

The concept of ecological debt: some steps towards an enriched sustainability paradigm

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Received: 4 June 2009 / Accepted: 23 October 2009 / Published online: 6 November 2009
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Abstract In this paper, we elaborate on the concept of ecological debt. Starting from the enriching environmental justice perspectives, this grass-roots concept has to offer to sustainability discourse, a broad conceptual discussion is presented resulting in a working definition for ecological debt. In elaborating on this definition, we try both to accommodate these enriching perspectives and to offer a more robust conceptualisation that is applicable in international sustainability discourse. Also, a scientifically sound methodology is presented which allows quantifying different aspects of ecological debt. Finally, both the conceptual analysis as well as the quantification method is applied to the case of climate change.

Keywords Ecological debt · Equity · Sustainability · Developing countries · Environmental justice · Carbon debt

1 Introduction

Sustainability, literally meaning the ability to be maintained at a certain rate or level, is a future-oriented concept. In its focus on a “development that meets the needs of the present without compromising the ability of future generations to meet their own need”, sustainable development indeed seems characterised by the absence of a historical perspective (Brundtland 1987). This lack of historical sensitivity can be observed in all the major sustainability debates, ranging from fishing over agriculture and deforestation to climate

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change. Indeed, looking at climate change as one of the foremost and encompassing sustainability issues of contemporary society, the lack of a genuine historical perspective becomes clear. Whereas the future-oriented focus is clearly present with global negotiations and an immense amount of research regarding necessary emission reductions, a historical perspective is only marginally present, the Brazilian proposal being one of the exceptions dealing with historical responsibility in distributing emission reductions. It is not a coincidence that developing countries try to push this perspective: it is indeed becoming clear that developing countries will suffer most from eventual climate change impacts. This also points to the main reason why a historical perspective on sustainability may be useful and even necessary as it opens up a space in which unsustainable realities, often hidden from the industrialised Western perspective, can be revealed and discussed. The concept of ecological debt, as it will be elaborated here, will be shown to provide an adequate historical scope to open up the debate on a manifold of unsustainable realities faced by “real people in real places” (Blowers 2003).

2 Opening up new perspectives on sustainability

It is well documented how, through the colonial period and the industrial revolution up till now, natural resources have been flowing from South to North and how this was often accompanied by plundering, ecological damage and social oppression. Recent cases that have been gathered under the campaigning concept of ecological debt include Texaco in Ecuador, Union Carbide in Bhopal, Shell in Nigeria over mine exploitations in Peru, South Africa and the Philippines, to shrimp farming in Thailand, biopiracy in Costa Rica, or dumping of toxic waste in India (e.g. Bravo and Yáñez 2003). The general pattern is often identical: as a result of industrial resource extraction (oil exploration, mining, farming, fishing, ...), multinational companies, often hardly restrained by governments, leave a ravaged land behind, with all its consequences for the local population. These practices have been facing increasing resistance from local and (mainly) rural communities in the South. The latter, as diverse as widespread, have recently been gathered under the denominator of “ecologismo popular” or “environmentalism of the poor” (Martinez-Alier 2002). With respect to the present analysis, it is interesting to observe that for several of these groups, the concept of ecological debt seems to offer an adequate language through which they can frame their struggle and formulate their demands.

The unofficial history of ecological debt traces its origins back to the beginning of the nineties and publications of the Chilean NGO Instituto de Ecología Política (IEP) (Robledo and Marcelo 1992). IEP presented the concept in the context of ozone depletion, concentrating on the costs related to the resulting health problems such as skin diseases and cancers in Southern Chile. In 1992, the concept made its way into the Debt Treaty, one of the alternative treaties formulated by NGOs and grass-roots groups during the UNCED conference (Pollard 1992). In this treaty, the foreign financial debt of developing countries is described as the “most recent mechanism of the exploitation of Southern peoples and the environment by the North”. It further points out the “existence of a planetary ecological debt of the North; this is essentially constituted by economic and trade relations based on the indiscriminate exploitation of resources, and its ecological impacts, including global environmental deterioration, most of which is the responsibility of the North ...” Currently, several NGO networks have adopted ecological debt as their main campaigning theme. The most important are the Southern Peoples Ecological Debt Creditors Alliance (SPEDCA), which groups NGOs from

Southern countries (the “creditors”), the European Network for the Recognition of the Ecological Debt (ENRED), which groups European NGOs and individuals (the European “debtors”), and Justicia Ambiental, Deuda Ecológica y Sustentabilidad (JADES), which is a discussion group between creditors and debtors. In this NGO-led discourse, several definitions of ecological debt are used alongside each other: definitions change over time and some are more far reaching than others. Bravo and Yáñez (2003) present a collection of essays after several years of campaign, and here ecological debt is defined as “the accumulated, historical and current debt, which industrialised Northern countries, their institutions and corporations owe to the peoples and countries of the South for having plundered and used their natural resources, exploited and impoverished their peoples, and systematically destroyed, devastated and contaminated their natural heritage and sources of sustenance” (Donoso 2003, p. 13). According to SPEDCA, the ecological debt includes amongst other things: the historical debt from plundering, destruction, devastation, slave labour and cultural annihilation in the South during the colonial era; debt from the social, environmental, economic and cultural impact of the extraction of natural resources (oil, gas, minerals, marine and forest life); debt from the intellectual appropriation and use of traditional knowledge through biotechnology by agro-business, first in the Green and now in the GMO revolution; debt from the degradation of land, water and air through monocultures, putting the food and cultural sovereignty of communities at risk; debt through pollution of the atmosphere and the appropriation of carbon absorption capacity of oceans, vegetation and forests; debt for the damage caused by chemical, nuclear and biological arms production and depositing of toxic substances. Ecological debt is thus a demand for justice, for understanding the causes of wealth and poverty, for identifying responsibilities and fighting against impunity, for stopping the destruction of Southern lives (Donoso 2003, p. 14).

