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SUSTAINABILITY AND HUMAN DEVELOPMENT: A PROPOSAL FOR A SUSTAINABILITY ADJUSTED HUMAN DEVELOPMENT INDEX

José PINEDA
Human Development Report Office
United Nations Development Program (UNDP), **United States**
jose.pineda@undp.org

Abstract:

This paper proposes sustainability - adjusted human development index (SHDI) in which countries' achievements in human development are penalized if there is over-exploitation of the environment. The human development approach has been a powerful framework in the past for advancing the measurement of human progress, particularly the human development index (HDI), which is a capabilities index aiming to capture to what extent people have the freedom to live substantively different lives. Today, this approach can help us make more explicit the profound connections between current and future generations' choices by offering a framework for understanding sustainability that connects inter- and intra-generational equity with global justice. The empirical analysis shows that there are important global sustainability challenges ahead since there are 90 (out of 185) countries with per capita CO_2 emissions above the planetary boundaries. There are 19 countries that lose at least one position in their HDI ranking after adjusting for sustainability. Between these countries, however, the countries that experienced the largest drop in ranking were 102 positions for the United States, 39 positions for China, and 22 positions for the Russian Federation.

Keywords: sustainability, HDI, human development.

JEL Classification: O1, O15, O5, Q5.

1. Introduction

The HDI, produced by the Human Development Report Office of UNDP, has contributed to global discussions to best measure human progress. Since its inception, it was recognized that the concept of human development is larger than what can be measured by the index. This creates policy challenges, since there may be situations in which HDI progress masks deterioration in other key aspects.

The evidence presented by Hughes et al (2012) suggests that, if no action is taken, the current and future environmental threats could jeopardize the extraordinary progress experienced in the HDI in recent decades. Moreover, projection-scenarios exercises done by Hughes et al (2012) suggest that, in an adverse "environmental disaster" scenario —envisioning vast deforestation and land degradation, dramatic declines in biodiversity and accelerated extreme weather events— the global HDI would be at least 15 percent below the projected baseline. Consequently, if no measures are taken to halt or reverse current trends, the environmental disaster scenario could lead to a turning point before 2050 in developing countries—their convergence with rich countries in HDI achievements begins to reverse.

The idea of this paper is to propose a sustainability-adjusted HDI (from now on SHDI) in which countries' achievements in human development are penalized, to reflect the over-exploitation of the environment and its relative intensity.

2. What can we learn from trends in measures of sustainability?

2.1. Aggregate measures

There is an on-going conceptual debate on how to define sustainability —mostly grouped either under weak sustainability or strong— which have implications for the measurement and assessment of sustainability trends. The main difference between both concepts of sustainability is that weak allows for substitutability across all forms of capital, while strong acknowledges that sustainability requires preserving so-called critical forms of natural capital (Neumayer, 2011). In fact, depending on which concept of sustainability is adopted the loss of the natural environment can be compensated by increased levels of other forms of capital, physical capital for example. This conceptual debate also makes it difficult to have a broadly acceptable quantitative measure of sustainability. Here we review some of the aggregate measures that are most in use, but for a comprehensive review of sustainability measures and indicators see Jha, and Pereira (2011).

Green national accounting is an approach that adjusts measures such as gross domestic product or savings for environmental degradation and resource depletion. This has been done under the System of Environmental-Economic Accounts (SEEA) framework, which contains the internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics on the environment and its relationship with the economy.

One important aggregate measure under this category is the World Bank's Adjusted Net Savings (ANS), also known as Genuine Savings, which takes the rate of savings, adds education spending and subtracts for the depletion of energy, minerals and forests as well as for damage from carbon dioxide emissions and pollution. Based on the theory developed in Hamilton and Clemens (1999), the ANS aims to measure the change in present and future well-being, by showing the true rate of savings in an economy after taking into account how the economy invests and consumes all its assets (human, natural and man-made). The measure could be used as an indicator of future consumption possibilities. Ferreira, Hamilton and Vincent (2008) use a panel data for 64 countries (1970-82) and empirically show a significant positive correlation –after adjusting by population growth- between past per capita genuine savings and future changes in per capita consumption. This measure is consistent with the weak sustainability framework, since it implies that the different kinds of capital are perfect substitutes, so that financial savings, for example, can replace a loss of natural resources or lower human capital.

The Adjusted-Net Savings measure has been criticized by many authors like Neumayer (2004, 2010, 2011), mainly because of the human capital investment and of the natural capital depreciation measures. The human capital investment (measured by current education expenditures) has been argued to be probably overestimated, because human capital is lost when individuals die. Also, health does not enter the calculus, which, according to Dasgupta (2007), makes the notion of human capital used inadequate.

The depreciation of natural capital from extraction of natural resources is calculated as the price of the resource minus the average cost of extraction (as an approximation of the marginal cost) times the resource extraction volume. According to Neumayer (2010), there are preferable methods to compute the natural resource rents, like the one described in El Serafy (1981), which includes future capital gains when valuing the depreciation of exhaustible resources. Neumayer (2010) argues that this method is preferable to the one used by the World Bank, mainly because it does not depend on the assumption of efficient resource pricing; it takes into account the country's reserves of natural resources, so that a given extraction volume has different implications for sustainability depending on the total stock available. For example, valuing natural resources at market prices can overestimate the sustainability of an economy that produces them as the resources become scarcer and thus more expensive. For more detailed discussion see Teignier-Baqué (2010). Nonetheless, Hamilton and Ruta (2009) show that the approach by El Serafy is likely to lead to artificially to low asset values and therefore to low values for the depletion of the assets, resulting in an over-estimation of the social welfare (higher ANS).

The CO_2 emission damages are valued at US$20 per metric ton of carbon in the ANS, following Frankhauser (1995). This, according to Dasgupta (2007) and others, is clearly an underestimate of the actual damage. The UNDP's Human Development Report 2007-2008, for instance, considers that an adequate carbon price would be on the range US$60-100, and the Stern Report concludes that is above US$100. As Frankhauser (1994) admits, the US$20 per metric ton of carbon value is only a rough order-of-magnitude assessment of the actual marginal costs of greenhouse gas emissions, and "care should be exercised when interpreting the figures". Tol (2008) reviews a number of studies and shows that many of them find higher costs than Frankhauser (1995).

This is particularly problematic given the uncertainty embodied in the measurement of greenhouse gas emissions and their monetary valuations. For instance, Garcia and Pineda (2011) using Tol (2008) meta-analysis showed that the number of countries considered unsustainable using adjusted net savings in 2005 would rise from 15 to 25 if we use a more comprehensive measure of emissions that includes methane and nitrous oxide as well as carbon dioxide and acknowledged monetary valuation uncertainties.

Two examples under the strong sustainability framework are the Ecological Footprint (EFP) - a measure of the annual stress people put on the biosphere— and the Environmental Performance Index.

As Neumayer (2011) explains, the carbon emissions constitute the main element in the Ecological Footprint of many countries, and in fact there is a strong and statistically significant cross-country correlation (0.85) between the per capita volume of carbon emissions and the value of the EFP. Van den Berth and Verbruggen (1999), argue that the conversion of consumption categories into land area is incomplete and that it uses a set of weights which do not necessarily correspond to social weights because they do not reflect scarcity changes. Other problems, they argued, are that the EFP denotes land area as something that is hypothetical, since the world's EFP can exceed the world's total available productive land. According to Neumayer (2011) another important objection related to the energy or carbon footprint, which constitutes the main component of the EF for many countries, is that there are much less land-intensive ways of sequestering or avoiding carbon emission from burning fuels than (hypothetical) reforestation.

From all of the aggregate measures of sustainability, only two are available for a large number of countries over a relatively long period of time: the World Bank's Adjusted Net Savings and the Global Footprint Network's Ecological Footprint. Another more recent measure is the Environmental Performance Index, developed at Yale and Columbia Universities. The EPI measures environmental performance using a set of policy targets, which are based on international treaties and agreements, standard developed by international organizations and national governments, the scientific literature and expert opinion. This composite index uses 25 indicators to establish how close countries are to established environmental policy goals — a useful policy tool, built from a rich set of indicators and providing a broad definition of sustainability. But the measure's data intensity (requiring 25 indicators for more than 160 countries) inhibits construction of a time series so we will exclude it from the analysis of trends. Another important limitation of the EPI for international comparison is that some of its data is modeled.

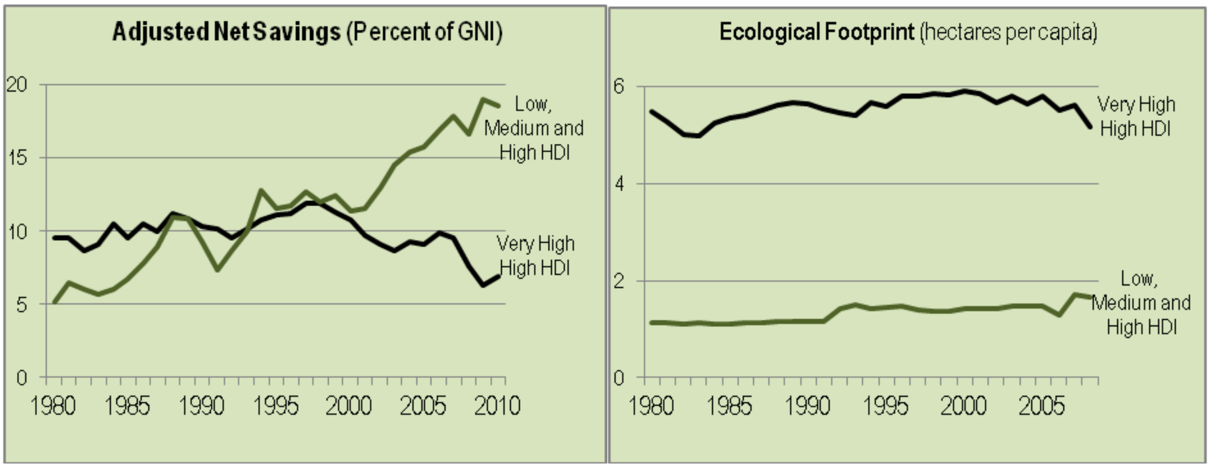

Figure 1. Aggregate measures of sustainability Adjusted net savings and ecological footprint.

Source: Based on data from World Bank (2012), Ecological Footprint Network and own calculations.

As we can see from Figure 1, the Adjusted Net Savings measure is positive for all groups according to the HDI, which means that the world is (weakly) sustainable. However, while the trend for low, medium and high HDI countries suggests that their sustainability (measured by this indicator) has improved over time, the trend of the very high HDI countries is declining.

In contrast, the sustainability trend that emerges from the ecological footprint shows that the world is increasingly exceeding its global capacity to provide resources and to absorb wastes. Given the calculations presented in the 2011 HDR, if everyone in the world had the same consumption level as people in very high HDI countries, with the current technologies, we would need more than three Earths to withstand the pressure on the environment. Current patterns of consumption and production are unsustainable at the global level and imbalanced regionally. And the situation is worsening, especially in very high HDI countries.

2.2. Specific indicators

Patterns of carbon dioxide emissions over time constitute a good, although imperfect, proxy for the environmental impacts of a country's economic activity on climate. Evidence from the 2011 HDR showed that emissions per capita are much greater in very high HDI countries than in low, medium and high HDI countries combined. It also showed that there are significant differences across groups with different HDI achievements. Today, the average person in a very high HDI country accounts for more than four times the carbon dioxide emissions and about twice the emissions of the other important greenhouse gases (methane, nitrous oxide) than a person in a low, medium or high HDI country.

