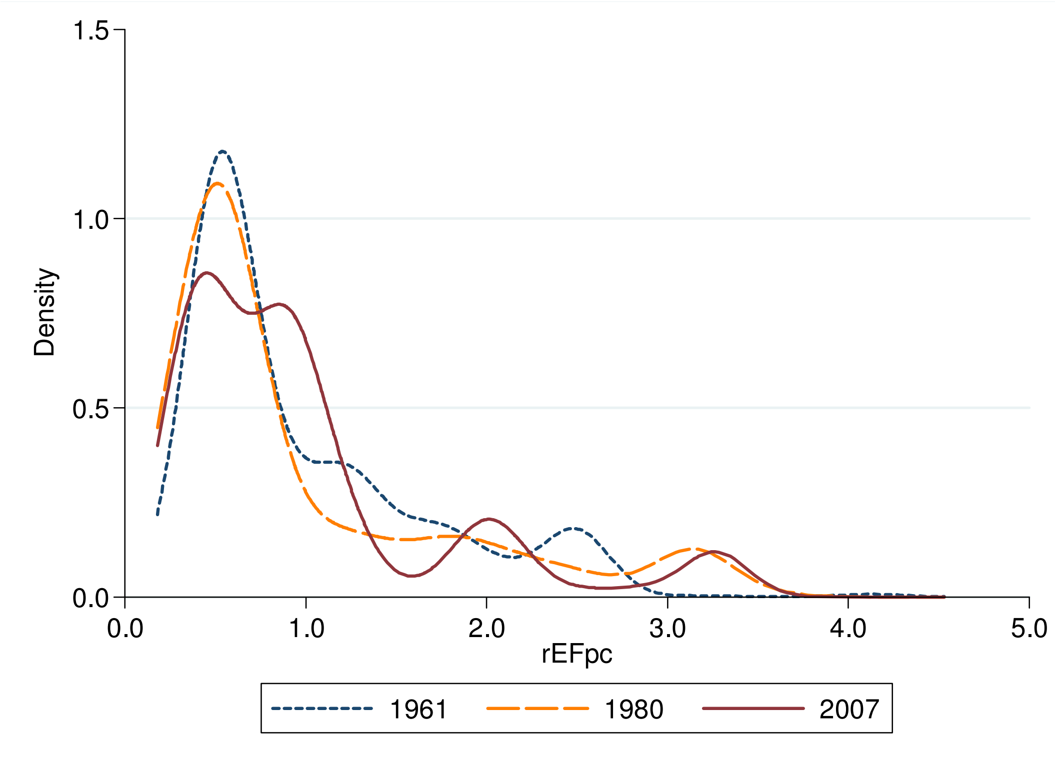
Source: Present author from Ecological Footprint Network

Again based on DER(0.25), polarization decreased 5% from 1980 to 2007, the alienation component also drove change, as it did for the rest of the DER indices also. If we retrieve the empirical density functions used above, concretely for the years 1961, 1980 and 2007 (see Figure 6), we can see the basic densities from which these indices have been estimated. The highest polarization level was reached in 1980 when alienation reached its highest level (the long dashed function), at the same time as identification was relatively smaller than in 1961 and 2007. Actually, as can be seen in Figure 6, 1980 has a less peaked density, which should intuitively bring polarization down, however at the same time there are more modes, hence less intrinsic alienation within the distribution and so lower polarization. In this case though, the higher average identifications of 1961 and 2007 does not compensate for the greater alienation of 1980.[150]

Consequently, since in DER indices, alienation corresponds to the Gini index (recall equation 7) and alienation explains the bulk of the changes in polarization according to this particular family, the decomposition of DER indices allows us to conclude that EF polarization is mainly enhanced by EF inequality.

[150] Notice that DER (1) is the only index in which the polarization of 2007 is lower than the level of 1961 so that according to this index, polarization has increased during the whole period. Actually, according to DER(1) the increase 1961-1980 was 4% and the decrease 1980-2007 was 5%. This is a direct consequence of different levels of sensitivity to identification (the value of α). As this sensitivity is directly linked to an aversion to polarization, the higher the value, the more aversion to polarization is assumed and by construction more importance is given to the identification process. To appreciate this, consider the 1961 distribution as a concentration of the 2007 distribution (as in Axiom 1 of appendix A2). This concentration brings down alienation and increases identification. However, as long as α=1, concentration increases total polarization, but this is not the case for α<1.

Figure 6. Density Functions of relative EF per capita for years 1961, 1980 and 2007



6.4 CONCLUSIONS

This chapter has aimed at extending the distributional analysis of the international distribution of EF, previously analysed from the inequality approach, by calculating different families of polarization indices: EGR indices which were designed to analyse discrete distributions and where the countries groups are defined endogenously, ZK indices whose main advantage is that they allow an exogenous definition of groups and so the groups can be organised according to common classifications on the international scene, and finally, DER indices which, in contrast to the previous ones, are designed to analyse polarization of continuous distributions. To the best of our knowledge, this is the only distributional analysis of EF from a polarization framework, and the first time that a polarization analysis of an environmental outcome has been extended by estimating DER indices.

Since an increase of polarization, may in principle be consistent with either an increase or a reduction in inequality, the present analyses ready us for such phenomenon when the results obtained are compared with the previous analyses of inequality. In this regard, observing the inequality trends as compared to the polarization trends estimated here, it might be claimed that, at least during the first two decades of the sample, polarization and inequality followed quite a similar increasing pattern. However, opposite directions between polarization and inequality were found for the periods 1980-1990 according to EGR and ZK indices (when inequality still increased and polarization decreased) and 2000-2007 according to EGR indices (inequality decreased and the three-groups polarization, which we noted as being the best fit for that period, increased).

The results of the three family indices used point to an inverted U trend along the period analysed (1961-2007), with an increase of bipolarization from 1961 to 1980-1990 (the two-group simplification appeared as the best fit in that period), followed by a decrease until 2000. From 2000 to 2007, the EGR indices have revealed that the three-group simplification of the distribution gives a better fit to the original distribution, so that the international distribution of EF per capita moved from a two-group segmentation to a three-group segmentation (a result also consistent with the ZK indices). In this regard, from 2000 to 2007, tri-polarization registered an increase, so that the EF distribution became more polarised among three groups of countries, despite the decrease in inequality observed in that same period.

The ZK indices and their consistency with the EGR results allow us to state that the driving groups of distribution (two until 2000, and three from then on) are linked to income groups. Indeed, the ZK indices point out that from 1961 to 1980 the polarization of EF distribution was mainly driven by the simplified world of rich-poor countries, while from 1980 on, distribution was mainly driven by a world described by the Rich, the Emergent and the Poor countries since it better captured the distribution pattern at the same time as it registered an increase in polarization in that line.

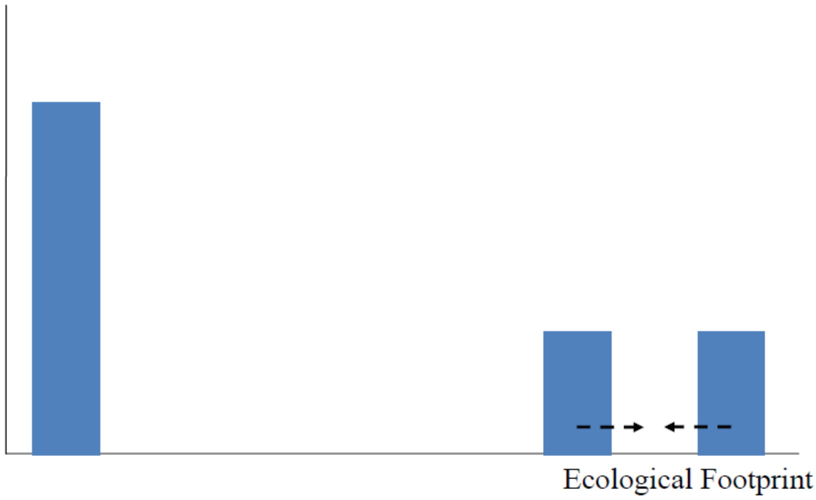
Finally, the DER indices for which, given the estimated empirical distribution, polarization is measured by each country's identification window, add more validity to the results since their change again traces out an inverted U-shape over the period. Additionally, according the decomposition of DER index between alienation and identification, the change in polarization has been critically driven by the alienation component rather than by identification. Consequently, it could be stated that as far as international EF distribution is concerned, inequality and polarization enhance each other for the majority of the period analysed.