The picture that emerges from this introductory description is one of an organic growth: ecological debt is a concept arising from and corresponding to unsustainable realities faced by “real people in real places”. The latter are often left out of the future-oriented sustainability equation because these issues are related to historically grown patterns. One of the main influences a concept such as ecological debt can have in this respect is that it serves as a lens through which North–South relations and sustainability issues can be seen in a different light. The concept has mainly been developed by Southern NGOs and peoples’ movements and as such, ecological debt is a way of looking at North–South relations and sustainability issues from a Southern peoples’ point of view. In that way, it becomes a potentially powerful tool for reframing and reorienting national and international sustainable development policies. Three changes of perspective are briefly discussed here: bringing an historical perspective to the sustainability debate; opening a new perspective on debtor–creditor relations in contemporary international politics and uniting comparable experiences of Southern peoples.

- First, ecological debt adds an historical dimension to the sustainability debate. As already mentioned, the Brundtland Report definition of sustainable development (Brundtland 1987) is characterised by the absence of an historical perspective. Ecological debt draws attention to how the present situation has grown out of the often violent and unjust past. It points to the collective responsibility of industrialised countries and companies in relation to socio-ecological problems. The climate debate is one of these examples where an historical perspective clarifies how developing countries are responsible for only a minor part of global emissions, while they will suffer the most from climate change impacts (Munasinghe and Swart 2005).

- Secondly, the ecological debt lens reveals a reversal in creditor and debtor positions in international relations. From an industrialised country perspective, people are used to thinking in terms of developing countries as debtors with a huge financial debt. The concept of ecological debt shows that countries can be in a creditor–debtor relationship on the basis of physical–ecological relations. Through the concept of ecological debt, industrialised and developing countries stand in another relationship: the North as debtor, the South as creditor. This is eloquently expressed in one of the slogans of the NGO campaigns, “Who owes whom?”, which summarises the central idea in the debate about ecological versus external debt. Ecological debt thus provides a different look, not only at the legacy of the colonial period, but also at “the era of development” after World War II: much of this development has been debt-driven, not only in financial terms (South–North) but certainly in ecological terms as well (North–South). It further testifies that international trade, generally considered to be one of the driving forces behind development, has often not been mutually beneficial, neither in monetary terms nor in ecological terms (Martinez-Alier 2002).
- Thirdly, looking at the groups that are involved in the campaigns and the examples of ecological debt that have been collected, it is clear that ecological debt offers a language and a discourse that is able to articulate common concerns and experiences from local groups all over the South and to unite them under the new label, *ecological debt*. The term ecological debt seems to be able to articulate the common concerns visible in, for example, protest against shrimp farming, mining, oil and gas exploitation, and of course the overuse of the absorption capacity of the atmosphere in the climate debate. In that way, it also challenges the popular notion in sustainable development discourse that poor people in the South are not interested in protecting their environment, and that therefore more development is the answer to the sustainability crisis.

In summary, these new perspectives on past and present relations between countries are some of the important “eye-openers” of ecological debt. Southern movements sometimes formulate this as “empowerment” of the South and Southern peoples in international relations. Through these new perspectives, the interpretation of sustainable development is enriched with typical environmental justice characteristics: an analysis of power relations and patterns that reproduce existing inequalities is added, with questions such as “who gets what, how much and why?”; a rights discourse is added, where the right to a clean and safe environment is defined as a human right; and a grass-roots perspective is added with a shift in perspective away from abstract sustainable development policies to the lives and problems of “real people in real places”.

In order to enable ecological debt to grow and stabilise into a powerful and enriching sustainability paradigm able to transcend its status of a mere campaigning instrument, it is in our view necessary to provide it with an adequate conceptualisation accommodating the richness of the different perspectives mentioned earlier. In this paper, we will first of all propose a broad conceptual view on ecological debt that will not only take into account the grass-roots perspectives mentioned earlier but moreover enable these perspectives to be applied in a coherent manner. Building on this broad definition, we will then present a scientifically sound methodological foundation allowing for quantification. In the possibility of quantification, however, lurks the danger of narrowing down a strong, meaningful and telling concept to an objectified number. In its obsession with scientific proof, Western society all too often reduces complex human realities to numbers, ruining any chance for these realities to “speak”. In order to give ecological debt the chance to grow into a really

new perspective on sustainability, it is of utmost importance that its “speaking power” does not get narrowed down by the Western, ‘scientific sieve’ (Goeminne and Paredis 2009). As the world and its problems do not present themselves in scientific facts, it is indeed important to see how ‘matters of concern’ are—through a ‘scientific sieve’—always already framed into ‘matters of fact’.¹ It is therefore disappointing to observe that nearly all of the few available scientific papers that elaborated on the concept of ecological debt have left aside a thorough conceptual discussion and concentrated on one particular interpretation that enables quantification (Azar and Holmberg 1995; Jenkins 1996; Smith 1996; Byrne et al. 1998; Torras 2003). The same can be said about the latest Living Planet Report (Hails 2006) that explicitly uses the concept of ecological debtor (and creditor) for countries having an ecological deficit; the latter being defined as the amount by which a country’s ecological footprint exceeds the locally available ecological capacity. A recent example of this urge to quantify can be found in a paper by Srinivasan et al. (2008). Here, ecological debt is straightforwardly quantified as “the environmental costs of human activities over 1961–2000 in six major categories”. Although it is briefly admitted that “valuing environmental and human health impacts is conceptually, ethically and empirically fraught”, the whole paper nevertheless deals with the quantification method, thrusting aside all these conceptual, ethical and empirical aspects which make out the heart of the concept of ecological debt. As we have mentioned, ecological debt is a language that allows local groups to speak up and voice their concerns. So, if we present a methodology to quantify ecological debt, this should be regarded as an attempt to broaden this language with a numeraire, not as a clear-cut scientific theory nailing down complex lifeworld problems to bare numbers.

The present analysis will focus on the concept of ecological debt of countries or what might be termed public ecological debt. This paper does not occupy itself with the ecological debt of other entities, such as companies, which might be termed private ecological debt. As a consequence, definitions, methodologies and calculations only refer to countries. In our view, the main potential for this concept as a new and enriched sustainability paradigm is first of all to be found in this sphere of application. As has happened with the ecological footprint concept, a second sphere of application may be found in applying ecological debt analysis to companies, individuals and even consumer goods. It is our view that the conceptual and methodological basis presented here can be translated in accordance in a rather straightforward way.