Results from the 2011 HDR also showed a strong positive association between the level of HDI (especially its income component) and carbon dioxide emissions per capita. This positive relationship was also found in terms of changes over time. Countries with faster HDI improvements have also experienced a faster increase in carbon dioxide emissions per capita. This hints at the fact that the recent progress in the HDI has been associated with higher emissions putting at risk its sustainability. The discussion about the relationship between the environmental threats due to carbon dioxide emissions and achievements in human development should take into account a historical perspective, since the stock of carbon dioxide trapped in the atmosphere is a product of historical emissions. Today's concentrations are largely the accumulation of developed countries' past emissions. With about a sixth of the world's population, very high HDI countries emitted almost two-thirds (64 percent) of carbon dioxide emissions between 1850 and 2005, with the United States representing about 30 percent of total accumulated emissions.

Climate change - with effects on temperatures, precipitations, sea levels and vulnerability to natural disasters - is not the only environmental problem. Degraded land, forests and marine ecosystems pose chronic threats to well-being, while pollution has substantial costs that appear to rise and then fall with increasing levels of development. The 2011 HDR showed that nearly 40 percent of global land is degraded due to soil erosion, reduced fertility and overgrazing. Between 1990 and 2010 Latin America and the Caribbean and Sub-Saharan Africa experienced the greatest forest losses, while desertification threatens the dry-lands that are home to about a third of the world's people. Some areas are particularly vulnerable - notably Sub-Saharan Africa.

The 2011 HDR also showed that since 1970, global carbon dioxide emissions have increased 248 percent in low, medium and high HDI countries and 42 percent in very high HDI countries. The global growth of 112 percent can be broken down into three drivers: population growth, rising consumption and carbon-intensive production. Rising consumption (as reflected by GDP growth) has been the main driver, accounting for 91 percent of the change in emissions, while population growth contributed 79 percent. The contribution of carbon intensity, in contrast, was a reduction of 70 percent, reflecting technological advances. Hence, when added the individual contributions we are able to explain the 100 percent of the total growth, and results show to forces inducing more emission and only one force reducing it. In other words, the principal driver of increases in emissions is that more people are consuming more goods - even if production itself has become more efficient, on average. Although the carbon efficiency of production has improved by 40 percent, total carbon dioxide emissions continue to rise. Average carbon dioxide emissions per capita have grown 17 percent over 1970–2007.

Patterns of carbon dioxide emissions vary widely across regions and stages of development. While very high HDI countries account for the largest share of world carbon dioxide emissions, low, medium and high HDI countries account for more than three-fourths of the growth in carbon dioxide emissions since 1970. East Asia and the Pacific is the largest contributor by far to the increase in these emissions (45 percent), while Sub-Saharan Africa contributed only 3 percent, and Europe and Central Asia, 2 percent. We have data for a shorter period for methane and nitrous oxide, but in these cases too, the contribution of the East Asia and the Pacific region is particularly pronounced. Trade enables countries to shift the carbon content of the goods they consume to the trading partners that produce them. Several countries that have committed to cutting their own emissions are net carbon importers, including Germany and Japan, as are countries that have not signed or ratified global treaties, such as the United States.

In a recent study Peters *et al.* (2011) examined the "virtual carbon trade" flows, by defining a country's carbon consumption as the difference between the tons of greenhouse gases it emits ("carbon production") and the net carbon content of its imports and exports. Their estimates highlight a sizeable transfer of carbon from the poor world to the rich world", so the authors argue that "the rich world has been 'off shoring' or 'outsourcing' its emissions" to developing countries. However, divergences between the production and consumption of carbon cannot be ascribed solely to the "outsourcing" of carbon-intensive production from developed to developing economies. Relatively large carbon exports largely reflect countries' natural resource endowments, rather than a "leakage" of carbon-intensive manufacturing away from developed economies. Furthermore, the virtual carbon trade data suggests that carbon- and energy-exporting countries are also more likely to allow domestic energy prices to lag behind world energy prices, in order to subsidize domestic energy consumption resulting in lower levels of energy efficiency.

3. Incorporating sustainability into the measurement of human development

3.1. Existing alternatives

UNDP's Human Development Index is one of the most prominent indicators of well-being. However, the HDI does not take into account sustainability variables in a broader sense. Recent academic work has mainly focused on examining the potential for 'greening' the HDI so as to include environmental and resource-consumption dimensions. These works have yielded various proposals for extending the HDI to take sustainability and environmental aspects into account.

Shreyasi Jha (2009) proposed modifying the income dimension of the HDI which reflects the use of natural resources by using a more inclusive measure of wealth per capita, that includes natural capital. In this regard, the author proposes three viable alternatives: replace GDP with Net National Production; use World Bank's Total Wealth indicator; or replace GDP with a measure for Green Net National Product.

De la Vega and Urrutia (2001), on the other hand, present a pollution-sensitive human development index. This indicator incorporates an environmental factor, measured in terms of CO2 emissions from industrial processes per capita with the standard measure of human development. This composite measure penalizes the income component by taking into account the environmental costs arising from such output.

Morse (2003) proposes an environmentally sensible HDI, equal to the sum of the HDI plus the integral environmental indicator, which is the average of an indicator of the environmental state of country and an indicator of the environmental evaluation of human activities. The author emphasizes that any greening of the HDI should make sure that the basic HDI remains unmodified.

Constantini (2005) proposes to calculate a composite Sustainable Human Development Index as the simple average of the four development components: education attainment, social stability, sustainable access to resources (Green Net National Product), and environmental quality.

Other efforts include Dewan (2009) Sustainable Human Development (SHD) – in which the developmental goal is to achieve higher human development for the maximum number of people in present and future generations. Dahme *et al.* (1998) Sustainable Human Development Index -an extension for the HDI which is produced by using total material requirement- sums all material inputs (a-biotic raw materials, biotic raw materials, moved soils, water and air) required to produce a country's national output. Ramanathan (1999). Environment Sensitive HDI -a product of HDI and Environment Endangerment Index (EEI) - is computed with data on deforestation, number of rare, endangered or threatened species, a greenhouse gas emissions index and a chlorofluorocarbon emissions index.

3.2. Sustainability adjusted human developed index (SHDI)

The capability approach sees human life as a set of 'doings and beings' or 'functionings', which are constitutive of a people's being, and an evaluation of a person's well-being has to take the form of an assessment of these constituent elements. In this approach, a functioning is an achievement of a person: what he or she manages to do or to be, while a capability reflects the various combinations of functionings he or she can achieve, reflecting his or her freedom to choose between different ways of living.

This conceptual approach is very different from a utilitarian approach, since the later may fail to reflect a person's real deprivation, which is not the case for the capability approach. For example, a thoroughly deprived person might not appear to be badly off in terms of the mental metric of utility, if the hardship is accepted with no-grumbling resignation, even though he or she may be quite unable to be adequately nourished, decently clothed, and minimally educated and so on.

The HDI, an index which tries to capture capabilities, is conceptually different from a social welfare function. The key difference is that a social welfare function is designed to be maximized, while a capabilities index is meant to give a measure of the extent to which people in different countries have accesses to substantively different lives. In this sense, the capabilities approach contrasts with traditional theories of social justice, such as utilitarianism, which postulate the maximization of utility as the final goal of human action. The capabilities approach is a partial theory of well-being, which does not ambition to establish a complete description of the entire components of a good life. Instead, a capabilities index aims to tell us the extent to which people have the freedom to live substantively different lives.

Neumayer (2004) stated that sustainability is the requirement to maintain the capacity to provide non-declining well-being over time. Sustainability, unlike well-being, is a future-oriented concept. Hence, he suggested that it is better to use separate indicators to trace these two concepts and not one. We propose an approach for which indicators are calculated separately for each country, and later, based our conceptual approach which connects present and future choices; they are combined on our Sustainability Adjusted HDI.

In the Annex 2 we present tables and graphical analysis of the relationship between 6 sustainability indicators, 2 aggregate (ANS and EFP) and 4 specific indicators (per capita CO2, per capita fresh water withdrawals, percentage of extinct species over total and percentage of land with permanent crops), and the HDI.

3.2.1. Linking present and future choices

Today, we are facing an increasing need for improvements in the measurement of human progress that would not only capture the scope of the choices available to the current generation but also the sustainability of these choices. In other words, we need a measure that is able to connect present choices to future choices. Sen (2009) argues the need to achieve "sustainable freedom", which implies the preservation of human's freedom and capabilities today without "comprising capabilities of future generations to have similar or even more freedom". As was already mentioned, the basic purpose of development is to enlarge people's choices. However, as Anand and Sen (2000) explain, the basic idea of human development involves equal rights applied to all. Universalism considers unacceptable any form of discrimination based on class, gender, race, community, and also generation. A more utilitarian view can be found in Roemer (2009), who proposes that an ethically attractive approach to sustainability is one in which today we choose a consumption path that maximizes the level of the worst-off generation. The justification, he argues, is that since the birth date of a person is arbitrary, no generation should be better off than any other unless it comes without lowering the utility of the worst-off generation. This implies that future generations should receive the same kind of attention than the current generation. The same idea can be found in the Human Development Report 1994: "There is no tension between human development and sustainable development. Both are based on the universalism of life claims".

Drawing upon the Universalist principle, people should not only care about the choices that are open to them (as measured by the HDI), but also about how they were procured, and their impact on the choices available to future generations globally. An index capturing capability should focus on the measurement of human achievement and freedom in a reflective – rather than mechanical – way Sen, A. (1989). As part of this reflective process invaded in the index, achievements today should also be valued taking into account its potential impact on future generations.

Thus, progress in human development achieved at the cost of the next generations should be viewed less favorably than progress achieved in a sustainable way. It is critical that this connection is fully integrated into the analysis and measurement of human progress. One of the main dimensions affecting the connection between the choices of current and future generations is the environment, but not the only one. For example, the savings and investment decisions of current generations will affect the possibilities for command over resources by the next generations; it is also well known that parents' education has a significant positive impact on the likelihood of their children being more educated, healthier, and with a future higher command over resources. Parents have an enormous influence on their children's education for several reasons, but most importantly because they are their children's first teachers (Gratz, 2006). They also affect children aspirations, since children with more highly educated parents developed higher aspirations for their own education and on average attained more education by age 19, which in turn related to higher levels of adult educational attainment Dubow *et al.* (2009). However, as we will see later in this paper, the existence of global sustainability thresholds and externalities (within and between generations), generates a particular relevance for environmental considerations when we explicitly connect present and future generation's choices.

3.2.2. National and global sustainability and the existence of tipping points

The previous analysis implies that inter-generational equity should be measured in a way that goes beyond national borders. When measuring progress at the country level, we should care about the potential negative effect of current generation's actions on the possibilities available to future generations globally.