Despite how fundamentally different the measures are, all of them broadly measure the same concept, a combination of within-group cohesion and between-group distance. Therefore, taking into consideration the whole picture of different calculated polarization measures, the international distribution of EF was becoming more polarised between two groups which, according to the evidence shown, were mainly driven by income. Hence in the period 1961-1980, there was polarization between Rich and Poor countries. Such increase though was accompanied by an increase in the inequality of distribution. Actually, as DER decomposition has shown, the polarization trend was mainly driven by the alienation effect (positive correlation with inequality) rather than by the identification effect (negative correlation with inequality). However, there were two periods (1980-1990) and (2007-2007) where inequality and polarization ran in opposite directions. The first of such periods may be caused by the transition from the increasing trend to the decreasing trend of the inverted U (where polarization started to decrease faster than the inequality), however, the results in the second period 2000-2007 are particularly interesting since all the inequality indices point to a decrease in dispersion, while polarization between the three groups (again driven by income) increased significantly. Consequently, the decreasing inequality observed in Chapter 3 is complemented by consideration of the increase in polarization.

APPENDIX

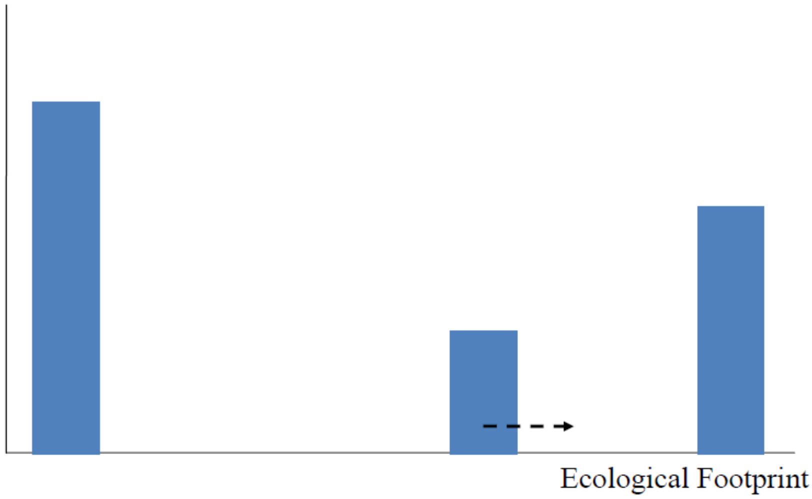
A1. Graphic axioms of Esteban and Ray (1994) for ER indices

Axiom 1



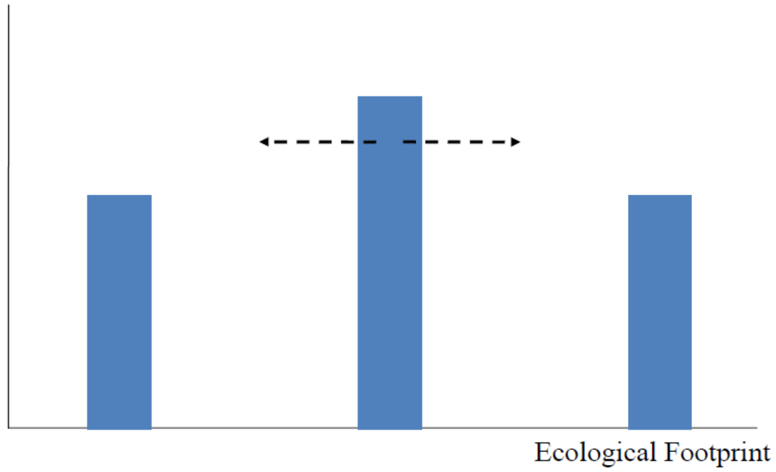
The two right-hand masses are very close to each other and they are individually smaller than the left-hand mass. If the two small masses are pooled like this while not changing the average distance from the left hand mass, polarization should increase.

Axiom 2



If the intermediate mass gets closer to the nearer and smaller mass (here the right-hand mass), then Polarization should increase.

Axiom 3



This axiom states that the disappearance of a middle class will increase polarization.

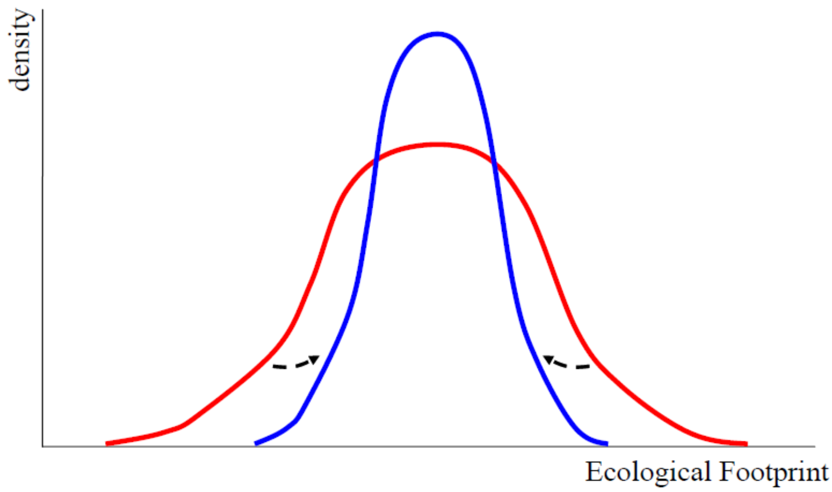
Axiom 4. Population neutrality. Polarization comparisons are invariant to population scaling by the same percentage on each side (see Chapter 3, Section 3.2 for population principle).

A2. Graphic axioms of Duclos et al. (2004) for DER indices

The axioms defined in Duclos et al. (2004) to characterise DER indices, despite being substantially different from those defined in Esteban and Ray (1994), are similar in spirit. The difference, as authors emphasise, comes from the fact that in DER indices are based on a domain of spaces of densities and continuous distributions, while ER and EGR indices (Esteban and Ray 1994, 1999) are based on distribution over a discrete number of points.

Axiom 1.

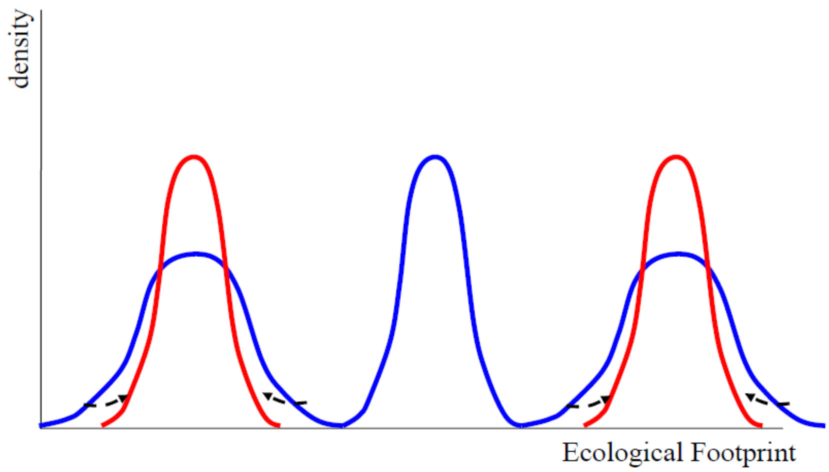
If distribution is just a single uniform density, a global concentration cannot increase polarization.