3 Towards a definition of ecological debt

In elaborating on a founding definition of ecological debt, it is important to retrieve the core meaning of the concept: what are the essential elements to be covered? Moreover, this definition should accommodate the environmental justice perspectives stemming from the organic growth described earlier. Also, if these new perspectives embraced by ecological debt are to be explored to their full potential, the definition needs to be expressed in a language acceptable in international political and negotiation discourse. Furthermore, such

¹ In contrasting ‘matters of concern’ with ‘matters of fact’, we gratefully borrow from Latour’s terminology (Latour 2004). In Goeminne (2009), one of the authors elaborates on an epistemology of ‘engaged knowledge’ showing how sustainability issues could be adequately framed as ‘matters of concern’ engaging experts and lay people in a participatory approach.

a general definition should allow further refinements, dependent on the context where ecological debt is applied.

As a starting point, it is interesting to compare the development of the concept of ecological debt with that of ecological footprint and environmental space, well-established concepts in sustainability discourse. The difference between ecological debt on the one hand and ecological footprint and environmental space on the other can be characterised as bottom-up versus top-down development. Ecological footprint and environmental space have been developed by scientists and then enthusiastically adopted by NGOs, and to some extent they have been made into the subject of political debate. With ecological debt, the development of the concept has almost been the other way round. As mentioned, the concept has primarily been developed through NGO-campaigning. It builds in particular on the work of Southern NGO's and campaigners (see e.g. the collection of essays in Bravo and Yáñez 2003), although not exclusively. Important contributions have also come from Friends of the Earth (McLaren 2003) and New Economics Foundation (Simms 2005). But in contrast to the ecological footprint, the concept of ecological debt in these campaigns was developed with only limited scientific analysis underpinning the claims.²

As already mentioned, most of the research published in scientific journals (Azar and Holmberg 1995; Jenkins 1996; Smith 1996; Byrne et al. 1998; Torras 2003; Hails 2006; Srinivasan et al. 2008) focuses on a particular interpretation allowing for quantification and has not been used in NGO campaigns, nor does this literature refer to the grass-roots interpretation of the concept. In this respect, the work of the Spanish ecological economist Joan Martinez-Alier constitutes an important exception. Building closely on his ties with grass roots and campaigning movements on ecological debt, he has mainly elaborated on a substantive analysis of the concept. Martinez-Alier (2002) states that ecological debt is an economic concept that arises from two separate ecological distribution conflicts. According to Martinez-Alier, the first cause of ecological debt is ecologically unequal exchange, or the fact that exports of raw materials and other products from relatively poor countries are sold at prices that do not include compensation for local or global externalities. Ecologically unequal exchange is responsible for the following components of ecological debt (Martinez-Alier 2002):

- The (unpaid) costs of reproduction or maintenance or sustainable management of the renewable resources that have been exported: for instance, the nutrients incorporated in agricultural products.
- The costs of the future lack of availability of destroyed natural resources: for instance, the oil and minerals no longer available, or the biodiversity destroyed.
- The compensation for, or the costs of, reparation (unpaid) of the local damages produced by exports (for example the sulphur dioxide of copper smelters, the mine tailings, the harm to health of flower exports and the pollution of water by mercury in gold mining) or the present value of irreversible damage.
- The (unpaid) amount corresponding to the commercial use of information and knowledge on genetic resources, when they have been appropriated gratis (...).

The second cause for ecological debt according to Martinez-Alier is the fact that rich countries make a disproportionate use of environmental space or services without payment, and even without recognition of other people's entitlements to such services. Lack of

² This is a mere observation and contains no normative ground. We do not intend that ngo-campaigning has to be based on scientific analysis or that scientific support to ngo-campaigning should be expected.

payment for environmental services and disproportionate use of environmental space are responsible for the following components of ecological debt (Martinez-Alier 2002):

- The (unpaid) reparation costs or compensation for the impacts caused by imports of solid or liquid toxic waste.
- The (unpaid) costs of free disposal of gas residues (carbon dioxide, CFC and so on), assuming equal rights to sinks and reservoirs.

Based on this brief review of the scientific literature available, and recalling the different perspectives stemming from the concept's organic growth, it is our view that the core meaning of ecological debt can be covered in the description of the two following processes. The first is that relations between countries can be described in several ways and that the physical–ecological relation has often been neglected. In accumulating wealth, countries and actors within these countries do not only use their own natural resources, but also make use of natural resources elsewhere. Since colonial times, this relationship has been constantly in favour of the current industrialised nations. The wealth of industrialised nations has been built extensively on natural resources from elsewhere, in particular (but not exclusively) from current developing countries. This specific feature of wealth accumulation has caused severe disruptions to ecosystems in developing countries. A second process is that in accumulating wealth countries and actors within these countries do not only cause ecological damage elsewhere, but also increasingly put pressure on ecosystems and ecosystem services, even if no immediate damage is visible. Particularly industrialised countries have been responsible for this pressure until now. The use of these ecosystems and ecosystem services limits their use by other countries and by future generations and as such has far reaching social and economic consequences. A typical example is the use of the sink capacities of the atmosphere, which are used in such quantities by industrialised countries that the emission possibilities of other countries are severely limited. In our view, these formulations come close to the essential processes made visible by ecological debt. Based on this core meaning, and recalling the different perspectives that should be accommodated, the following definition is proposed (Paredis et al. 2008):

“The ecological debt of country A consists of

- (1) the ecological damage caused over time by country A in other countries or in an area under jurisdiction of another country through its production and consumption patterns, and/or
- (2) the ecological damage caused over time by country A to ecosystems beyond national jurisdiction through its consumption and production patterns, and/or
- (3) the exploitation or use of ecosystems and ecosystem goods and services over time by country A at the expense of the equitable rights to these ecosystems and ecosystem goods and services of other countries or individuals.”