For the analysis of sustainability it is crucial to distinguish between the local, national and global dimensions. Measures of global sustainability examine the aggregate, although the effects of policies may vary greatly by location not only between countries but within countries as well. For example, as Dasgupta (2009) discusses, the world's poorest people often have no substitutes when their local resource base is degraded, so even if they live in a country considered sustainable, the conditions in which these disenfranchised groups live may not be. While recognizing that the local level is essential in the human development approach as well as for policy-making, the present analysis focuses on the global level owing to the pressing need to find a measurement tool that integrates both inter-generational and global equity. Most of existing aggregate measures of sustainability, as already discussed on section 2 of this paper, typically lack of this integrated framework; since they mostly focus on the country level, without taking into account the complexity of the global challenges that we are facing on this shared planet. They also tend to focus only on adjusting economic or environmental indicators in ways that do not necessarily reflect non-linearities and tipping points, and which assume near-perfect substitutability of all types of capital or not substitutability at all.

Given the need of a general framework in which the concept of human development could be enhanced in a shared planet -not only today but tomorrow- we take a global perspective of sustainability, aiming to capture up to what extent our current life style is compromising future generations' human development. It is important also to clarify that our vision is not presented as necessarily contradictory with any other particular view of sustainability, but rather as an approach that is closer and more coherent with the human development paradigm.

The impact of a particular country to the global sustainability of the earth can be measured by taking into account the relative damage that the country's actions impose on the whole world, or, in other words by including the externalities of such country's action. Most existing approaches to sustainability, particularly those that use resource accounting such as the Adjusted Net Saving, have a country focus which does not allow them to internalize the global implications of countries' behavior. In fact, such an approach does not analyze the reasons why a particular country is depleting its assets, nor does it take into account that it is as important to sustain the stock of capital as how to (globally) sustain it (Neumayer (2011, 2010)). The human development approach is a better guidance of what is important to sustain and how it should be sustained, by putting people at the centre of the analysis now and in the future through the lens of the "universalist" principle.

There is an increasing consensus about the seriousness of the threats that humanity is facing in terms of global sustainability. As the Report of the United Nations Secretary-General's High-level Panel on Global Sustainability emphasized, awareness is growing on the fact that there is an increased danger of surpassing "tipping points" beyond which environmental changes accelerate, and become self-perpetuating, making it difficult or even impossible to reverse. The existence of these threats supports a vision of non-substitutability across all forms of capital, as the strong sustainability approach argues with respect to the role natural capital plays in absorbing pollution and providing direct utility in the form of environmental amenities (Neumayer, 2010). They also support a vision in which a global perspective of sustainability is taken into consideration and not just the sustainability of individual countries in isolation.

This analysis aims for a greater integration of science into all levels of policymaking on sustainable development, as it has been the call from the Report of the United Nations Secretary-General's High-level Panel on Global Sustainability. The analysis of planetary boundaries developed by Rockström *et al.* (2009) is an important example of scientific work in this field. This approach argues that the anthropogenic pressures on the Earth System have reached a scale where abrupt global environmental changes can no longer be excluded. It proposes an approach to global sustainability based on definitions of planetary boundaries within which humanity can be expected to live safely. Transgressing one or more of these (nine) planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems. The Millennium Ecosystem Assessment and the Intergovernmental Panel on Climate Change (IPCC) are also important references that assess environmental challenges on human well-being based current knowledge, scientific literature, and data.

3.3. The loss function

In our analysis, we use a pragmatic approach between a single composite indicator and a dash-board. Indicators of sustainability are calculated separately for each country and then integrated into a single indicator, but the interpretation can be easily decomposed. The indicators to be used should preferably reflect the planetary boundaries that have been identified, for which given the current scientific understanding, there are seven quantifications: climate change; ocean acidification; stratospheric ozone; biogeochemical nitrogen cycle and phosphorus cycle; global freshwater use; land system change; and the rate at which biological diversity is lost. The two additional planetary boundaries for which they have not yet been able to determine a boundary level are chemical pollution and atmospheric aerosol loading. Because of data limitations in terms of country coverage but also time coverage, there are only a few areas for which environmental indicators with implications for global sustainability can potentially be identified at the national level for a large number of countries over time, namely carbon dioxide emissions, land use for permanent crops and fresh water withdrawals. We aim at identifying those countries that are exceeding the "*threshold*" or planetary boundary needed to achieve sustainability. As better and more comprehensive data is available other areas of sustainability can be integrated to the analysis. However, not all these indicators can easily be linked to global sustainability by just looking at their national values. This highlights the difficulties to connect the global and local dimensions in our evaluation of sustainability.

The following table illustrates the case for fresh water withdrawals, in which we have many countries exceeding the global threshold that are within their local boundary. For example, Canada has large water resources while Kuwait is water constrained, while the first is exceeding the global threshold and not its local threshold, the second is experiencing the opposite. Also, we can see how the United Arab Emirates is locally constrained by water availability and uses 20.32% of its own water resources, while using 56% of their water global threshold. A similar case could be made for land usage, particularly given the lack of information on the quality of the land that is used.

Given the challenges in the use of indicators related to water and land usage, we will focus the calculations of the loss function on the use of CO_2 emissions, for which data is relatively of good quality, it is collected regularly as a time series, and its connections to global sustainability are better understood in the literature. Of course, CO_2 is one out of many GHGs, but a very important one for which there is data for most countries and for many years.

Table 1. Countries exceeding local/global thresholds of fresh water withdrawals

Country	water per capita usage as % of global threshold	% water/own resources	Country	water per capita usage as % of global threshold	% water/own resources
Turkmenistan	544.2	100.8	Kuwait	35.7	2465
Guyana	244.4	0.7	United Arab Emirates	55.7	2032
Uzbekistan	239.8	118.3	Saudi Arabia	93.1	943.3
Kazakhstan	227.9	28.9	Libyan	75.5	718
Iraq	221.2	87.3	Qatar	25.9	455.2
Kyrgyzstan	209	43.7	Bahrain	29.7	219.8
Tajikistan	190.8	74.8	Yemen	15.7	168.6
United States	171.1	15.6	Egypt	91.9	119
Estonia	151.4	14	Uzbekistan	239.8	118.3
Canada	149.7	1.6	Israel	28.7	101.9

Source: UNDP and World Bank.

The thresholds are taken from Rockström *et al.* (2009), and Meinshausen *et al.* (2009). For CO_2 total accumulated emissions over the next 50 years likely to keep temperature change within 2°C (886 gigatons a year gives 8-37% probability of exceeding 2°C).

Despite the considerable uncertainty and estimated variance around these thresholds in the scientific community, they are an important point of reference and it is important to do extensive sensitivity analysis including as many indicators and incorporating the uncertainties around these thresholds as much as possible.

In section 4, we present results for the lower bound and upper bound of the thresholds. The tighter threshold will be used for the baseline calculations, while the more relaxed will be presented as part of the sensitivity analysis. The upper bound for CO_2 emissions is 1,437 gigatons accumulation for the next 50 with a 29-70% probability of exceeding 2°C. Note that both thresholds used are calculated by taking the global total CO_2 emissions and divide it by 50 years and the level of total global population.

The environmental variable included to calculate the loss function in the SHDI is not to be thought of as adding an extra dimension to the determination of societal well-being in a country. This point of view is in principle warranted by the very nature of the environmental variable under consideration, since this is not a factor that affects the inhabitants of the country alone, but the planet as a whole.

3.3.1. The loss function: fair share and global responsibility

In order to guide policy action, it is of critical importance to combine the best available evidence provided by science with a sound concept of social justice. The issue of climate change has an important dimension of distributive justice. Nevertheless, since there is not a consensus on which is the most appropriate equity principle; it is necessary to specify which equity criteria is applied. The measure proposed should be consistent with this equity criterion, a point that we will discuss in more detail in this section and in Annex 1.

There is a wide variety of criteria that have been used in the climate change literature, such as egalitarianism - equal use right of the environment for every person - sovereignty - equal use right of the environment at the level of nations-, ability to pay –proportionality of costs according economic well-being- and Rawl's maximin - the welfare of the worst-off country should be maximized-. A more detailed discussion can be found in Rose and Kverndokk (2008). We follow a "Rights" approach by proposing a universally equal or "fair" use of the environment, in which everyone has the same right to use the planet's natural capital and the ecosystem services it generates, subject to constraints imposed by planetary boundary considerations. This point has also been made by authors like Raworth (2012): "*Sustainability cannot be achieved without a necessary degree of fairness and justice. It appears therefore necessary to reconcile the social foundations of fairness with the planetary boundaries of a sustainable world"*.

The way in which we incorporate this "*Rights*" approach is by a proper normalization of the indicators, looking for a combination in which resources are used both fairly and sustainably. We express our relevant sustainability indicator in per capita terms (in this case we use per capita CO_2 emissions), and compare the per capita use of the environment of a citizen in a given country to the per capita threshold or maximum fair share according to the planetary boundary. This indicator enables us to capture situations in which the citizens of a country are having an excessive use of the environment by exceeding their fair share of the planetary boundaries. The important point to signal is that everyone in the planet has the right to achieve higher human development but within the limits imposed by the sustainability of our shared planet.

It is also understood that even though each individual has the same right to a fair use of the environment, country level analysis requires an additional consideration for justice depending on the relative size of the country. We call this global responsibility, and we argue that the country's weight in regards to its behavior on the excessive use of the environment should be higher, the larger its population. By incorporating the global responsibility factor we are able to combine both inter- and intra-generational equity considerations. The fair share of the planetary boundary indicates that every individual has an equal right to the environment, including those of future generations, and this is why our use of the environment should stay within these boundaries. The global responsibility increases with the size of the country with respect to the rest of the world. In this sense, it produces a balance between individual actions and a country's responsibility for the state of global sustainability.

If a country's population is exceeding its fair share of the planetary boundaries, its HDI is affected by a loss function, G^i, which is the multiplication of two components, the fair share and the global responsibility, which captures the potential negative effect of current actions of the citizens of a country on the possibilities available to future generations globally.

The loss function, G^i, is bounded between 0 and 1, for each country. The loss is 0 if the country per capita CO2 emissions are below the fair share, while a country that in isolation exceeds the maximum boundary has a loss of 1. The loss function depends on the whole world's situation (by using the thresholds defined by the planetary boundaries), but it gives a particular value for each country according to its level of per capita emissions and its share of the world's population. Also, when the per capita CO2 emissions of a country increase, all other things equal, the loss for such a country cannot decrease. Finally, in order to maintain comparability across countries, if two countries which are exceeding their fair share increase (reduce) their per capita CO2 emissions in the same amount; the relative value of their loss functions remains constant.

To summarize, we propose a Sustainability Adjusted HDI (SHDI), which imposes a loss function to a country's human development achievements given its degree of unfair use of the environment, according to the planetary boundaries, and its share in the global population as a relative size indicator. This is represented in equation 1, where we showed the SHDI for country i. See annex 1 for a mathematical representation of the SDHI.

$$SHDI^i = \left(1 - G^i\right) * HDI^i \quad (1)$$

3.3.2. Interpretation of SHDI

The standard interpretation of the HDI is that it is a capabilities index, thus intended to be a crude measure the size of the set of capabilities of the inhabitants in a country. The question is, then: what does it mean to apply a loss to the HDI of country i by $(1-G_j^i)$? In other words: How is the SHDI in equation (1) to be interpreted given environmental indicator j and country i?