This axiom is self-evident. The concentration, as defined here, would entail not only a reduction of polarization but also a reduction in inequality.

Axiom 2.

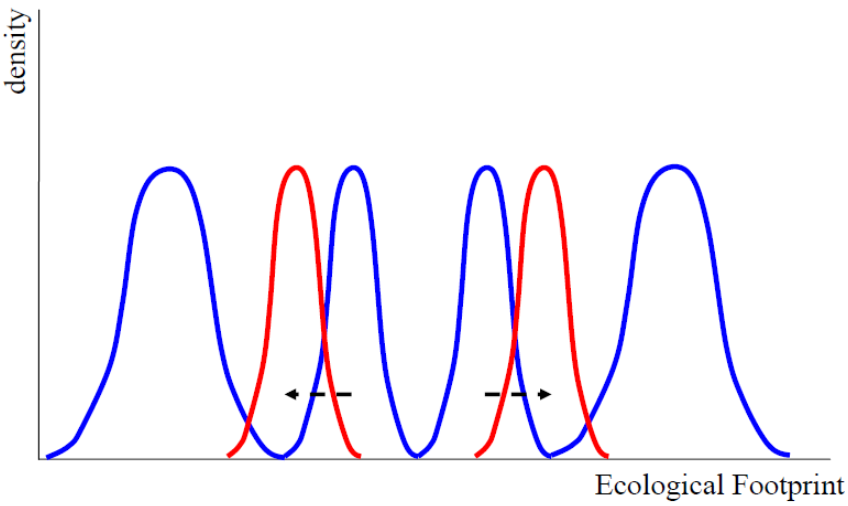
If a symmetric distribution is composed of three uniform kernels, the concentration of the side kernels cannot reduce polarization.



This axiom is the defining axiom of polarization and so it has been used to motivate the difference between inequality and polarization. In this situation the local concentration appears to be opposed to the global one of the previous axiom.

Axiom 3.

If a symmetric distribution is composed of four uniform kernels, then a symmetric slide of the two middle kernels away from each other must increase polarization.



This axiom is considering a growing alienation between defined groups of the distribution. In this situation both inequality and polarization increase.

Axiom 4.

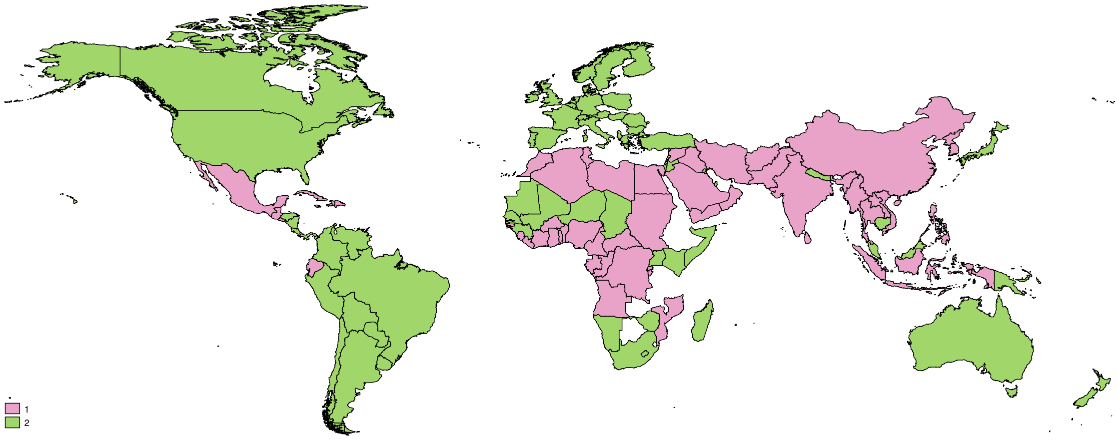
Population neutrality. Polarization comparisons are invariant to population scaling by the same percentage on each side (see Chapter 3, Section 3.2 for population principle).

According to Duclos et al. (2004) measure P satisfies axioms 1-4 if and only if it is proportional to

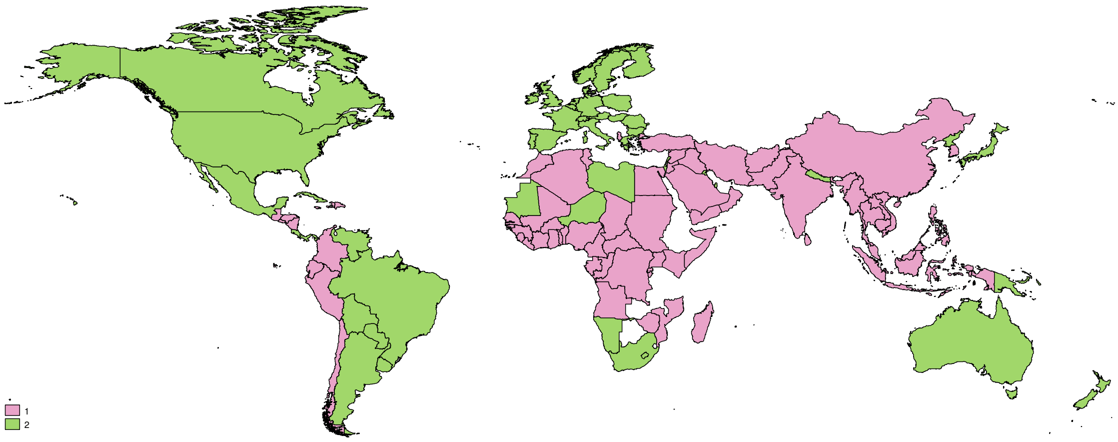
$$P_\alpha(f) = \iint f(e_i)^{1+\alpha} f(e_j)\left|e_i - e_j\right| de_i de_j \qquad \text{(A1)}$$

A3. Endogenous groupings of countries for EGR indices

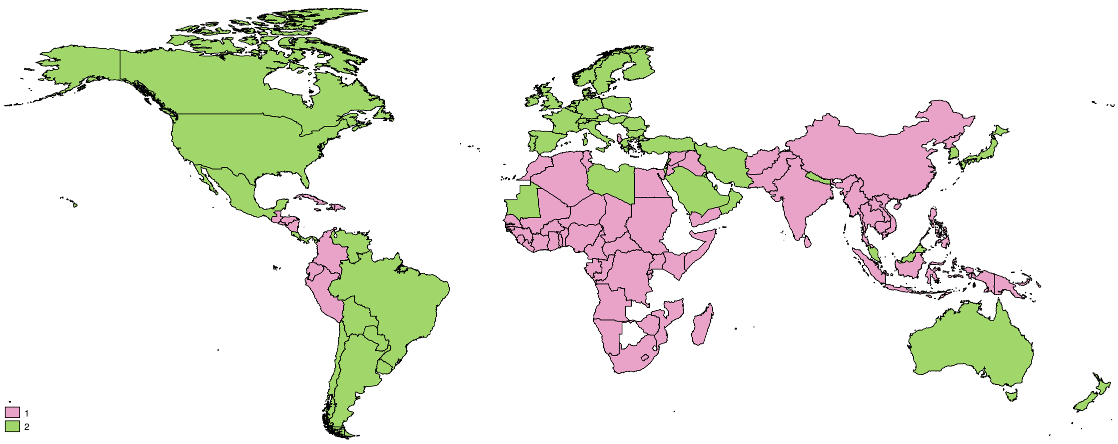
2 endogenous groups (1961).