This phrasing has been carefully chosen through discussions with experts in international law and multilateral agreements. For instance, “country” is not further defined so that in principle, all countries can be ecological debtors or creditors (this issue is presently gaining in importance, considering, for example, the relations between China and some African countries). An area under the jurisdiction of another country means an area in which a country can legally exercise sovereignty or sovereign rights, such as the territorial sea and the exclusive economic zone. “Beyond national jurisdiction” refers to those areas in which no state can exercise sovereignty or sovereign rights, such as the high seas and space. Ecological damage is caused “over time”: this explicitly adds the historical dimension. The terminology “ecological damage” is preferred over “environmental

damage” because in judicial interpretations of the majority of environmental liability conventions and subsequent case law, where possible the content of “environmental damage” is restricted to compensation and restoration of traded natural goods (e.g. fish for consumption). This would imply that compensation for damage to non-economic, non-traded goods based on economic techniques to assess the value of goods or services that have no market value, is not feasible within the concept of “environmental damage.”

In spite of the carefully chosen phrasing of this definition, a lot of questions, normative as well conceptual, remain to be answered if it is to be applied to concrete cases. One might e.g. ask what the exact meaning is of equitable rights to ecosystems and what the implications are of such a statement. Or which allocation and quantification methodology can be used to trace ecological damage, keeping in mind the complex value chains that make it difficult to link consumption in other countries to ecological damage in country A. Therefore, the next section discusses several questions that have to be answered before the concept can be applied in a case such as the carbon debt. In discussing the normative underpinnings, rather than closing them down, we want to point to the inherent political dimension of this concept. As already mentioned, it is exactly here that a major strength of ecological debt can be found: rather than giving definite scientific answers, ecological debt opens up new perspectives, raising genuine normative, i.e. political questions about human development issues (Goeminne and Paredis 2009). Depending on how these kind of questions are answered, the concept can be refined in several ways, and thus different operationalisations of ecological debt are possible. An overview of possible refinements is given in Table 1. In Sect. 5, we apply the conceptual framework developed here to the case of climate change. This will illustrate the relevance and need of deliberating the normative and conceptual questions presented later in concrete cases.

3.1 Does each alteration of the environment create ecological debt, or what is ecological damage?

Trade between countries almost always has a physical–ecological component, so it will result in an alteration of the environment in both countries. The crucial question, however, is when such an alteration becomes a problem or put equivalently: how can environmental problems or ecological damage be defined? Environmental problems are socially constructed, meaning that they are the result of a process in which actors interact to decide what these problems are, how they should be judged and how they might be solved. Different actors will try to propagate their version of reality (their discourse), which means that, depending on time, location, position and group, different environmental problems will be formulated. It is no coincidence that the concept of ecological debt originates from Southern NGOs and critical scientists. For most inhabitants of industrialised countries, it is a most unusual and uneasy way of looking at their own position. The last decennia have seen a rapid multiplication of the “social discovery” of environmental problems, leading to new conceptual frameworks and tools for describing them. A classification of environmental problems listing them by type of interference with the environment may be useful in deepening the understanding of ecological debt. Three kinds of interference can be distinguished: pollution, depletion and degradation (Cörvers and Slot 1998).

Pollution is the introduction into the environment of substances in amounts higher than natural background levels, causing damage to humans, animals, plants ecosystems and cultural heritage. It is possible to measure whether the concentration of a specific substance is higher than its background concentration, so pollution can be defined objectively. The

Table 1 Overview of possible refinements to the definition of ecological debt

Definition	Possible refinements
<p>“The ecological debt of country A consists of</p> <p>(1) the ecological damage caused over time by country A in other countries through its production and consumption patterns, and/or</p> <p>(2) the ecological damage caused over time by country A to ecosystems beyond national jurisdiction through its consumption and production patterns, and/or</p> <p>(3) the exploitation or use of ecosystems and ecosystem goods and services over time by country A, at the expense of the equitable rights to these ecosystems and ecosystem goods and services of other countries or individuals.”</p>	<p>Refinement for ecological damage:</p> <p>According to type of interference: pollution, depletion, degradation</p> <p>According to spatial scale of ecological damage: global, continental, fluvial, regional, local</p> <p>Refinement for ecosystems and ecosystem services:</p> <p>According to type of ecosystem and service provided</p> <p>Refinement for equitable rights:</p> <p>Different interpretations of “equity” for different ecosystems and ecosystem services</p> <p>Refinement for actors (debtors and creditors)</p> <p>Countries</p> <p>Present and future generations</p> <p>Classes within countries (e.g. globalised rich, globalised poor)</p> <p>Actors such as companies</p> <p>Refinement for quantification:</p> <p>Physical units</p> <p>Monetary units</p> <p>Refinement for time dimension:</p> <p>A time perspective can be constructed for each category of refinements</p>

setting of a norm beyond which level the higher concentration is considered harmful to the environment or humans is of course socially constructed.

Depletion is the extraction or use of natural resources at such a speed or rate that the exploitation can only continue for a limited time at a certain level of quality. A distinction can be made between renewable and non-renewable resources. In the case of renewable resources, depletion is exploitation at such a rate or speed that natural regeneration capacity is strongly diminished or disappears. In the case of non-renewable resources, the situation is more complex. Strictly speaking, depletion means that the resource no longer exists, but in reality, depletion is determined by whether the resource is available in terms of existing techniques, costs of exploitation, (political) accessibility of the region, etc.

Degradation, finally, is a structural change in landscape or ecosystems, causing a reduction of quality in diversity or productivity of that landscape or ecosystem. It can be caused by a way of exploitation that does not deplete a resource or ecosystem, but that profoundly changes that ecosystem. Discussions on whether reduction in quality is actually occurring are much more frequent than in the case of pollution or depletion.

A further refinement of ecological damage could be based on a classification of environmental problems based on spatial dimensions yielding different problems for different spatial scales. In Dutch environmental policy, a classification of environmental problems according to spatial scale has been developed that may be helpful in the refinement

exercise. Five spatial levels are distinguished: global problems having an impact on the whole planet (climate change, ozone layer depletion), continental problems having an impact on the continent and ocean level (acidification, winter smog, air emissions of heavy metals), fluvial problems having an impact on the sea and river basin level (pollution of rivers, regional waters, salt waters), regional problems having an impact on the region, landscape and lake level (pesticides and herbicides in soil and groundwater, pollution of soil and groundwater by heavy metals, desertification, removal of waste, deforestation) and finally, local problems having an impact on the human habitat level (noise nuisance, smell nuisance, air pollution in cities and in houses).