Individuals in a country not only care about the multidimensional choices that are open to them (as measured by the HDI) but also about how those possibilities were procured and the impact that this will have on the choices of future generations. This implies that people care about inter-generational equity (which will now be captured by the SHDI). Thus, human development achievements at the cost of significantly contributing towards global environmental un-sustainability (and then a significant reduction of the choices available to future generations) are viewed less favorably, by the citizens of that country, than those achieved in a sustainable way. Other things equal, the citizens of a country that is within its fair share of the planetary boundaries (and thus not compromising the possibilities for future generations) have more reason to value their achievements in human development. This is a country whose citizens exhibit a higher degree of attention to inter-generational equity, and the prospects for future generations' human development achievements globally. Finally, after the loss function is calculated, the level of human development (and not just the economic activity) plays a role because the loss is multiplied with the HDI to obtain the SHDI. Thus, for two countries with similar CO2 emissions and similar populations but with different levels of HDI, the absolute penalty level will differ.

4. Results

The following tables show a statistical description of per capita CO_2 emissions that we used for the calculation of the loss function of the SHDI. We show the values for the set of countries in the HDI sample transgressing the planetary boundary (at the lower threshold, 2.66 tons of CO_2 per capita), and a secondary threshold that is the value at the upper boundary in the level of uncertainty (less restricting, 4.29 tons of CO_2 per capita).

As we can see from Table 2, for per capita CO_2 emissions there are 90 countries that transgress the lower threshold and 75 countries that transgress the upper bound out of 185. These results are consistent with the fact that CO_2 emissions are one of the three planetary boundaries that - according to Rockström *et al.* (2009) - humanity has already transgressed (along with biodiversity loss and the nitrogen cycle).

The first two column presents basis statistics related to the "Intensity" of emissions (by how much countries are exceeding the global threshold). The fifth and sixth column presents the statistics for global responsibility, while the last column presents the loss due to un-sustainability for those countries exceeding the global threshold (both the lower bound and upper bound). The 90 countries exceeding the more restrictive threshold (lower bound threshold), do so on average by more than 2.4 times. While the 75 countries exceeding the less restrictive threshold (upper bound threshold), do so on average by more than 1.4 times. These differences are reflected in the last column, where the average and maximum loss are almost twice for the more restrictive threshold. Finally, as we can see for the third and fourth column, countries did not differ much in terms of their share of population between groups, with a few countries with a relatively large share of population but the majority is small countries.

Table 2. Intensity, global responsibility and losses due to un-sustainability for per capita emissions

stats	CO_2 Emissions intensity		CO_2 Emissions global responsibility		CO_2 Emissions losses due to un-sustainability	
	above threshold (CO_2 per capita >4.29) (number of times exceeding threshold)	above threshold (CO_2 per capita >2.66) (number of times exceeding threshold)	above threshold (CO_2 per capita >4.29) (share between 0-1)	above threshold (CO_2 per capita >2.66) (share between 0-1)	above threshold (CO_2 per capita >4.29) (between 0-1)	above threshold (CO_2 per capita >2.66) (between 0-1)
mean	1.38	2.43	0.0064	0.0061	0.00567	0.0112971
s.d.	1.8	2.84	0.0282	0.0258	0.01885	0.0388
min	0.009	0.010	0.000	0.000	0	0
max	10.37	17.4	0.2408	0.2408	0.15004	0.273
N (obs.)	75	90	75	90	75	90

Using this information, we were able to generate SHDI for a total of 185 countries. The analysis shows that even though the correlation between the original HDI and the SHDI is very high (0.99), there are significant changes in ranking for some countries.

The effects of adjusting for sustainability using all indicators are higher for very high and high human development groups, which includes some oil producing countries (as can be seen from figure 2). At the lower boundary, there are 90 (out of 185) countries with per capita CO2 emissions above the planetary boundary (which implies a positive penalty).

There are 3 countries for which the penalty is higher than 5% the United States (27.2%), China (23.9%), and the Russian Federation (7.3%). The largest drop in ranking from our sample of 185 countries were 106 positions for the United States, 39~~7~~ positions for China, and 22 positions for the Russian Federation. In the following table, we present the list of countries with losses in HDI ranking after adjusting for sustainability.

Table 3. Countries positions lost with SHDI (at the lower boundary)

Country	HDI	SHDI	Loss due to Un-sustainability	Rank HDI	Rank SHDI	Number of position lost
United States	0.9099	0.6616	0.2728	4	106	102
China	0.6871	0.5223	0.2399	100	139	39
Russian Federation	0.7553	0.6997	0.0737	65	87	22
Japan	0.9006	0.8581	0.0472	11	25	14
Germany	0.9051	0.8771	0.0310	8	18	10
Saudi Arabia	0.7704	0.7537	0.0216	55	63	8
Iran (Islamic Republic of)	0.7074	0.6935	0.0197	87	94	7
Canada	0.9081	0.8848	0.0257	6	12	6
Ukraine	0.7292	0.7215	0.0106	75	79	4
Korea (Republic of)	0.8972	0.8787	0.0206	14	17	3
Poland	0.8133	0.8038	0.0117	38	41	3
Malaysia	0.7605	0.7546	0.0078	60	62	2
Turkey	0.6991	0.6953	0.0055	91	93	2
South Africa	0.6194	0.6087	0.0173	122	124	2
Netherlands	0.9099	0.9034	0.0071	3	5	2
Kazakhstan	0.7447	0.7365	0.0110	67	68	1
Mexico	0.7700	0.7620	0.0105	56	57	1
Italy	0.8738	0.8600	0.0159	23	24	1
United Arab Emirates	0.8459	0.8377	0.0098	29	30	1

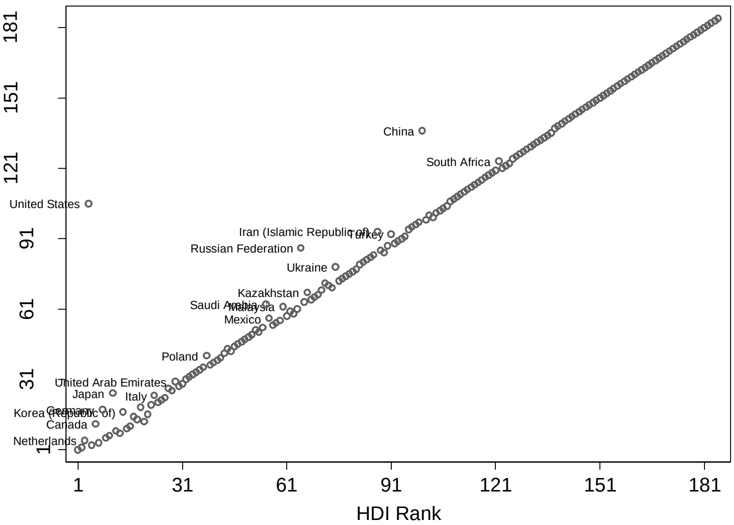

Figure 2. Rank comparison between HDI and SHDI (at the lower boundary)

Our results are based on countries contribution to global sustainability issues; however it is not necessarily the case that the countries that contribute the most to climate change will be the one mostly affected. In fact, as shown in the HDR 2011, the low HDI countries have contributed the least to global climate change, but they have experienced the greatest loss in rainfall and the greatest increase in its variability, with implications significant impact in their human development. These countries are also very likely to experience the largest losses, in terms of lower HDI, in case of an extremely adverse environmental scenario by 2050. When we check the correlation between these expected losses (more from the impact side) and the losses calculated for the SHDI (more from the contribution side), we find it to be low and negative (-0.1057). The country with expected highest loss is

Central African Republic (0.2054), while it has 0 losses for the SHDI. In the opposite situation is the United States, it has a 0.2720 loss for the HDI and a zero expected loss for 2050 due to extreme environmental challenges.

Table 4 presents the results with the less restrictive threshold generating smaller losses, and consequently, smaller variations in rankings for the 75 countries with a positive loss. The largest drop in ranking from our sample of 185 countries were 476 positions for the United States, 12 positions for the Russian Federation, and 9 positions for China and Japan.

Table 4. Countries positions lost with SHDI (at the upper boundary)

Country	HDI	SHDI	Loss due to Un-sustainability	Rank HDI	Rank SHDI	Number of position lost
United States	0.9099	0.7733	0.1500	4	51	47
Russian Federation	0.7553	0.7271	0.0374	65	77	12
Japan	0.9006	0.8808	0.0220	11	20	9
China	0.6871	0.6489	0.0556	100	109	9
Canada	0.9081	0.8955	0.0139	6	10	4
Saudi Arabia	0.7704	0.7613	0.0117	55	59	4
Germany	0.9051	0.8919	0.0145	8	12	4
Malaysia	0.7605	0.7581	0.0032	60	63	3
South Africa	0.6194	0.6145	0.0078	122	125	3
Ukraine	0.7292	0.7263	0.0040	75	78	3
Netherlands	0.9099	0.9067	0.0035	3	5	2
Iran (Islamic Republic of)	0.7074	0.7018	0.0080	87	89	2

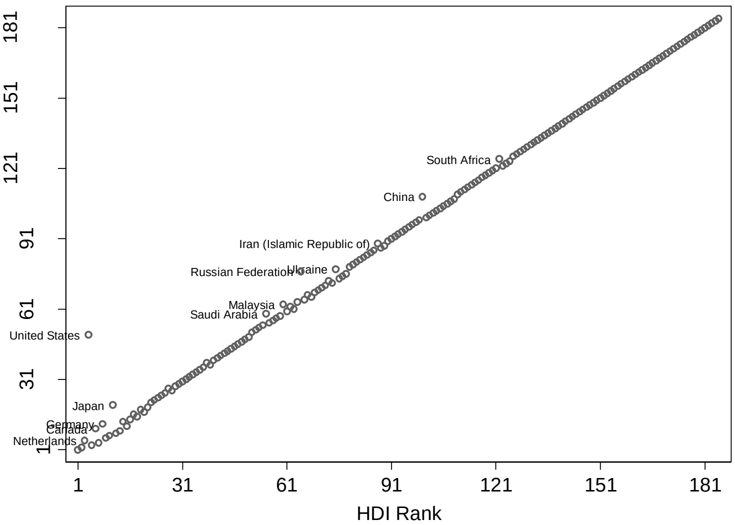

Figure 2. Rank comparison between HDI and SHDI (at the upper boundary)

Conclusions

The current challenges that human progress faces underscore the need to improve our measurement tools. We build upon this in a framework that combines the best available scientific evidence, a human centered development approach, and a social justice criterion in order to connect the choices available to current generations with those that could be available to future generations. The human development approach has been a powerful framework in the past for advancing the measurement of human progress in a multidimensional way. Today, this approach can help us make more explicit the profound connections between current and future generations' choices by offering a framework for understanding sustainability that connects inter- and intra-generational equity with global justice.

This analysis shows that there are important sustainability challenges ahead since there are 90 (out of 185) countries with per capita CO_2 emissions above the planetary boundary (taking into account the more restrictive threshold). There are 19 countries that lost at least one position in the ranking after adjusting for sustainability. Between these countries, however, there are 3 countries for which the penalty is higher than 5%: the United States (27.2%), China (23.9%), and the Russian Federation (7.3%). These countries experience the largest drop in ranking from our sample of 185 countries was 102 positions for the United States, 39~~7~~ positions for China, and 22 positions for the Russian Federation.

Finally, the relevance of this proposal for a SHDI comes primarily from the fact that it does not try to add more dimensions to the HDI or to use monetary valuations in order to adjust one of its components (mainly income), which has important practical and conceptual limitations, since it does not look at the broader set of capabilities that is captured by the HDI. This approach is not necessarily contradictory with any other particular view of sustainability (in particular those discussed in this paper), but it is closer and more coherent with the human development approach and a capability index such as the HDI.