2 endogenous groups (1980)



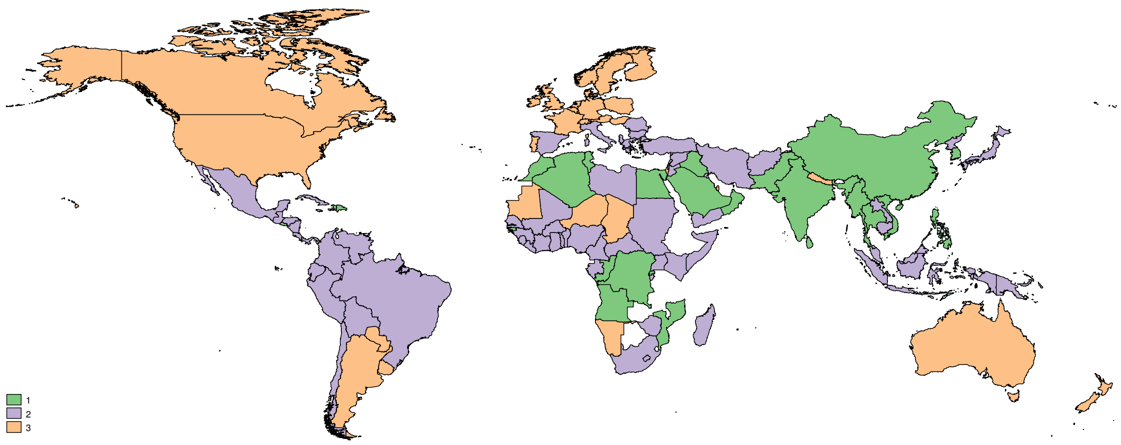
2 endogenous groups (2007)



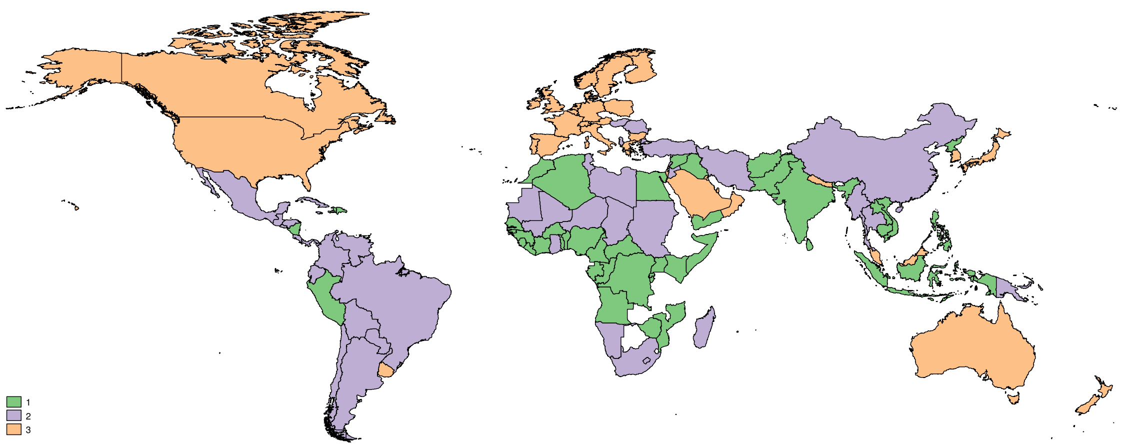
2 endogenous groups (1961)		2 endogenous groups (1980)		2 endogenous groups (2007)	
Group 1	**Group 2**	**Group 1**	**Group 2**	**Group 1**	**Group 2**
Afghanistan	Albania	Afghanistan	Argentina	Afghanistan	Argentina
Algeria	Argentina	Albania	Australia	Albania	Australia
Angola	Australia	Algeria	Austria	Algeria	Austria
Benin	Austria	Angola	Belgium	Angola	Belgium
Burkina Faso	Belgium	Benin	Bolivia	Benin	Bolivia
Burundi	Bolivia	Burkina Faso	Brazil	Burkina Faso	Brazil
Cameroon	Brazil	Burundi	Bulgaria	Burundi	Bulgaria
Central African R	Bulgaria	Cambodia	Canada	Cambodia	Canada
China	Cambodia	Cameroon	Costa Rica	Cameroon	Chile
Congo	Canada	Central African R	Cuba	Central African R	Costa Rica
Congo, DR	Chad	Chad	Denmark	Chad	Denmark
Côte d'Ivoire	Chile	Chile	Finland	China	Finland
Cuba	Colombia	China	France	Colombia	France
Dominican Rep	Costa Rica	Colombia	Germany	Congo	Gambia
Ecuador	Denmark	Congo	Greece	Congo, DR	Germany
Egypt	Finland	Congo, DR	Hungary	Côte d'Ivoire	Greece
El Salvador	France	Côte d'Ivoire	Ireland	Cuba	Hungary
Gabon	Gambia	Dominican Rep	Israel	Dominican Rep	Iran, IR
Ghana	Germany	Ecuador	Italy	Ecuador	Ireland
Guatemala	Greece	Egypt	Japan	Egypt	Israel
Guinea-Bissau	Guinea	El Salvador	Korea, DPR	El Salvador	Italy
Haiti	Honduras	Gabon	Kuwait	Gabon	Japan
India	Hungary	Gambia	Lebanon	Ghana	Korea, Rep
Indonesia	Ireland	Ghana	Libyan AJ	Guatemala	Kuwait
Iran, IR	Israel	Guatemala	Luxembourg	Guinea	Lebanon
Iraq	Italy	Guinea	Mauritania	Guinea-Bissau	Libyan AJ
Jamaica	Japan	Guinea-Bissau	Mexico	Haiti	Luxembourg
Korea, DPR	Jordan	Haiti	Namibia	Honduras	Malaysia
Korea, Rep	Kenya	Honduras	Nepal	India	Mauritania
Lao PDR	Kuwait	India	Netherlands	Indonesia	Mauritius
Liberia	Lebanon	Indonesia	New Zealand	Iraq	Mexico
Libyan AJ	Luxembourg	Iran, IR	Niger	Jamaica	Nepal
Mauritius	Madagascar	Iraq	Norway	Jordan	Netherlands
Mexico	Malaysia	Jamaica	Panama	Kenya	New Zealand
Morocco	Mali	Jordan	Papua New Guinea	Korea, DPR	Norway
Mozambique	Mauritania	Kenya	Paraguay	Lao PDR	Oman
Myanmar	Namibia	Korea, Rep	Poland	Liberia	Panama
Nigeria	Nepal	Lao PDR	Portugal	Madagascar	Paraguay
Oman	Netherlands	Liberia	Qatar	Mali	Poland
Pakistan	New Zealand	Madagascar	Romania	Morocco	Portugal
Philippines	Nicaragua	Malaysia	Singapore	Mozambique	Qatar
Rwanda	Niger	Mali	South Africa	Myanmar	Romania
Saudi Arabia	Norway	Mauritius	Spain	Namibia	Saudi Arabia
Sierra Leone	Panama	Morocco	Sweden	Nicaragua	Singapore
Sri Lanka	Papua New Guinea	Mozambique	Switzerland	Niger	Spain
Sudan	Paraguay	Myanmar	Trinidad and Tobago	Nigeria	Sweden
Syrian Arab Rep	Peru	Nicaragua	United Kingdom	Pakistan	Switzerland
Thailand	Poland	Nigeria	United States of A	Papua New Guinea	Trin. and Tobago
Timor-Leste	Portugal	Oman	Uruguay	Peru	Turkey
Togo	Qatar	Pakistan	Venezuela, BR	Philippines	United Kingdom
Trin. and Tobago	Romania	Peru		Rwanda	United States of A.