3.2 To which ecosystems and ecosystem goods and services do countries have equitable rights?

Implicit in the definition of ecological debt is the idea that access to ecosystems and ecosystem services is not on a first come, first serve basis, but that countries and individuals can claim some form of equitably distributed rights to these ecosystems and ecosystem services. This raises two questions. First, which ecosystems and ecosystem services are susceptible to such a claim? And secondly, what is meant by equitable rights to them? The answers to these questions are intimately linked.

An interesting and usable classification of different meanings and operationalisations of equity is provided in an IPCC report on mitigation (McCarthy et al. 2001), where besides the egalitarian principle, many others are mentioned such as sovereignty, polluter pays, ability to pay, utilitarian and Rawls's maxim. Although the context here is climate change and greenhouse gas emissions, the interpretations and operational rules can inspire and be translated to other ecosystems and ecosystem services. The egalitarian approach might for instance be used for other ecosystems and services. In the context of the environmental space concept, Spangenberg (1995) states that "energy and non-renewable raw materials are seen as global commodities, with globally accessible resources, global sinks and causing environmental problems on a global scale." Consequently, these are divided on a per capita basis on a global scale. Wood and agricultural products are regarded as continental resources, "so that each continent should have a balanced production and consumption, not occupying fertile land in foreign countries on a permanent basis." Here, the per capita calculation is done on a continental basis. Finally, water is considered a regional resource, "so the availability and the permitted use will be calculated on a regional basis." Apart from the egalitarian interpretation, others are possible. For example, in the case of information and knowledge on genetic resources, it is often argued that traditional farmers or indigenous peoples are the owners of the knowledge, implying that there is no equal access for all inhabitants of the planet. In the case of raw materials, different interpretations exist. According to international law, countries have the sovereign right to the resources on their territory, but in debates on sustainable development, a per capita approach is sometimes advocated. Still another form of "equitable" might be an interpretation of equity as subsistence rights, which encompass what individuals need to develop as living beings: clean air and drinkable water, elementary health provision, adequate nourishment and clothing and a roof over one's head (Sachs 2003). In conclusion, it is clearly necessary to make explicit which ecosystems and ecosystem goods and services are relevant and which interpretations of equitable are assigned to them. Table 2 gives a schematic overview of how different ecosystem goods and services may be combined with different interpretations of equitable.

Table 2 Overview of how different ecosystem goods and services may be combined with different equity principles

Ecosystem goods and services	Equity principle	Interpretation
Climate regulation	Adjusted egalitarianism	Per capita approach serves as a moral guiding principle but is modified by other considerations, e.g. historical responsibility, capacity to act or different geographical circumstances
	Other approaches for climate: see McCarthy et al. (2001)	
Raw materials	Sovereignty	Nations own the resources on their territory
	Egalitarian	Every inhabitant on earth has an equal right to resources anywhere
Genetic resources	Sovereignty	Nations own the resources on their territory
	Group rights	Groups such as traditional farmers and indigenous peoples who have the knowledge of the genetic resources, own the knowledge
Food/water supply	Subsistence rights	Everybody has a right to clean air and drinkable water, elementary health provision, adequate nourishment and clothing and a roof over one's head

3.3 Is ecological debt a matter between countries; or who are the debtors and the creditors?

This paper concentrates on ecological debt of countries. In the NGO campaigns, industrialised countries are considered to be debtors; developing countries are considered to be creditors. However, it can be argued that also future generations can be considered as creditors. When the North is damaging and overusing global ecosystem services and goods (such as the sink capacities of the atmosphere), the question is whether all of this ecological debt is owed to the South. In applying the concept to the case of climate change (see further), two simple models will be discussed of how one could think about attributing debt in interstate and intergenerational terms.

As we showed earlier, some existing definitions of ecological debt do not only refer to countries but also to actors within countries such as their institutions, banks, political and economic elite, corporations (...) and their allies in Southern countries (Donoso 2003). A possible way of specifying actors beyond country boundaries is by using concepts such as the global North and the global South, or the globalised rich and the globalised poor, but the problem is that these are not very clearly defined. According to Sachs (2002), the global North is the consumer class, “one-third of which, roughly speaking, lives in North America, another third in Europe, and the last third in the South”. The global South are people living in South and North who are excluded from the consumer class. When the analysis turns to actors, it becomes evidently necessary to transform the definition of ecological debt accordingly.

3.4 Can ecological debt be quantified?

Until now, ecological debt has primarily been quantified in monetary terms, but no methodology has been agreed upon. Another way of tackling the quantification problem may be to try expressing ecological debt in physical units. This seems essential anyway when the intention is to monetise at a later stage. But quantification does not necessarily have to progress to monetisation. It is our view that quantification in physical units is enough to operationalise ecological debt in several contexts. In climate negotiations,

carbon debt in CO₂ equivalents for example is enough to demonstrate the historical responsibility of industrial countries for the climate problem. We will return to the issue of quantification in the next section.

3.5 Since when have different forms of ecological debt been accumulated?

Existing definitions, particularly those used in campaigning, usually state that ecological debt has been built up since colonial times. When one starts examining the topic in terms of ecological problems caused, this is clearly too simple, particularly for global and continental environmental problems. Before the industrial revolution, human interference in nature was not so significant that it caused global environmental problems. But local, regional and fluvial problems have certainly been caused since colonial times. In principle, a specific time frame can be constructed for each kind of ecological damage. Carbon debt can be considered to have originated at the time of the Industrial Revolution although one might also argue that climate change has only been known for a few decades to be an ecological concern. Two fundamental considerations have to be made here. First of all, it should be realised that ecological debt is not only a historical issue; the ecological debt is increasing day by day and in some cases (e.g. carbon debt) is sure to increase for dozens of years to come. Secondly, ecological debt implies intergenerational issues pointing towards a crucial moral question at stake here: are we responsible for the deeds of our ancestors? A thorough discussion of this issue in the context of historical injustices and restitution can be found in Barkan (2000) where it is argued that who we are and what we have (in terms of wealth) is also the result of our history; we enjoy the riches of our past. Consequently, we should at least feel some responsibility for the problems our riches have caused and still cause.