There are significant data limitations (which must be seriously addressed) in terms of frequency and country coverage, but the results clearly show important policy implications for understanding how to capture sustainability considerations when measuring human development. We particularly consider important the connection between present and future generations within a development framework that is people-centered. We know that this is work in progress and further discussion, both conceptually and empirically (including intensive sensitivity analysis to different functional forms and alternative indicators, in addition to those presented in the annex), will help us to continue the constant search for improving our measures of human progress. So far we consider this to be the starting point of a larger research agenda, but we consider this to be a positive contribution to the broader discussion of sustainability from a human development perspective.

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References

[1] Anand, S., and Sen, A. 2000. Human Development and Economic Sustainability, World Development, *Elsevier* 28(12): 2029-2049.

[2] Baqué, M.T. 2010. Integrating Sustainability into the Human Development Framework, *Manuscript UNDP-HDRO*, New York.

[3] Constantini, V. and Monni, S. 2005. Sustainable Human Development for European Countries, *Journal of Human Development* 6(3): 329-351.

[4] Dahme, K., F. Hinterberger, H. Schutz, and E. K. Seifert. 1998. Sustainable Human Development Index: A Suggestion for Greening the UN's Indicator, *Wuppertal Institute for Climate, Environment and Energy Working Paper.*

[5] Dasgupta, P. 2007. The Idea of Sustainable Development, Sustainable Science, 2: 5-11.

[6] Dasgupta, P. 2009. The Welfare Economic Theory of Green National Accounts, *Environment Resource Economics* 42: 3-38.

[7] De la Vega, M. C. *et al.* 2001. HDPI: a Framework for Pollution-Sensitive Human Development Indicators, *Environment, Development and Sustainability* 3: 199-215.

[8] Dewan, H. 2009. Redefining Sustainable Development to Integrate Sustainability and Human Development Goals, *The International Journal of Environmental, Cultural, Economic and Social Sustainability* 5(4): 147-162.

[9] Dubow, E.F., Boxer, P., and Huesmann, L.R. 2009. Long-term effects of parents' education on children's educational and occupational success: Mediation by family interactions, child aggression, and teenage aspirations. *Merrill-Palmer Quarterly* 55(3): 224-249.

[10] El Serafi, S. 1981. Absorptive Capacity, the Demand for Revenue, and the Supply of Petroleum, *Journal of Energy and Development* 7(1): 73-88.

[11] Ferreira, S., Hamilton, K. and Vincent, J.R. 2008. Comprehensive Wealth and Future Consumption: Accounting for Population Growth. *World Bank Econ Rev* (2008) 22(2): 233-248 first published online May 25, 2008.

[12] Frankhause, S. 1994. The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach, *Energy Journal* 15(2): 157-184.

[13] Frankhauser, S. 1995. *Valuing Climate Change: The Economics of Greenhouse*, London: Earthscan.

[14] Garcia, C., and Pineda, J. 2011. Measuring the Sustainability of Countries: An Uncertainty and Sensitivity Analysis of the Adjusted Net Savings Measure. *Human Development Research Paper 12. UNDP–HDRO*, New York.

[15] Gratz, J. 2006. The Impact of Parents' Background on their Children's Education. Educational Studies 268: Saving Our Nation, Saving Our Schools: Public Education for Public Good", 1-12.

[16] Hamilton, K. and Ruta, G. 2009. Wealth Accounting, Exhaustible Resources and Social Welfare, *Environmental and Resource Economics* 42:53-64.

[17] Hamilton, K. and Clemens, M. 1999. Genuine Savings Rates in Developing Countries. *World Bank Econ Rev* 13(2): 333-356.

[18] Herrero, C., and Villar, A. 2001. The three musketeers: four classical solutions to bankruptcy problems, *Mathematical Social Sciences.*

[19] Herrero, C. 2012. "On E. Zambrano Further thoughts about the proposed SHDI. *Manuscript. Universidad de Alicante, Ivie & IAE.*

[20] Hughes, B.I. *et al.* 2012. Exploring Future Impacts of Environmental Constraints on Human Development". *Sustainability* 2012 4(5): 958-994.

[21] Jha, S. 2009. "Environmental Sustainability Measurement: A Critical Review. *UNDP-HDRO. New York.*

[22] Jha, S., and Pereira, I. 2011. Existing Measures of Sustainability: A Review. Background Paper for the 2011 *Human Development Report*. UNDP–HDRO, New York.

[23] Klugman, J., Rodríguez, F., and Hyung - Jin Choi. 2011. The HDI 2010: New Controversies, Old Critiques. Human Development Research Paper 2011/01. *UNDP–HDRO, New York*.

[24] Meinshausen, M. *et al.* 2009. Greenhouse-Gas Emission Targets for Limiting Global Warming to 2°C. *Nature* 458(30): 1158–63.

[25] Morse, S. 2003. Greening the United Nation's Human Development Index, *Sustainable Development*, 11: 183-198.

[26] Neumayer, E. 2011. Sustainability and Inequality in Human Development. *Human Development Research Paper 2011/04.* UNDP–HDRO, New York.

[27] Neumayer, E. 2004. Sustainability and Well-Being Indicators, *United Nations University – World Institute for Development Economics Research,* Research Paper 23/2004.

[28] Neumayer, E. 2010. *Weak versus Strong Sustainability. Exploring the limits of two opposing paradigms*, Cheltenham and Northampton: Edward Elgar Publishing, Third Edition.

[29] Peters, G., Minx, J.C., Weber, C.L., and Edenhofer, O. 2011. Growth in emission transfers via international trade from 1990 to 2008, *Proceedings of the [US] National Academy of Sciences*, 2011.

[30] Ramathan, B. 1999. Environment Sensitive Human Development Index: Issues and Alternatives, *Indian Social Sciences Review*, 1: 193-201.

[31] Raworth, K. 2102. A Safe and Just Space for Humanity. Can We Live within the Doughnut?, *Oxfam Discussion Papers.*

[32] Rockstrom, J. *et al.* 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*.

[33] Roemer, J.E. 2009. The Ethics of Distribution in a Warming Planet, *Cowles Foundation Discussion Paper* 1693, Yale University.

[34] Rose, A. and Kverndokk, S. 2008. Equity and justice in global warming, *Review of Environmental and Resource Economics*.

[35] Sen, A. 1989. Development as capability expansion in Readings in Human Development (2003) edited by Sakiko Fukuda-Parr and A.K. Shiva Kumar pp. 3-16. *Oxford University Press*. New Delhi, India.

[36] Sen, A. 2009. The Idea of Justice. *Cambridge, MA: Harvard University Press*.

[37] Slay, B. 2011. Carbon consumption, transition and developing economies: Sinners, or sinned against?, *manuscript*. UNDP.

[38] Stern, N. 2007. *The Economics of Climate Change – The Stern Review,* Cambridge: Cambridge University Press.

[39] Stiglitz, S., and Fitoussi, J.P. 2009. *Report by the Commission on the Measurement of Economic Performance and Social Progress.*

[40] Tol, R. 2008. The Social Cost of Carbon: Trends, Outliers and Catastrophes. Economics: The Open-Access, *Open-Assessment E-Journal* 2: 2008-25.

[41] Van den Bergh, J. and Verbruggen, H. 1999. "Spatial Sustainability, Trade and Indicators: an Evaluation of the Ecological Footprint", *Ecological Economics* 29(1): 61-72.

[42] Zambrano, E. 2012. "Further thoughts about the proposed SHDI". *Manuscript,* Orfalea College of Business, Cal Poly.

*** United Nations Development Program 1990. "*Human Development Report 1990".* UNDP-HDRO, New York.

*** United Nations Development Program 1994. *"Human Development Report 1994".* UNDP-HDRO, New York.

*** United Nations Development Program 2008. "*Human Development Report 2007/08".* UNDP-HDRO, New York.

*** United Nations Development Program 2011. *"Human Development Report 2011"*. UNDP-HDRO, New York.

*** United Nations Secretary-General's High-level Panel on Global Sustainability 2012. *"Resilient People, Resilient Planet: A future worth choosing"*. New York: United Nations.

Annex 1
Data and mathematical representation of the sustainability adjusted HDI (SHDI)

A.1.1 Data

Carbon dioxide emissions per capita (2008), Annual freshwater withdrawals, percentage of water from own resources (2009) and Adjusted Net Savings (2010) are provided by the World Bank data query17. Land area and permanent crop area (2009) is found in FAO Stats18. The Ecological Footprint (2008) is found in the Global Footprint Network latest report (2011)19. Data regarding extinct and assessed species by country is found in the International Union for Conservation of Nature (IUCN) "Red list"20.

A.1.2 Mathematical representation of the Sustainability Adjusted HDI (SHDI)

This section uses extensively inputs from Zambrano (2012) and Herrero (2012). The world has K countries. For simplicity countries are assigned a number from 1 to K, so that i=1,2, …, K. Total world population is N individuals, where

$$N=\sum_1^K N_i, \quad (1.1)$$

and Ni is the population of country i. Therefore, $\{N_i\}_{i\in k}$ is the country's population. And let us call

$$\theta_i=\frac{N_i}{N} \quad (1.2)$$

For the environmental sustainability indicator j, $\{S_j^i\}_{i\in k}$, represents the level of use of the environment for indicator j in each country i. $\bar{s}_j$ corresponds to each individual in the planet's 'maximum fair share' according to the planetary boundary for indicator j, that is, the per capita equal share of the global planetary boundary, $\bar{S}_j$, where

$$\bar{S}_j=N^*\bar{s}_j \quad (1.3)$$

We want to create a loss function with respect to the environmental sustainability indicator (or a combination of them). Therefore, let us start with a general definition of what the loss function should comprise.

Definition: A loss function,

$$G_j^i: \langle\{\bar{s}_j,\bar{S}_j\},\{N_i\}_{i\subset k},\{S_j^i\}_{i\in k},\{\theta_i\}_{i\in k}\rangle\rightarrow[0,1]_{i\in k} \quad (1.4)$$

such that each component of G is weakly increasing in S_i.

This function has three important features:

1. *It depends on the whole world's situation, and gives a particular value for each country.*
2. *It is bounded between 0 and 1, for each country.*
3. *When the pollution of a country increases, all other things equal, the penalty for such a country cannot decrease.*

[17] World Bank, "World Development Indicators", World Data Bank. http://databank.worldbank.org/ddp/home.do.
[18] Food and Agriculture Organization of the United Nations (FAO), FAOSTAT. http://faostat3.fao.org/home/index.html#DOWNLOAD.
[19] Global Footprint Network, "The data tables from the 2010 edition", Data and Results. http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_data_and_results/.
[20] The IUCN Red List of Threatened Species, "Summaries by country", Summary Statistics. http://www.iucnredlist.org/about/summary-statistics.

Now we want some other properties, in order to obtain our desired loss function. With these properties, we specify which countries are going to be positively penalized:

P1. **No penalty for good behavior**. A country that pollutes less than its share minimum fare gets no penalty: If $S_j^i \leq \theta_i \bar{S}_j$ then,

$$G_j^i\left[\langle\{\bar{s}_j, \bar{S}_j\}, \{N_i\}_{i \subset k}, \{S_j^i\}_{i \in k}, \{\theta_i\}_{i \in k}\rangle\right] = 0 \tag{1.5}$$

We can call this the exclusion property. Together with the wealth increasing it implies that all countries polluting below their minimum fair share receive no penalty.