Tunisia	Senegal	Philippines	Senegal	Uruguay
Vietnam	Singapore	Rwanda	Sierra Leone	Venezuela, BR
Yemen	Somalia	Saudi Arabia	Somalia	
	South Africa	Senegal	South Africa	
	Spain	Sierra Leone	Sri Lanka	
	Sweden	Somalia	Sudan	
	Switzerland	Sri Lanka	Syrian Arab Rep	
	Turkey	Sudan	Thailand	
	Uganda	Syrian Arab Rep	Timor-Leste	
	United Kingdom	Thailand	Togo	
	United States of A	Timor-Leste	Tunisia	
	Uruguay	Togo	Uganda	
	Venezuela, BR	Tunisia	Vietnam	
	Zimbabwe	Turkey	Yemen	
		Uganda	Zimbabwe	
		Vietnam		
		Yemen		
		Zimbabwe		

3 endogenous groups (1961)



3 endogenous groups (2007)



3 endogenous groups (1961)			3 endogenous groups (2007)		
Group 1	**Group 2**	**Group 3**	**Group 1**	**Group 2**	**Group 3**
Algeria	Afghanistan	Argentina	Afghanistan	Albania	Australia
Angola	Albania	Australia	Algeria	Argentina	Austria
Central African R	Benin	Austria	Angola	Bolivia	Belgium
China	Bolivia	Belgium	Benin	Brazil	Bulgaria
Congo	Brazil	Canada	Burkina Faso	Chad	Canada
Congo, DR	Bulgaria	Chad	Burundi	Chile	Denmark
Dominican Rep	Burkina Faso	Denmark	Cambodia	China	Finland
Egypt	Burundi	Finland	Cameroon	Colombia	France
El Salvador	Cambodia	France	Central African R	Costa Rica	Germany
Guinea-Bissau	Cameroon	Germany	Congo	Cuba	Greece
Haiti	Chile	Hungary	Congo, DR	Ecuador	Ireland
India	Colombia	Ireland	Côte d'Ivoire	El Salvador	Israel
Iraq	Costa Rica	Israel	Dominican Rep	Gambia	Italy
Korea, Rep	Côte d'Ivoire	Luxembourg	Egypt	Ghana	Japan
Morocco	Cuba	Mauritania	Gabon	Guatemala	Korea, Rep
Mozambique	Ecuador	Namibia	Guinea	Honduras	Kuwait
Myanmar	Gabon	Nepal	Guinea-Bissau	Hungary	Luxembourg
Oman	Gambia	Netherlands	Haiti	Iran, IR	Malaysia
Pakistan	Ghana	New Zealand	India	Jamaica	Mauritius
Philippines	Greece	Niger	Indonesia	Jordan	Nepal
Rwanda	Guatemala	Norway	Iraq	Lebanon	Netherlands
Saudi Arabia	Guinea	Paraguay	Kenya	Libyan AJ	New Zealand
Sri Lanka	Honduras	Poland	Korea, DPR	Madagascar	Norway
Thailand	Indonesia	Portugal	Lao PDR	Mali	Oman
Timor-Leste	Iran, IR	Qatar	Liberia	Mauritania	Poland
Tunisia	Italy	Sweden	Morocco	Mexico	Portugal
Vietnam	Jamaica	Switzerland	Mozambique	Myanmar	Qatar
	Japan	United Kingdom	Nicaragua	Namibia	Saudi Arabia
	Jordan	United States of A	Nigeria	Niger	Singapore
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	Kuwait		Philippines	Paraguay	Switzerland
	Lao PDR		Rwanda	Romania	United Kingdom
	Lebanon		Senegal	South Africa	United States of A
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	Libyan AJ		Somalia	Thailand	
	Madagascar		Sri Lanka	Trinidad and Tobago	
	Malaysia		Syrian Arab Rep	Tunisia	
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	Mauritius		Togo	Venezuela, BR	
	Mexico		Uganda		
	Nicaragua		Vietnam		
	Nigeria		Yemen		
	Panama		Zimbabwe		
	Papua New Guinea				
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	Sierra Leone				
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Spain	
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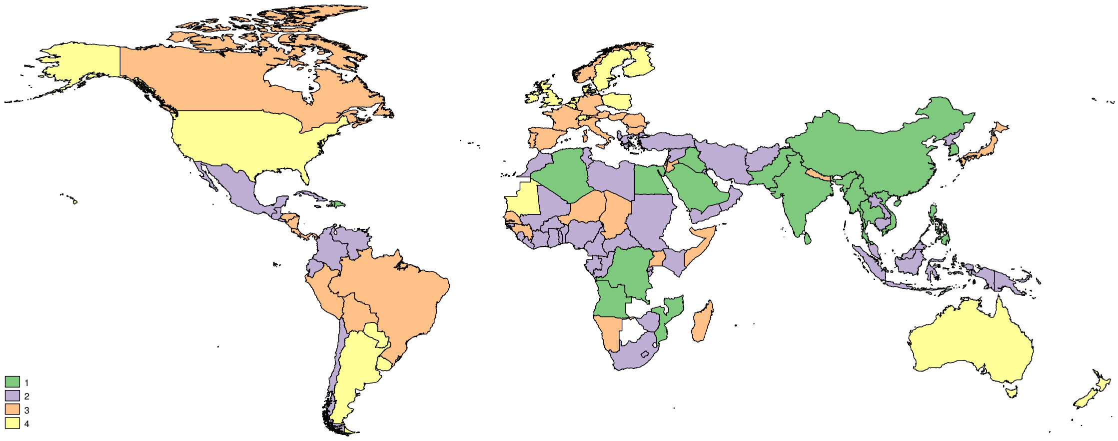
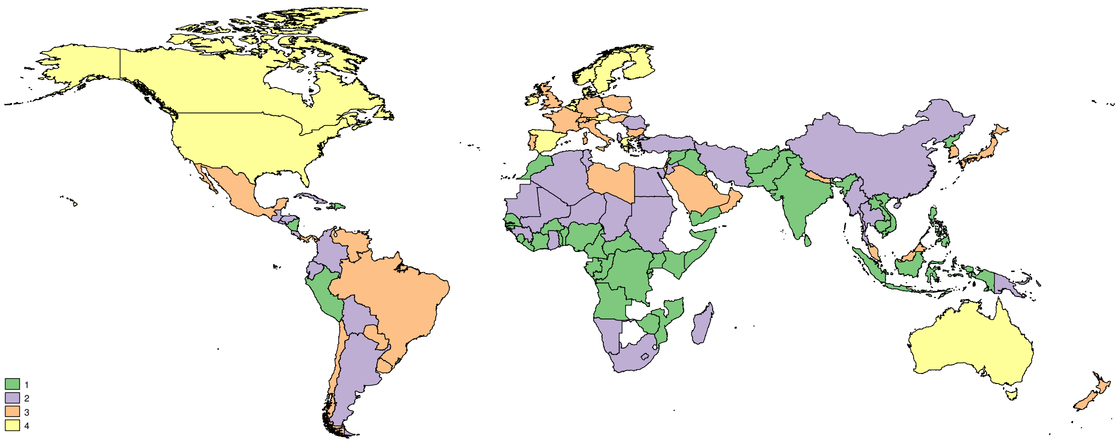
4 endogenous groups (1961)



4 endogenous groups (2007)