4 Towards a quantification methodology for ecological debt

In line with the definition presented and discussed earlier, a generally applicable methodology is developed here which is schematically presented in Fig. 1. An adequate quantification methodology should be able to measure the different components of ecological debt: first, the ecological damage caused in other countries or an area under jurisdiction of another country and secondly, the use of ecosystems and ecosystem services at the expense of other countries or individuals (even without damage being caused).

4.1 Quantifying ecological damage

A much-employed method for measuring ecological damage is through the use of systems of indicators. In this case, it is necessary to select indicators that describe the three identified categories of ecological damage: pollution, depletion and degradation. A much-employed model for classifying these indicators is the so-called DPSIR-scheme (Driving Forces, Pressures, State, Impact, Response). This model is used amongst others by Eurostat and the European Environment Agency for analysing environmental problems and developing appropriate indicators (see e.g. Shah 2000). A cause-effect chain model such as DPSIR can be examined from two angles. A first possibility is to start from human activities and examine which impacts they have. A second possibility is to look at undesired consequences or impacts and go backwards to identify possible causes. A weakness of a DPSIR-type model is that it suggests a linear relationship in the interaction between

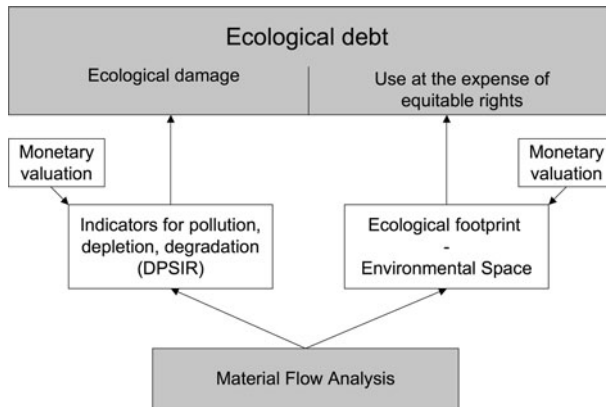


Fig. 1 Quantification methodology. Methodological scheme for calculating ecological debt in its physical and/or monetary form. Biophysical accounting systems form the basis; monetary valuation is an optional next step

human activities and environment, while in reality most environmental problems have highly complex cause and effect relations. Consequently, opinions on what can be considered cause and effect may differ a lot. Still, it can serve as a valuable approximation for refining and quantifying the ecological damage aspects of ecological debt. As mentioned earlier, the methodology has to be able to trace ecological damage caused by country A in other countries or in areas under the jurisdiction of another country or to ecosystems beyond national jurisdiction. Therefore, an analysis of material flows between countries will be indispensable to trace the origin and composition of material flows to country A. A discussion of Material Flow Analysis (MFA) in the context of ecological debt is presented in the following paragraphs.

4.2 Quantifying use at the expense of equitable rights

Two equivalent methods are identified to quantify the aspect of “use at the expense of the equitable rights”: ecological footprint and environmental space. Whereas the latter deals with the use of individual ecosystem goods or services, ecological footprint aggregates all ecological pressures in one indicator. Depending on the context and purpose, one of both methodologies may be opted for. Both of these methods are often interpreted as working with an equal per capita (egalitarian) approach, so they may appear to imply a preference for an “equal” interpretation of equitable. In fact, other interpretations are possible. This is shown in footprint analysis with the concept of “ecological deficit”, which, as already mentioned, refers to the amount by which a country’s ecological footprint exceeds the locally available ecological capacity (Hails 2006). This approach is clearly not based on equal per capita entitlements of carrying capacity, but on what may be called a “sovereignty” approach to equity (see above). The same type of reasoning can be applied to the environmental space concept. The concept was originally coined by Opschoor (1995) stating that environmental space “reflects [the fact] that at any given point in time, there are limits to the amount of environmental pressure that the Earth’s ecosystems can handle without irreversible damage to these systems or to the life support processes that they enable”. He states that this space has to be shared with present and future generations and with other species. In principle, this formulation of environmental space can be linked to

different operationalisations of equity. An advantage of environmental space is that it counts CO₂ in CO₂, tons of materials in tons, litres of water in litres, etc. When a more aggregate view is preferred, ecological footprint is preferable. Also, individual components of the ecological footprint (e.g. cropland footprint, grazing footprint, forest footprint, fishing ground footprint) may be interesting in the study of space-related aspects of ecological debt. Again, as with the ecological damage aspect of ecological debt, MFA will be a necessary complement for calculating several aspects of “use at the expense of”.

4.3 Material flow analysis

In the last 15 years, several approaches have been developed that provide comprehensive information on the relations between socio-economic activities and resulting environmental pressures in biophysical terms. Direct physical trade flows mainly provide information about the global redistribution of natural resources as direct physical inputs to the socio-economic systems of countries and regions. While trade relations between two countries or world regions may be balanced in monetary terms, they may at the same time be characterised by substantial inequality with regard to the flows of natural resources. In addition, some regions may systematically drain off ecological capacity from others by importing resource intensive products and exporting wastes (Andersson and Lindroth 2001). But even if direct physical imports and exports are balanced between trading partners, distribution can still be unequal with regard to indirect flows embodied in traded goods. Physical accounting can thus serve as a suitable framework for the analysis of environmental distribution issues in international trade relations. Moreover, by taking into account indirect flows, it is regarded as a viable accounting method for ecologically unequal exchange (Giljum 2003). From the point of view of ecological debt, MFA is necessary to trace possible impact abroad and the magnitude of this impact. MFA can provide clarity on the countries in which the impact will be situated, the resources used in these countries, the volume of this use and the evolution over time of composition and volume. While MFA is a booming scientific field, some methodological shortcomings should be kept in mind: the unavailability of adequate data, especially on indirect flows; the high degree of aggregation of most MFA indicators, which do not allow disaggregated assessments by economic sector or product, and the fact that qualitative aspects (such as the potential for environmental harm) of different types of material flows remains unconsidered.