P2. **Full penalty for full pollution**. A country that in isolation exceeds the maximum boundary receives full penalty: If $S_j^i \geq \bar{S}_j$, then

Gijsj,Sj,Niiϵk,Sjii∈k,θii∈k=1 (1.6)

This property is similar to the exhaustion property in Herrero and Villar (2001). For countries exceeding the global planetary boundary -and given weak monotonicity- all countries above that level receive full penalty.

P3. **Constant penalty trade-offs**. If two countries, 1 and 2, keeping their emissions in the intervals $[\theta_1 \bar{s}_j, \bar{S}_j]$, $[\theta_2 \bar{s}_j, \bar{S}_j]$ for indicator j respectively, increment their emissions in the same amount, the relative value of their penalties is constant (independent of the common amount they increase). That is, if $s_1'' - s_1' = s_2'' - s_2'$, then

$$\frac{G_1'' - G_1'}{G_2'' - G_2'} = k(1,2) \tag{1.7}$$

This property has been called "Direct Capability", meaning that a country that diminishes (or improves) the environmental variable by an amount of, say "D" when polluting beyond its "fair share", diminishes (improves) its capabilities in direct proportion to "D". P3 is an extension to that principle, but applied to two countries, making explicit a sort of fair treatment in the relationship between the behaviors of the penalties for different countries.

Theorem: *A penalty function satisfies P1. P2 and P3 iff*

$$G_j^i\left[\langle\{\bar{s}_j, \bar{S}_j\}, \{N_i\}_{i \subset k}, \{S_j^i\}_{i \in k}, \{\theta_i\}_{i \in k}\rangle\right] = \max\left\{0, \min\left\{1, \left[\frac{\left[S_j^i - \theta_i \bar{S}_j\right]_+}{\bar{S}_j - \theta_i \bar{S}_j}\right]\right\}\right\}$$

$$= \max\left\{0, \min\left\{1, \left[\frac{\left[s_j^i - \bar{s}_j\right]_+}{\bar{s}_j}\left(\frac{N_i}{N - N_i}\right)\right]\right\}\right\} \tag{1.8}$$

Therefore, we could also represent the loss function G_j^i for indicator j and country i, as the following:

$$G_j^i\left[\langle\bar{s}_j, \{\beta_j^i\}_{i \subset k}, \{s_j^i\}_{i \in k}\rangle\right] = \min\left\{1, \beta_j^i * \frac{\left[s_j^i - \bar{s}_j\right]_+}{\bar{s}_j}\right\} \tag{1.9}$$

Given that

$$\frac{\left[S_j^i-\theta_i\bar{S}_j\right]_+}{\bar{S}_j-\theta_i\bar{S}_j}=\frac{\left[S_j^i-\frac{N_iS_j}{N}\right]_+}{\bar{S}_j-\frac{N_i\bar{S}_j}{N}}=\frac{\left[S_j^i-\frac{N_iS_j}{N}\right]_+}{\bar{S}_j\left(1-\frac{N_i}{N}\right)}=\frac{\left[S_j^i-\frac{N_iS_j}{N}\right]_+}{\bar{S}_j}\left(\frac{N}{N-N_i}\right)\left(\frac{N_i}{N_i}\right)=\frac{\left[S_j^i-\frac{N_iS_j}{N}\right]_+}{\bar{S}_j}\left(\frac{N_i}{N-N_i}\right)\left(\frac{N}{N_i}\right)=$$

$$\frac{\left[\frac{s_j^i}{N_i}-\frac{N_i\bar{s}_j}{NN_i}\right]_+}{\frac{\bar{s}_j}{N}}\left(\frac{N_i}{N-N_i}\right)=\frac{\left[\frac{s_j^i}{N_i}-\frac{\bar{s}_j}{N}\right]_+}{\frac{\bar{s}_j}{N}}\left(\frac{N_i}{N-N_i}\right)=\frac{\left[s_j^i-\bar{s}_j\right]_+}{\bar{s}_j}\left(\frac{N_i}{N-N_i}\right) \qquad (1.10)$$

So,

$$\beta_j^i=\left(\frac{N_i}{N-N_i}\right) \qquad (1.11)$$

where c refers to the environmental sustainability indicator used, in this case carbon dioxide emissions per capita, so j=c,w,l; and, the operation $[\quad]_+$ is defined as $[x]_+=\max\{x,0\}$.

The term

$$\frac{\left[s_j^i-\bar{s}_j\right]_+}{\bar{s}_j} \qquad (1.12)$$

measures the degree or intensity of "unfair" or "excessive" use of the environment of the average citizen in each country i (as a proportion of the per capita threshold or maximum fair share). While β_j^i measures the weight given to the average unfair used by country i of the environment (measure by indicator j). Notice that our empirical implementation of the SHDI used only per capita CO_2 emissions, but the framework could be flexible to the use of more indicators.

So, G_j^i is the overall loss function that is imposed to country *i*'s human development achievements given its degree of unfair use of the environment, according to the global planetary boundary for environmental indicator j.

G_j^i is intended to be the answer to the following question: Imagine a country A, with perfect achievements in health, education, and income (thus having an HDI of "1"), and that it is between the global environmental boundaries (thus also having an SHDI of "1"). Compare this to country B, also with perfect achievements in health, education, and income but with a level of, say, its per capita CO_2 emissions are exactly twice the level of per capita maximum fair share. Country B will also have an HDI of "1" but an SHDI of (1*(1- G_c^i)). This is similar for any other indicator on j.

Given the existing research on the planetary boundaries and the available data, we are able to have measures of the fair or unfair use of the global environment.

The intuition for the value of β_j^i is that we can argue the case so that when a country, say country *i*, alone hits the planetary boundary, this will impose unacceptable negative effects on the available choices of future generations and thus in this case the country receives the maximum loss and therefore $G_j^i=1$. This will create two changes in the shape of the loss function for country *i* on environmental dimension j. The first one is that its value is 0 if the country's per capita use of the environment is lower than the fair per capita share (P1. No penalty for good behavior); and the second one is that it has a value of 1 if country's per capita use of the environment is such that it hits or exceeds the planetary boundary (P2: full penalty for full pollution). The intuition could be enhanced by the following figure.

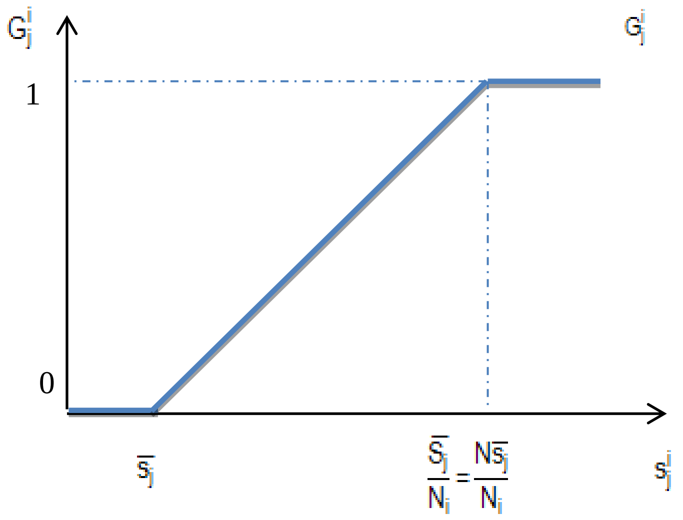

Figure A.1.1. Graphical representation of the loss function G_j^i

We can therefore give the following interpretation of the two components of G_j^i:

The term

$$\frac{[s_j^i-\bar{s}_j]_+}{\bar{s}_j} \tag{1.13}$$

is called the *fair share* of the environment, given that this is an expression that compares the per capita use of the environment of a citizen in country *i* to the per capita threshold or maximum fair share according to the planetary boundary. This terms capture when a country is having an excessive use of the environment by exceeding its fair share.

The term

$$\frac{N_i}{N-N_i} \tag{1.14}$$

is called the *global responsibility* term, given that this is an expression that gives higher weight to excessive use of the environment behavior, the larger is the population of the country. In other words, the larger a country is with respect to the rest of the world, the larger is its responsibility for the use of the environment from its average citizen.

Including levels of uncertainty in the loss function

Since the planetary boundaries are intrinsically uncertain values, we use the confidence interval that Rockstrom *et al*. (2009) use in their estimations. Therefore, the Figure A.1.1 under two possible thresholds becomes:

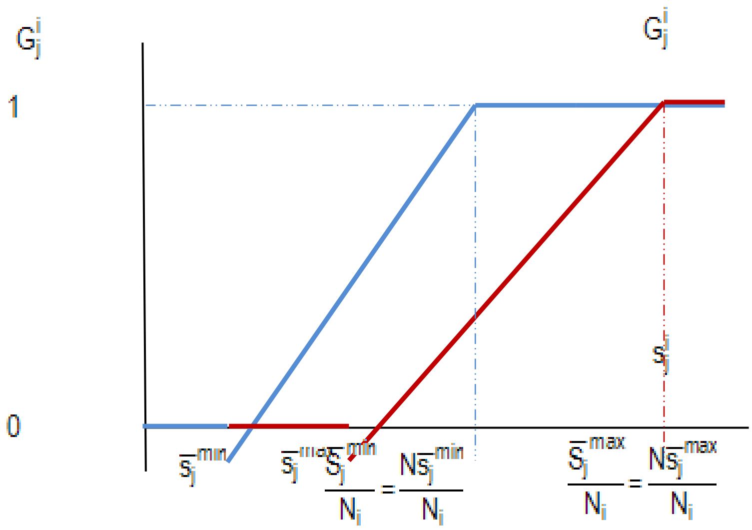

Figure A.1.2. Graphical representation of the loss function G_j^i with a minimum and a maximum planetary boundary

An interesting possibility is to define our loss function as to include the minimum per capita fair share and the maximum global planetary boundary. The graph would therefore become:

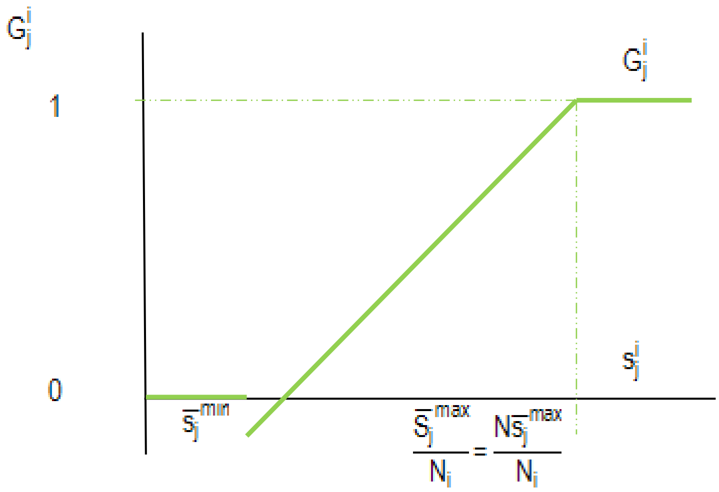

Figure A.1.3. Graphical representation of the loss function G_j^i with the minimum per capita fair share and the maximum global planetary boundary