4 endogenous groups (1961)				**4 endogenous groups (2007)**			
Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Algeria	Afghanistan	Austria	Argentina	Afghanistan	Albania	Brazil	Australia
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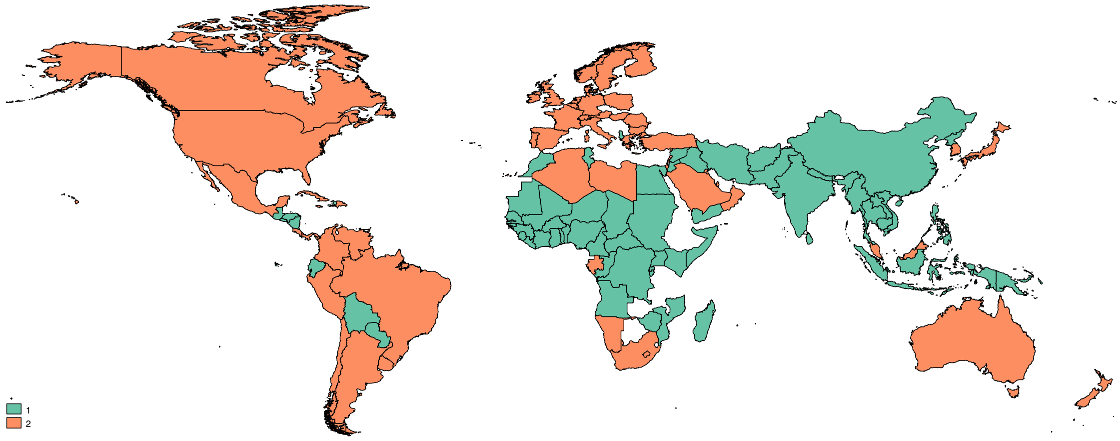
China	Benin	Brazil	Belgium	Benin	Argentina	Chile	Belgium
Congo, DR	Burkina Faso	Bulgaria	Denmark	Burkina Faso	Bolivia	France	Canada
Dominican Rep	Burundi	Canada	Finland	Burundi	Chad	Gambia	Denmark
Egypt	Cambodia	Chad	Ireland	Cambodia	China	Germany	Finland
Haiti	Cameroon	Costa Rica	Luxembourg	Cameroon	Colombia	Hungary	Greece
India	Central Afric. R	France	Mauritania	Central Afric.R	Costa Rica	Israel	Ireland
Iraq	Chile	Gambia	Netherlands	Congo	Cuba	Italy	Kuwait
Korea, Rep	Colombia	Germany	New Zealand	Congo, DR	Ecuador	Japan	Luxembourg
Mozambique	Congo	Guinea	Paraguay	Côte d'Ivoire	Egypt	Korea, Rep	Netherlands
Myanmar	Côte d'Ivoire	Honduras	Poland	Dominican Rep	El Salvador	Lebanon	Norway
Pakistan	Cuba	Hungary	Sweden	Gabon	Ghana	Libyan AJ	Qatar
Philippines	Ecuador	Israel	Switzerland	Guinea-Bissau	Guatemala	Malaysia	Singapore
Saudi Arabia	El Salvador	Italy	UK	Haiti	Guinea	Mauritius	Spain
Sri Lanka	Gabon	Japan	USA	India	Honduras	Mexico	Sweden
Thailand	Ghana	Jordan	Uruguay	Indonesia	Iran, IR	Nepal	USA
Timor-Leste	Greece	Madagascar		Iraq	Jamaica	New Zealand	
Vietnam	Guatemala	Namibia		Kenya	Jordan	Oman	
	Guinea-Bissau	Nepal		Korea, DPR	Madagascar	Panama	
	Indonesia	Nicaragua		Lao PDR	Mali	Paraguay	
	Iran, IR	Niger		Liberia	Mauritania	Poland	
	Jamaica	Norway		Morocco	Myanmar	Portugal	
	Kenya	Panama		Mozambique	Namibia	Saudi Arabia	
	Korea, DPR	Peru		Nicaragua	Niger	Switzerland	
	Kuwait	Portugal		Nigeria	Papua New G.	Trin. and Tob.	
	Lao PDR	Qatar		Pakistan	Romania	UK	
	Lebanon	Romania		Peru	South Africa	Uruguay	
	Liberia	Senegal		Philippines	Sudan	Venezuela, BR	
	Libyan AJ	Singapore		Rwanda	Thailand		
	Malaysia	Somalia		Senegal	Tunisia		
	Mali	Spain		Sierra Leone	Turkey		
	Mauritius	Uganda		Somalia			
	Mexico			Sri Lanka			
	Morocco			Syrian AR			
	Nigeria			Timor-Leste			
	Oman			Togo			
	Papua New G.			Uganda			
	Rwanda			Vietnam			
	Sierra Leone			Yemen			
	South Africa			Zimbabwe			
	Sudan						
	Syrian AR						
	Togo						

Trin. and Tob.	
Tunisia	
Turkey	
Venezuela, BR	
Yemen	
Zimbabwe	

A4. Income Classification according to World Bank

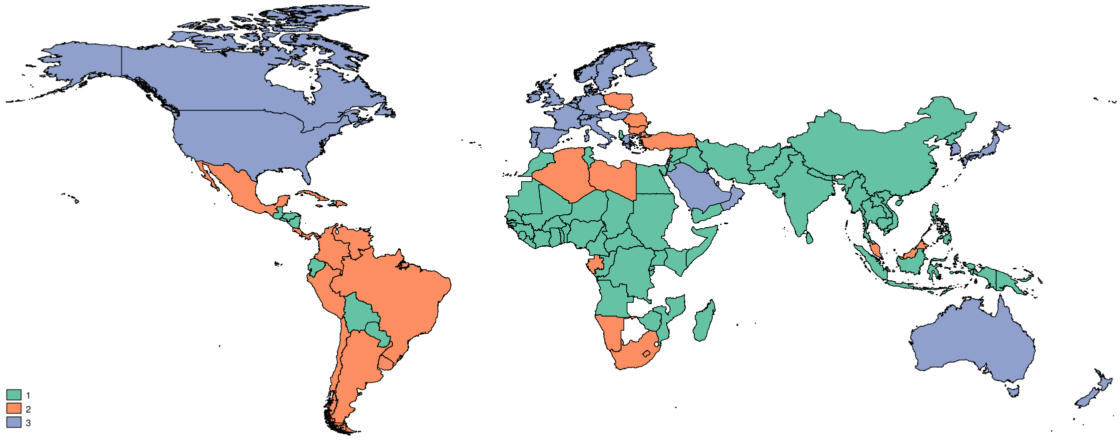
Low Income	Lower middle Income	Upper middle Income	High Income
Afghanistan	Albania	Algeria	Australia
Benin	Angola	Argentina	Austria
Burkina Faso	Bolivia	Brazil	Belgium
Burundi	Cameroon	Bulgaria	Canada
Cambodia	China	Chile	Denmark
Central African Rep	Congo	Colombia	Finland
Chad	Côte d'Ivoire	Costa Rica	France
Congo, DR	Ecuador	Cuba	Germany
Gambia	Egypt	Dominican Republic	Greece
Ghana	El Salvador	Gabon	Hungary
Guinea	Guatemala	Jamaica	Ireland
Guinea-Bissau	Honduras	Lebanon	Israel
Haiti	India	Libyan AJ	Italy
Kenya	Indonesia	Malaysia	Japan
Korea, DPR	Iran, IR	Mauritius	Korea, Rep
Lao PDR	Iraq	Mexico	Kuwait
Liberia	Jordan	Namibia	Luxembourg
Madagascar	Morocco	Panama	Netherlands
Mali	Nicaragua	Peru	New Zealand
Mauritania	Nigeria	Poland	Norway
Mozambique	Pakistan	Romania	Oman
Myanmar	Papua New Guinea	South Africa	Portugal
Nepal	Paraguay	Turkey	Qatar
Niger	Philippines	Uruguay	Saudi Arabia
Rwanda	Sri Lanka	Venezuela, BR	Singapore
Senegal	Sudan		Spain
Sierra Leone	Syrian Arab Republic		Sweden
Somalia	Thailand		Switzerland
Togo	Timor-Leste		Trinidad and Tob.
Uganda	Tunisia		United Kingdom
Vietnam			United States of A.
Yemen			
Zimbabwe			