4.4 Monetary valuation

After the physical calculations, it becomes possible to perform a monetary valuation of physical–ecological debt. Monetary valuation of environmental goods and services or of environmental damages is a much-discussed topic in environmental economics and ecological economics. As already mentioned, we do not think monetary valuation is a necessary step. Policy implications can also be drawn from physical calculations: emissions of CO₂ or figures on land use abroad, and related pollution (e.g. through fertiliser and pesticide use) can guide policy reforms in such fields as energy and climate or agriculture. Of course, monetisation adds additional information and there is the so-called “cultural soup” argument: the language of money has no problems making itself understood. In some cases, monetisation will be necessary, for instance when ecological debt has to be used as a counter-argument to external debt.

5 Application to the case of climate change: the carbon debt

As an illustration of the present analysis of ecological debt, the concept will now be applied to the issue of climate change. For sake of simplicity, the analysis will be limited to direct CO₂ emissions, excluding other greenhouse gasses (and sinks) from the analysis. In recapitulating the general definition, it is clear that all three aspects are of relevance here, i.e. ecological damage in other countries and ecosystems beyond national jurisdiction, and the exploitation or use of ecosystems and ecosystem services at the expense of the equitable rights to these ecosystems and ecosystem services by other countries or individuals. These considerations rather straightforwardly result in a concrete definition of the carbon debt, i.e. the ecological debt related to anthropogenic CO₂ emissions:

The carbon debt of a country A consists of (a) “over-emission of CO₂ by country A over time with respect to a sustainable level; i.e. emission levels which overshoot the absorption capacity of the atmosphere and are thus causing ecological impact in other countries and ecosystems beyond national jurisdiction” and (b) “over-emission of CO₂ by country A over time at the expense of the equitable rights to the absorption capacity of the atmosphere by other countries or individuals”.

It should be stressed that the carbon debt as defined here is not merely the sum of both aspects (a) and (b), as both aspects are intertwined. Mostly, over-emitting at the expense of the equitable rights to the absorption capacity of the atmosphere by other countries or individuals includes at the same time over-emitting with respect to a sustainable level. Simply summing up both debts would obviously lead to double counting in these cases. Further on, it will become clear how this will be dealt with.

Both the aspects of the carbon debt imply the evaluation of emission levels against normative standards, i.e. “sustainable level” and “equitable rights to the absorption capacity of the atmosphere”. As already discussed, this points to the inherent political dimension of the concept. Here, we will briefly discuss both issues and propose tentative estimates allowing for quantification. Agarwal and Narain (1991) argue that since the atmosphere is a global resource, every citizen of planet Earth should have an equal entitlement to greenhouse gas emissions. This egalitarian approach to equity is, however, not without problems. There are a number of factors (e.g. Torvanger et al. 1996) in addition to population size that could be taken into account in order to allocate greenhouse gas emission rights on a national basis under a global limit. These include geographical as well as climatic conditions, and strength and energy intensity of the economy. “Adjusted egalitarianism” has been proposed as a compromise solution that takes equal per capita entitlements as the moral guiding (Ott and Sachs 2000). For reasons of simplicity and clarity, we will apply equal per capita emission rights as the equity principle here. The approach presented here can be adjusted to the adjusted egalitarianism premise. This egalitarian principle, however, needs further clarification before it can be applied to quantify the carbon debt of individual countries. The crucial issue here is one of responsibility in relation to the so-called embodied CO₂ emissions of traded goods. Two main approaches can be identified: the “producer responsibility” perspective focuses on emissions based on where they were produced or emitted, whereas the “consumer responsibility” perspective focuses on the end-user or consumer of the products which were created using those emissions (e.g. Bastianoni et al. 2004). Both approaches bring valuable arguments to the responsibility discussion. For reasons of simplicity, data availability and coherence with the IPCC-guidelines we will stick here to the producer responsibility perspective. We do, however, stress that a genuine

political discussion on equity and responsibility issues is appropriate: these are exactly the kind of issues that the paradigm of ecological debt raises. The choice of a sustainable level of greenhouse gas emissions is not straightforward: such a level is based on a selection of assumptions concerning the pressures nature can stand, and estimations of what level of environmental pressures and risks a society is willing to accept. Based on the latest IPCC assessment reports, a 60% reduction with regard to 1990 could be regarded as a first rough estimate for such a “sustainable level” of worldwide greenhouse gas emissions.

In an effort to further refine the definition on the level of actors, we further split up the carbon debt into two different parts: the Historical Carbon Debt (HCD) and the Generational Carbon Debt (GCD) which together make up the total Carbon Debt (CD). The HCD represents the intra-generational interstate part while the GCD stands for the intergenerational part of the carbon debt. Two models are proposed illustrating different possibilities of distinguishing between debt accumulated by one state towards other states and debt accumulated towards future generations. In a first model (Fig. 2; left), it is argued that debtor countries (over-consumers of CO₂-absorption capacity) are in debt towards individual creditor countries (HCD; depicted in light grey) only in as much as the latter are under-consuming with respect to the sustainable level. The rest of the debtor countries’ over-consumption (depicted in dark grey) is then regarded as debt towards future generations (GCD; indicated in dark grey).

In the second model (Fig. 2; right), it is initially argued that over-average-consumers are in debt towards under-average-consumers (HCD; depicted in light grey). One could argue that once this debt has been compensated for (supposing this is possible) one is dealing with a notional average consumer (this generation) who is over-consuming with respect to the sustainable level and thus could be regarded as being in debt towards future generations (GCD; indicated in dark grey). More details about the calculation methodology are provided in the “Annex”. Here, detailed formulas are provided that allow calculating the CD, HCD and GCD for individual countries in accordance with the conceptual definitions of the models given here.