In this case, the loss function would be defined as:

$$G_i\left[\langle\{s^{min}, s^{max}\}, \{w_i\}_{i\in N}, \{s_i\}_{i\in N}, \{\theta_{ij}\}_{i\in N}\rangle\right] \tag{1.15}$$

And the same former three properties would apply.
The loss function would look like this:

$$G_i\left[\langle\{s^{min}, s^{max}\}, \{w_i\}_{i\in N}, \{s_i\}_{i\in N}, \{\theta_{ij}\}_{i\in N}\rangle\right] = \max\left\{0, \min\left\{1, \left[\frac{[s_i - \theta_i s^{max}]_+}{s^{max} - \theta_i s^{min}}\right]\right\}\right\} \tag{1.16}$$

From this, we can derive the global responsibility term, by setting G_j^i equal to 1. Therefore, when country's i per capita consumption hits the planetary threshold, so for this country $s_j^i = \frac{\overline{S}_j^{max}}{N_i} = \frac{N\overline{s}_j^{max}}{N_i}$. Given this, β_j^i can be defined as follow:

$$1=\beta_j^i * \frac{\left[\frac{\overline{s}_j^{max}}{N_i} - \overline{s}_j^{min}\right]_+}{\overline{s}_j^{min}} \tag{1.17}$$

We can think that the maximum threshold is a value proportional to the minimum:

$\overline{S}_j^{max} = \alpha_j \overline{S}_j^{min}$, so that $\alpha_j = \frac{\overline{s}_j^{max}}{\overline{s}_j^{min}}$

In which $\alpha_j > 1$

Therefore,

$$1=\beta_j^i * \frac{\left[\frac{\alpha_j \overline{s}_j^{min}}{N_i} - \overline{s}_j^{min}\right]_+}{\overline{s}_j^{min}} \tag{1.18}$$

So,

$$1=\beta_j^i * \frac{\overline{s}_j^{min}\left[\alpha_j N - N_i\right]_+}{\overline{s}_j^{min} N_i} \tag{1.19}$$

$$\beta_{ji} = \frac{N_i}{\alpha_j N - N_i} \tag{1.20}$$

Calculation of SHDI

We can adjust the HDI by using the loss function G_j^i for indicator j and country i:

$$SHDI_j^i = \left(1 - G_j^i\right) * HDI^i \tag{1.21}$$

Giving the data limitations discussed in section 3, we focus the calculation of the loss function G^i for country i only to per capita CO_2 emissions:

$G^i = G^i_{emissions}$ With this loss function, we adjust the HDI for country i as follows:

$$SHDI^i = \left(1 - G^i\right) * HDI^i \tag{1.22}$$

Annex 2
Relationship between sustainability indicators and the Human Development Index

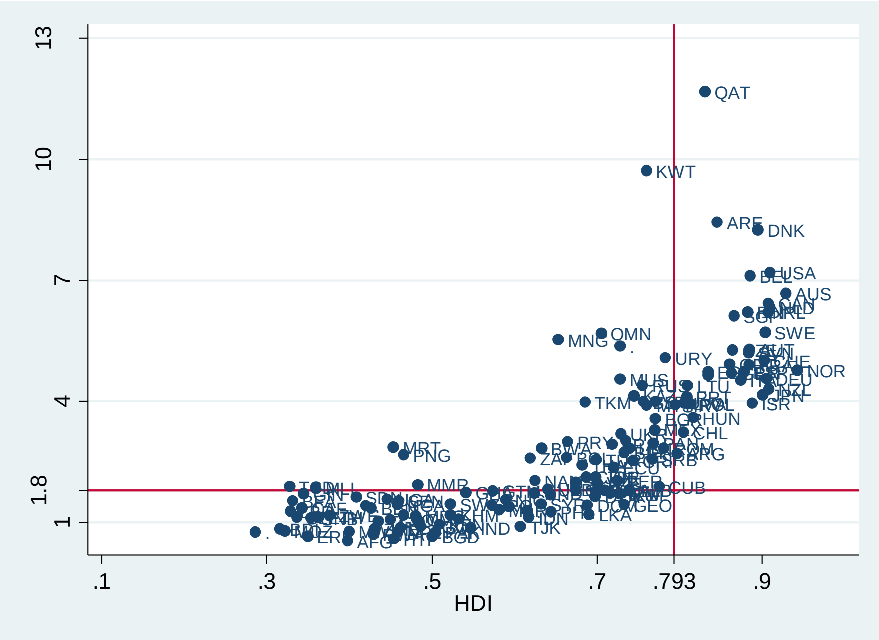

Figure A.2.1. Human Development Index and Ecological Footprint (2008)

Source: UNDP and Global Footprint Network (2011), own calculations.

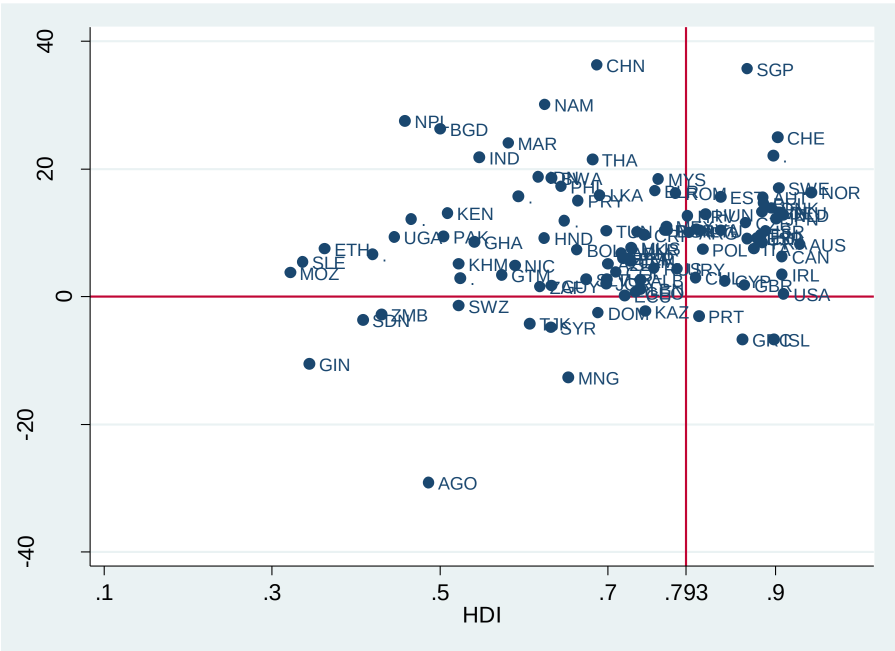

Figure A.2.2. Human Development Index and Adjusted Net Savings (2010)

Source: UNDP and World Bank, own calculations.

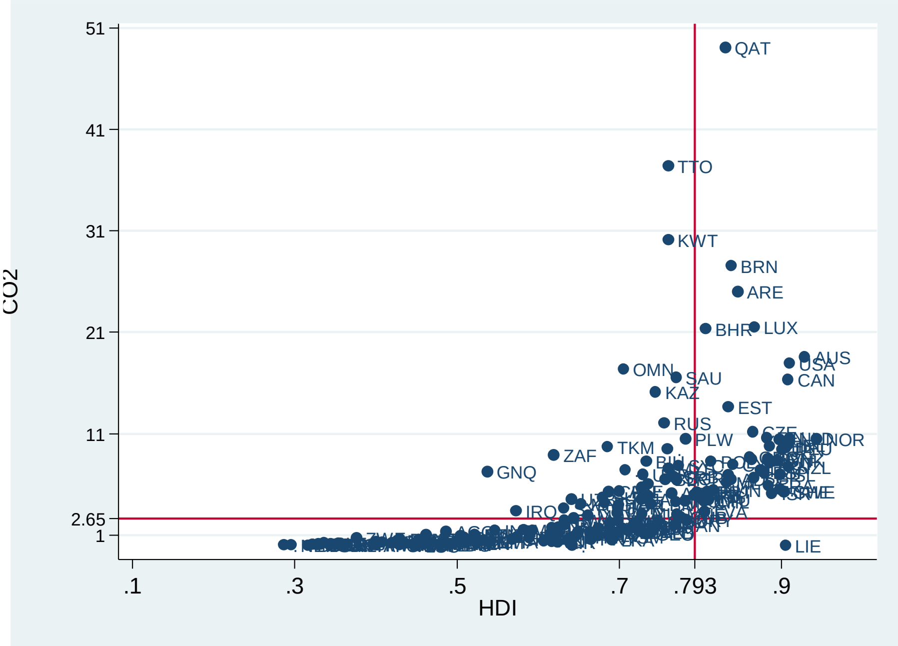

Figure A.2.3. Human Development Index and CO_2 emissions per capita (2008)

Source: UNDP and World Bank, own calculations.

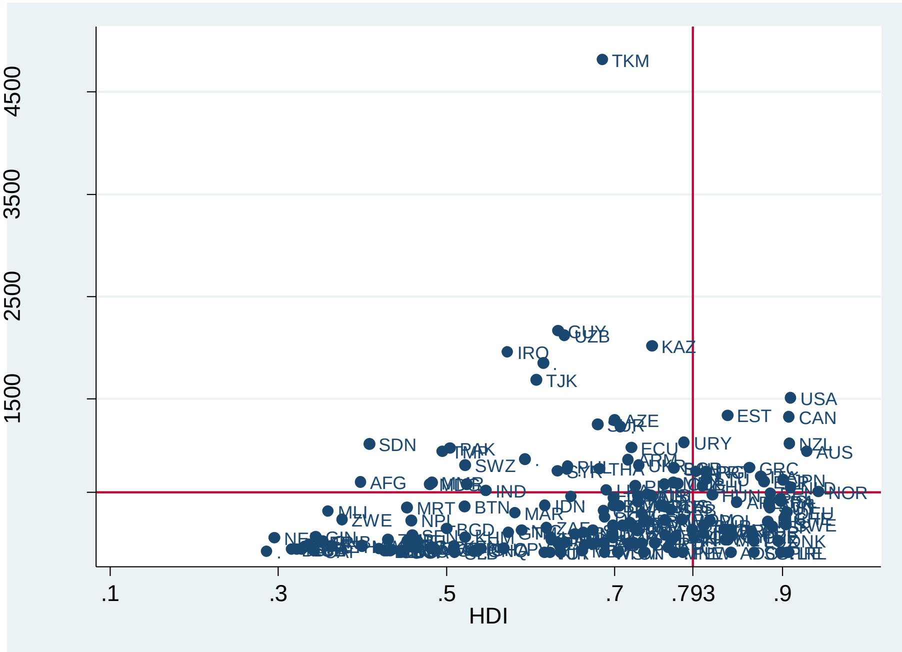

Figure A.2.4. Human Development Index and fresh water withdrawals per capita (2009)

Source: UNDP and World Bank, own calculations.