2 exogenous groups by income (ZK(2))*



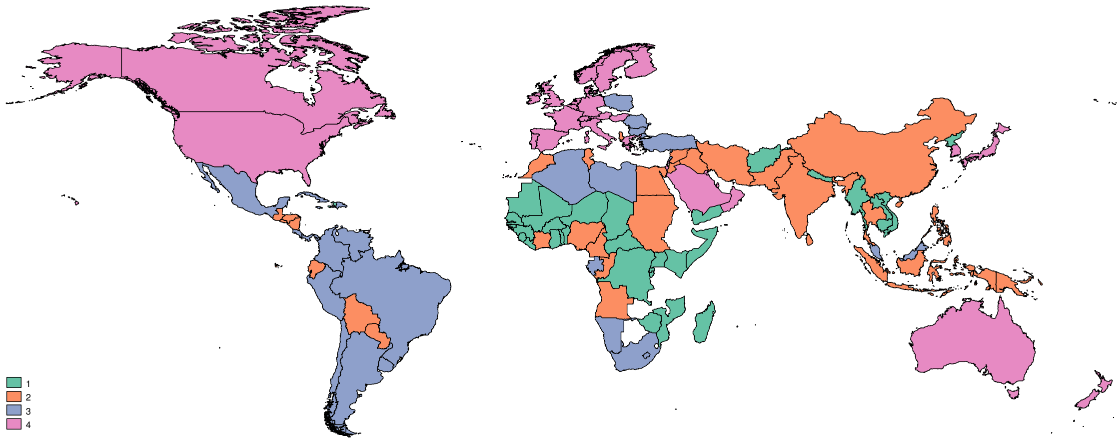
* Group 1 is the lower income and low middle income countries; Group 2 is the upper middle and high Income countries.

3 exogenous groups by income (ZK(3))**



** Group 1 is the low and lower middle income countries; Group 2 is the upper middle income countries; Group 3 is the high income countries.

4 exogenous groups by income (ZK(4))



*** Group 1 is the low income countries; Group 2 is the lower middle income countries; Group 3 is the upper middle income countries; Group 4 is the high income countries

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CHAPTER 7
GENERAL CONCLUSIONS

This thesis has focused on analysing the international distribution of the demand in natural resources, as measured using the EF framework, by applying and adapting methodology borrowed from inequality economics. The empirical analyses have been organised into four chapters that, despite addressing different and specific research questions, all deal with the international distribution of EF.

The object of such analyses has been the addition of an empirical dimension to the intragenerational equity concern. It has been argued that tracking empirical distributional patterns of ecological indicators, such as EF, is a fundamental part of sustainable development. Economic growth is a function of, inter alia, natural resources, however, as many scientists point out, such growth, together with the population size reached, has exceeded, on several different dimensions, the earth's boundaries; consequently, given the finite limit of natural resources, the scale of the economy cannot grow infinitely, and therefore consumption equity in terms of natural resource emerges as a political goal of international governance. The distributional analyses performed allow not only the monitoring of whether the distribution has become more equitable or not, but also the determination of its underlying drivers, in consequence deriving various policy implications.

Furthermore, the importance of this subject is related to the very concept of sustainability which is based on distributional concerns; its most popular definition attempts to meet present needs without compromising the needs of future generations. In this way, sustainable development, as we understand it, is about equity *between* and *within* generations. This study adds empirical evidence to the *within* issue, an area that has received relatively little attention in the ecological economics literature up to now, and places special emphasis on the interactions between intragenerational and intergenerational equity. Indeed, research into international ecological distribution has highlighted the direct impact that certain particularities of the ecological distribution of natural resource consumption have on the achievement of a global sustainable scale from different perspectives. For instance, distributional analysis is extremely important in the context of Multilateral Environmental Agreements between countries; considering environmental inequalities in such a context can help to reach greater consensus towards the creation of a sustainable global economy. The inequalities in different countries, however, might not be rooted in the simple sum of an individual nation's demands but in a structural world system where the world is the result of a social system historically built on unequal power relations (Hornborg 2011, Wallerstein 1974–1989). Consequently, in this theoretical framework, the distribution of environmental benefits and hazards is structurally determined by a global system where what matters is the country's position in the international resource flow rather than its own choices. From this perspective, the theoretical question is whether the global distribution of environmental impacts is somehow structurally determined or not. If it is, then achieving international equity in terms of natural resource consumption (and the positive synergies that might evolve in terms of sustainable scale) may well require deep political transformations of the global socioeconomic system. Although this hypothesis cannot be reduced to any single statistic, the distributional analyses of inequality economics on ecological distribution have provided relevant insights when discussing their results within this political economy framework.

The empirical analyses of the international distribution of EF have been used to discuss and to contribute to the field as already mentioned. Obviously, other ecological indicators are available to do so (see Chapter 2), however, the advantage of the EF in the analysis of international distribution is that, since it measures consumption in terms of land (hectares), inequality concerns are more easily raised than when using other indicators. This is because, automatically, a large EF might imply the appropriation of resources of either other countries or of future generations. In fact, the very concept of EF emerged in order to demonstrate that the extension of the ecological impact of natural resource demand goes beyond national boundaries.

In this study, each chapter made its own specific conclusions and for a detailed conclusion of the results obtained one should consult the relevant chapter; this final chapter aims to conclude the thesis by making general conclusions derived from a wider. It is organised into two sections: in the first, the principal empirical findings of the thesis have been summarised while, in the second section, some of the limitations of the research conducted and possible future research directions are discussed.

7.1 EMPIRICAL FINDINGS AND ITS IMPLICATIONS

This study has shown that international inequality in EF per capita has increased by 31% from 1961 to 2007 according to the neutral inequality indices (GE(2) and CV^2), which it has been argued are the indices that best suit ecological distribution analyses. Such an increase, however, mainly occurred in the seventies and eighties, from then on, inequality stabilized and indeed decreased slightly. In any case, in focusing on the increase over the whole period in question, it could be suggested that, even assuming the ecological impact had remained constant along the whole period (which it has not), the inequality level of 1961 compared to the inequality level of 2007 highlights the fact that future generations may not enjoy the same standards of living of present generations if ecological inequality is not dealt with. Therefore, if one were to define sustainability as "not decreasing the capacity to provide non-declining per capita utility for infinity" (Neumayer 2010), then it might happen that the capacity did not decrease however, equity aside, the per capita utility of significant parts of the world population might decline due to unequal distribution. In this regard, it seems only sensible that we should consider sustainability and equity equally. Of course, it might be argued that the more the earth's boundaries are being transgressed, the more the scale issue should be of importance, however, despite the risk of adopting an extreme anthropocentrism, a healthy planet with unequal share is far from ideal.

Additionally we have learnt that the international distribution of EF hugely depends, and in a way that persists over time, on the world region to which it belongs. This finding suggests, on the one hand, that the high homogeneity within these regional groups might represent an advantage in terms of global governance; they would achieve greater consensus in environmental negotiations than in broader discussions where inequalities are greater. For this reason, regional environmental institutions, such as those within Europe or Latin America, should be encouraged to become leading world environmental agencies. On the other hand, the fact that the international EF inequality has been determined during the entire period by the world region suggests that the global flow of natural resources is somehow structurally determined, so that individual countries might be linked to the wider international picture.