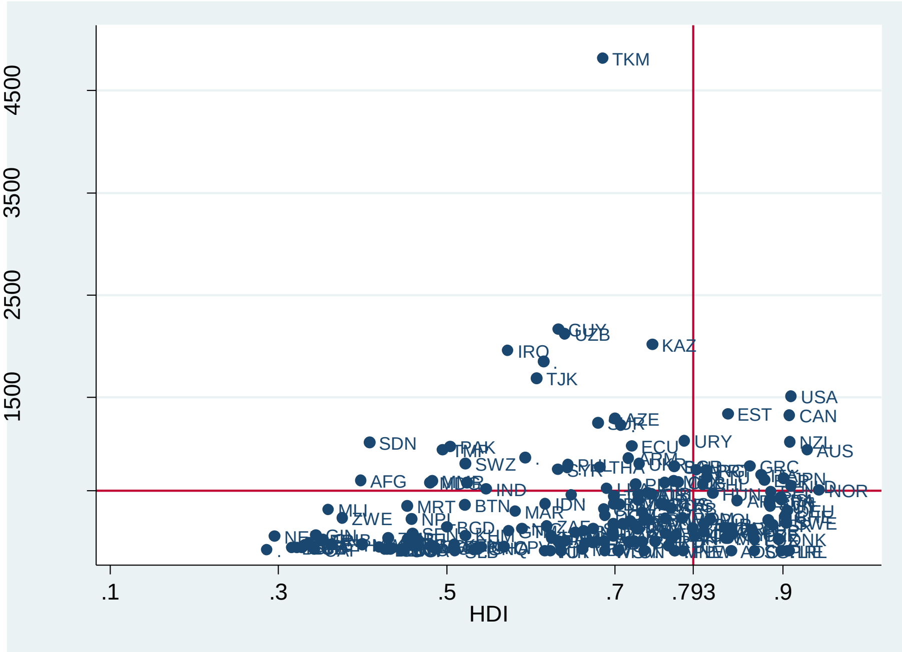

Figure A.2.5. Human Development Index and share of land with permanent crops (2009)

Source: UNDP and FAO, own calculations.

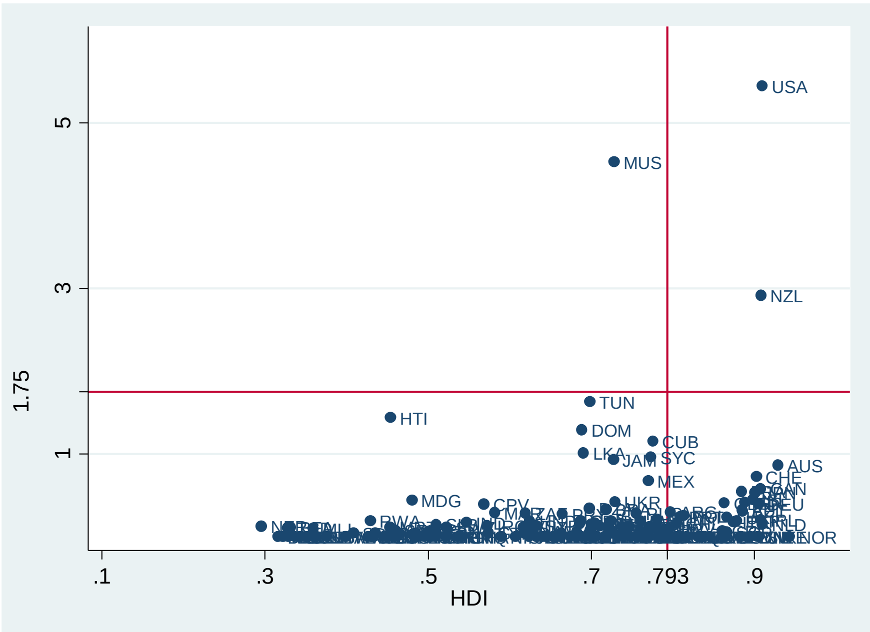

Figure A.2.6. Human Development Index and species extinct as percentage of total species (2010)

Source: UNDP and the IUCN "Red list", own calculations.

Table A.2.1 is similar to the one presented in section 4, which shows a statistical description of the relevant variables. For each one of them, we show the values for the whole set of countries in the HDI sample (column "All") and in its left side, the values for the subset of countries transgressing the planetary boundary (at the lower threshold). In the case of the Ecological Footprint (EFP) the threshold is 1.8, and for the Adjusted Net Savings (ANS) the threshold value is 0, and for the share of extinct species over total we use one standard deviation above the mean.

Table A.2.1. Selected sustainability indicators

stats	EFP		ANS		CO_2		Freshwater		Crop share		Ext share	
	above threshold (>1.8)	All	below threshold (<0)	All	above threshold (>2.66)	All	above threshold (>590.29)	All	above threshold (>15)	All	above threshold (>1.75)	All
mean	4.1	2.9	-6.98	8.64	9.13	4.87	1090.68	467.78	25.1	4.02	4.79	0.25
s.d.	1.91	2.05	7.44	9.6	7.55	6.71	688.53	556.26	10.44	6.82	1.43	0.75
min	1.8	0.54	-29.16	-29.16	2.69	0.02	604.76	8.94	15.28	0	2.92	0
max	11.68	11.68	-1.43	36.26	49.05	49.05	4818.18	4818.18	46.88	46.88	6.25	6.25
N (obs.)	82	140	13	104	90	185	49	172	11	186	4	186

Source: UNDP, World Bank and Global Footprint Network (2011), own calculations.

As we can see from the figures, the only two indicators with a strong positive and statistically significant correlation with HDI are EFP and CO_2 emissions per capita (.75 and .55, respectively). These indicators have the largest share of countries above the threshold, while the share of extinct species over total has the lowest. In fact, their figures look very similar when we just represent the common sample of countries for which both indicators exist (figure A.2.1 has an original sample of 185 countries, here the common sample is only 140 countries).

Figure A.2.7. Human Development Index, CO2 emissions per capita and Ecological Footprint (2008) (Common sample, 140 countries)

Source: UNDP, World Bank and Global Footprint Network (2011), own calculations.

Annex 3
Changes in rank of the top 10 and bottom 10 countries according to the HDI and SHDI ranks

The following tables present the top 10 countries (out of 185) according to the HDI rank and SHDI as well as the change in rankings due to the adjustment from unsustainable environmental behavior. As the tables shown, most of the changes in rankings occur at the upper portion of the distribution, while fewer changes occur at the lower part of it. This result is just consistent with the fact that relatively low human development countries contribute very little to the global environmental un-sustainability.

Table A.3.1. Changes in rank of the top 10 countries after adjusting for sustainability (lower bound)

Country	HDI	SHDI	Loss due to un-sustainability	Rank HDI	Rank SHDI	Change in rank
Norway	0.9430	0.9410	0.0021	1	1	0
Australia	0.9289	0.9106	0.0197	2	2	0
Netherlands	0.9099	0.9034	0.0071	3	5	2
United States	0.9099	0.6616	0.2728	4	106	102
New Zealand	0.9084	0.9073	0.0012	5	3	-2
Canada	0.9081	0.8848	0.0257	6	12	6
Ireland	0.9081	0.9065	0.0018	7	4	-3
Germany	0.9051	0.8771	0.0310	8	18	10
Sweden	0.9038	0.9026	0.0014	9	6	-3
Switzerland	0.9025	0.9016	0.0011	10	7	-3

Table A.3.2. Changes in rank of the top 10 countries after adjusting for sustainability (upper bound)

Country	HDI	SHDI	Loss due to un-sustainability	Rank HDI	Rank SHDI	Change in rank
Norway	0.9430	0.9420	0.0010	1	1	0
Australia	0.9289	0.9188	0.0109	2	2	0
Netherlands	0.9099	0.9067	0.0035	3	5	2
United States	0.9099	0.7733	0.1500	4	51	47
New Zealand	0.9084	0.9079	0.0005	5	3	-2
Canada	0.9081	0.8955	0.0139	6	10	4
Ireland	0.9081	0.9073	0.0008	7	4	-3
Germany	0.9051	0.8919	0.0145	8	12	4
Sweden	0.9038	0.9035	0.0003	9	6	-3
Switzerland	0.9025	0.9023	0.0002	10	7	-3

Table A.3.3.Top 10 countries for HDI and SHDI

Country	Rank HDI	Country	Rank SHDI (lower bound)	Country	Rank SHDI (upper bound)
Norway	1	Norway	1	Norway	1
Australia	2	Australia	2	Australia	2
Netherlands	3	New Zealand	3	New Zealand	3
United States	4	Ireland	4	Ireland	4
New Zealand	5	Netherlands	5	Netherlands	5

Country	Rank HDI	Country	Rank SHDI (lower bound)	Country	Rank SHDI (upper bound)
Canada	6	Sweden	6	Sweden	6
Ireland	7	Switzerland	7	Switzerland	7
Germany	8	Iceland	8	Hong Kong, China (SAR)	8
Sweden	9	Hong Kong, China (SAR)	9	Iceland	9
Switzerland	10	Denmark	10	Canada	10

Results with combined thresholds (minimum per capita fair share and maximum global planetary boundary)

Table A.3.4. Top rank positions lost with SHDI (combined thresholds)

Country	HDI	SHDI	Loss due to un-sustainability	Rank HDI	Rank SHDI	Number of position lost
United States	0.9099	0.7595	0.1652	4	59	55
China	0.6871	0.5941	0.1354	100	126	26
Russian Federation	0.7553	0.7213	0.0451	65	81	16
Japan	0.9006	0.8746	0.0289	11	20	9
Canada	0.9081	0.8937	0.0158	6	11	5
Germany	0.9051	0.8879	0.0190	8	12	4
Turkey	0.6991	0.6968	0.0034	91	95	4
Saudi Arabia	0.7704	0.7601	0.0133	55	58	3
Malaysia	0.7605	0.7569	0.0048	60	63	3
Ukraine	0.7292	0.7245	0.0065	75	78	3
Iran (Islamic Republic of)	0.7074	0.6989	0.0121	87	90	3
Netherlands	0.9099	0.9059	0.0044	3	5	2
South Africa	0.6194	0.6128	0.0106	122	124	2
Italy	0.8738	0.8653	0.0097	23	24	1
Poland	0.8133	0.8075	0.0072	38	39	1
Venezuela (Bolivarian Republic of)	0.7351	0.7326	0.0034	72	73	1

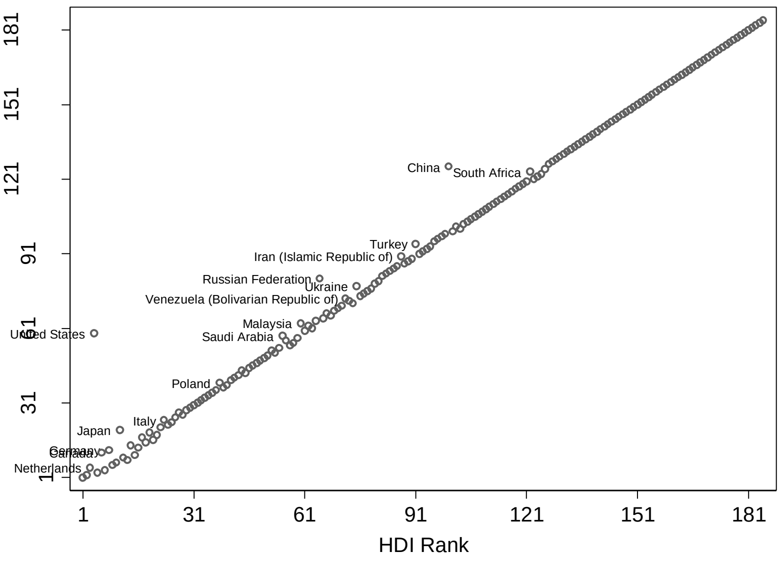

Figure A.3.1. Rank comparison between original HDI and SHDI (combined thresholds)

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