By decomposing the EF inequality in terms of its underlying sources, this thesis has shown that the types of land more unequally distributed are those more associated with an industrial countries' diet (grazing land and fishing grounds), while those more equally distributed correspond to cropland, which is in direct relation to the fact that this type of land supports basic subsistence. However, taking into account the weight of the sources in the EF accounting and the interaction effects among them, the carbon footprint emerged as being the greatest contributor of EF inequality because of its greater share in EF accounting (in the last few years) despite accounting for lower inequality than other sources (but greater than whole EF). At the same time, cropland contribution to EF inequality has reduced significantly as a result of both having historically low inequality and having decreased its EF share at the expense of an increase in carbon footprint for the period mentioned. In other words, we have observed empirically how, as the world moved from a cropland based EF to a Carbon based EF, the international inequality in EF also changed. Taken together, these results suggest that reducing per capita carbon footprint of countries will lead, not only to a more sustainable level, but also to a fairer distribution of EF. However, in doing so the interactions with other components must be considered. Multi-criteria decision making has been suggested not only for assessing sustainability (Martinez-Alier, et al. 1998) but also for dealing with environmental equity issues, since policies aimed at reaching further sustainability but focused on one single indicator might neglect the negative interactions with other environmental issues: in relation to this, it has been argued that international environmental negotiations, such as those of Climate Change mitigation, should put on the table a wider set of ecological indicators in order to avoid wrong incentives such as, for instance, those given to convert traditional cropland uses into energy uses. Doing so would imply threatening the low inequality of this type of land upon which the subsistence of many nations may depend.

Therefore, the international distribution of different ecological impacts, and their interactions, must be taken into account since they might have deep consequences for a significant proportion of humanity. Indeed, such concern becomes more challenging when, as has been shown, the bulk of the EF distribution is determined by anthropogenic causes instead of natural endowments. Specifically, EF distribution is driven mainly by the distribution of purchasing power, here approximated by GDP per capita, rather than environmental intensities among countries. In this regard, it has been shown that GDP growth not only leads to a higher natural resource demand, but also to a more unequal distribution of resources. Therefore, what determines the direction of natural resource flows, here measured by EF, is affluence. Nevertheless, population characteristics, such as the percentage of urban population or the shape of the demographic pyramid, also play a significant role in distribution by highlighting, on one hand, the importance of making cities more sustainable and, on the other, the necessity of changing consumer habits.

Since inequality does not capture the polarisation trends of a distribution, and it has been shown that inequality and polarisation may in fact move in opposite directions, several methodological techniques have been employed to allow us to determine to what extent the distribution of natural resource demand has become more polarised and thus contains inherent conflictual tensions. The empirical evidence suggests that the increase in inequality that occurred in the first years of the period analysed (1961–1980) was driven by a similar increase in polarisation between two groups of countries, creating an unsuspected link between rich and poor countries. Therefore, it could be stated that during this period, the distribution of natural resources (as measured by EF) became more unequal and also more polarised. In contrasting, the period 2000 to 2007 registered a decrease of EF inequality while the polarisation analysis suggested at the same time an increase in the polarisation of the three groups, again apparently driven by income groups (rich, emergent and poor countries). These results therefore suggest that EF distribution has not necessarily become more equitable in the period mentioned due to lower but more polarised inequality (so instead of converging to the distributional mean, countries are converging to local means).

Taken together, all these empirical findings paint quite a clear picture of how the demands for natural resources, as defined by EF framework, have been distributed during the period 1961 to 2007. As can be seen, the main implications derived from these analyses take two main forms which are not necessarily divergent. On one hand, some of the conclusions drawn from the analyses point towards using the information derived from distributional analyses as an additional tool in order to build a more sustainable and equitable world. On the other hand, the conclusions are framed under a political economy umbrella and so contribute to the discussion of unequal exchange theories and world-system analyses Thus it is clear that the existence of structural EF distribution is driven by social relationships between peripheral countries; in such cases, however, equity and also sustainability might require deep political transformation of global institutions, since one of the underlying assumptions of these theories is that inequality and polarisation is a condition of the existing world system. In this context then, it appears that the best policy recommendation that takes into account both of the dimensionalities that have come to light in this thesis, and which would foster equity and sustainability, would be income transfers between rich and poor countries i.e. claiming the historical ecological debt: this would undoubtedly generate some of the positive interaction discussed which would help to solve the global problem of resource depletion; however, such an idea would involve deep political transformation.

In any case though, these equity-oriented policies may be essential to ensure sustainability if we take into account the fact that the more popular policy recommendations, in terms of efficiency improvements in technology, its dematerialisation hypothesis, and so on, are physically constrained from the top; at some point, as Georgescu-Roegen pointed out, every economic activity is subject to the second law of thermodynamics: matter-energy enters the economic process in a state of low entropy and comes out of it a state of high entropy. In other words, from a purely physical point of view, the economic process only transforms valuable natural resources into waste (Georgescu-Roegen, 1993). In this regard, complete decoupling between economic activity and resource demand is not feasible in the long-term; consequently, such positive synergies of equity-oriented policies should become an important part of the picture of global environmental governance to somehow complement the physical constraint of technology.

7.2 LIMITATIONS AND FUTURE WORK

By analysing the international distribution of EF, this study has looked at how natural resources are being shared internationally and has pointed out several general implications in terms of global sustainability and equity. As a direct consequence of this methodology, this thesis has come up against several limitations, which need to be considered. The first thesis limitations are those linked to the limitations of the EF itself as ecological indicator. As discussed in Chapter 2, the EF is an appealing indicator for analysing the distribution of resources because of its particular method of accounting for them. However, its construction is not free from criticism. For instance, the fact that different types of land are aggregated implicitly assumes an actually infeasible type of substitutability among them. In this sense, the carbon footprint, actually a fictive type of land, has a significant weighting the whole EF: despite providing important and interesting discussions when its inequality is assessed, it might make some other results (when only non-fictive lands were considered) less clear-cut. Secondly, despite our having argued that the samples from the different empirical exercises were representative in that they accounted for the bulk of world population, world GDP and world EF, it must be kept in mind that some countries have dropped out of the samples by virtue of our considering longer periods or merging databases. Thirdly, this discussion may, in some occasions, have neglected important considerations in terms of sustainability, country endowments and countries' preferences, amongst other matters. Nonetheless, the main object of this thesis was to emphasise distributional issues rather than such considerations.

In spite of all of this, the present research may be seen as a first step towards an on-going understanding of how natural resources are being distributed around the world. It is a topic that has been tackled by ecological economics literature from different perspectives and using different methodologies: from international trade to material balances of industrial metabolism, the pollution haven hypothesis and environmental justice/racism, etc. It is necessary to continue developing the empirical strategies carried out in this thesis in order to further broaden our knowledge of this topic. Thus, we would like to expand and contrast the discussions in this essay by adding to this analysis the distributional patterns of other well-known indicators such as MFA, HANPP, CO_2, and a range of others. In this way, pieces can be added into the jigsaw of ecological distribution. Also, it would be it would be interesting to move into micro data and to apply the inequality economics tools to ecological data in order to monitor different hypotheses such as those of environmental racism. Additionally, just as welfare indices assess income inequality and income level, equity and sustainability must be also measured under the same index: in this way, it would be of great value to adapt some of the welfare indices of inequality economics into the framework drawn here in order to see be able to jointly and consistently assess the impact level and its distribution.

On balance, improved research methods continue to address the existing limitations on providing answers as to how natural resources are being shared around the world. In this thesis, we have made an attempt to contribute some of those answers. Nonetheless, the worthiest fruit of this thesis, and probably of any thesis ever written, it is not so much the answers it provides, but the new questions which emerge from reading it.

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