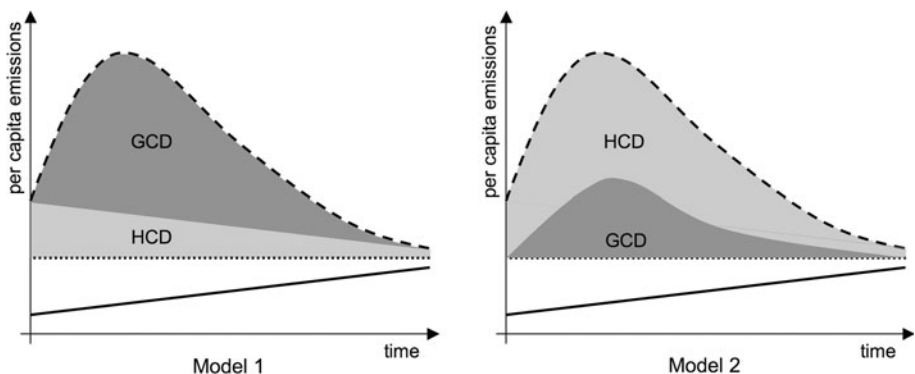


Fig. 2 Differentiating between the Historical Carbon Debt and the Generational Carbon Debt. The schematic models illustrate two ways of distinguishing between carbon debt accumulated by one state towards another state and carbon debt accumulated towards future generations. In this hypothetical case, CO₂ emitters are split into over-consumers (*dashed line*) and under-consumers (*full line*) who follow a path of contraction and convergence. The sustainable level is indicated by a *dotted line*

Table 3 Resulting carbon debt values (1950–2000) for a selection of countries according to model 2

Country	Model 2		
	CD (10 ⁶ ton)	HCD (10 ⁶ ton)	GCD (10 ⁶ ton)
Belgium	4,231	3,512	719
Brazil	−4,941	−14,790	9,849
China	−30,105	−107,886	77,781
Ecuador	−271	−951	680
Germany	37,010	31,273	5,738
India	−50,530	−107,584	57,055
Netherlands	4,320	3,260	1,061
Uganda	−1,318	−2,598	1,280
USA	183,942	166,226	17,716
Congo	−2,688	−5,286	2,599

Based on historic National CO₂ Emission data from fossil fuel burning provided by Carbon Dioxide Information Analysis Centre (Marland et al. 2008), the CD, HCD and GCD according to model 2 have been calculated for a selected set of countries for the 1950–2000 period. Unavailability of emission data for all existing countries makes it impossible to calculate HCD and GCD separately according to model 1 (see “Annex”). The results according to model 2 are listed above in Table 3.

As we have mentioned earlier, these carbon debt figures have to be seen as an addition to the “language” of the ecological debt paradigm rather than a clear-cut, exact numerical answer to the question what ecological debt is in the case of climate change. Together with the discussions about possible refinements regarding ecological damage, equitable rights and actors, these numbers constitute the carbon debt paradigm, which indeed opens up the new political, economic, ethical and ecological perspectives already mentioned. The figures presented in Table 3 nicely illustrate how the carbon debt concept works as an “eye-opener” giving rise to an enriched sustainability paradigm. Besides pointing to an important historical responsibility of industrialised countries in climate change, these figures also question another widely accepted North–South view. From an industrialised country perspective, people are used to think in terms of developing countries as debtors of a huge financial debt. The carbon debt figures now turn this relation upside down. A monetary valuation of this carbon debt could make use of estimates of the price of one ton of CO₂ based on proposed non-compliance penalty mechanisms, market process, etc, leading to a value ranging from €1 to €100 per ton CO₂ emitted. Applying a very conservative estimate of €10, the carbon debt figures from Table 3 illustrate that developing countries become the creditors of a huge ecological debt owed by developed debtor countries. This reversing of the mainstream debtor–creditor relation clearly brings a new political perspective to international relations discourse.

6 Conclusions

This paper looks at ecological debt from different angles in an effort to integrate the enriching perspectives this grass-roots concept has to offer into a more structured approach towards a broader sustainability framework. Starting from a historical

description of the organic growth of the concept, its potential to enrich sustainability discourse with amongst other things a historical perspective and a new perspective on debtor–creditor relations in contemporary international politics has been made clear. Indeed, ecological debt allows reframing relations between North and South in the light of both an historical and an ecological equity perspective on trade and development. In order for ecological debt to realise this potential and transcend its status of a campaigning instrument, it is, however, necessary to provide it with a more robust conceptualisation accommodating the richness of the different perspectives mentioned. Combining insights from the NGO literature and from the little scientific work available, two core elements in the meaning of ecological debt were distilled: “causing ecological damage elsewhere” and “using ecosystem goods and services at the expense of equitable rights of others”. These two core elements lay the foundation for a working definition of ecological debt that, taking into account its formal character, is applicable in diverse contexts. As extensively elaborated in this paper, the definition allows for several refinements raising both scientific and inherent normative arguments. Indeed, what is meant by ecological damage and equitable rights cannot be settled in a purely scientific manner only. It is our view that this inherent political dimension of ecological debt has to be regarded as a strength rather than a weakness. The paradigm of ecological debt opens up a political space in which certain unsustainable realities, previously hidden from the Western eye, can be revealed and discussed. The two main elements of the working definition also lay the foundation for a quantification methodology. “Ecological damage” can be measured by a combination of indicators, while “use at the expense of equitable rights” can be measured by ecological footprint or environmental space approaches. A necessary underlying tool for calculating both aspects is material flow analysis, since the methodology has to be able to trace “ecological damage” or “use of ecosystem goods and services” elsewhere. Also here, the normative arguments that were raised in the suggested refinements for the definition come up and need to be settled before any quantification can effectively take place. This illustrates our point that, although quantification can add figures to the language of ecological debt, it should not be viewed as the only possible framing of ecological debt. Finally, the conceptual, methodological as well as normative issues discussed in this paper have been illustrated with the case of climate change and the carbon debt.

Acknowledgments The authors thank Frank Maes, Bernard Mazijn, Patrick Van Damme, Wouter Vanhove, Jesse Lambrecht, Leida Reinhout, Geert Fremout and two anonymous reviewers for helpful comments and suggestions. The underlying research for this paper was mainly funded by the Policy Preparation Research Program 2003 of the Flemish Interuniversity Council. Gert Goeminne acknowledges support of a postdoctoral fellowship of the Research Foundation—Flanders.

Annex: calculation methodology

This annex deals with the mathematical details of calculating the Historical Carbon Debt (HCD), the Generational Carbon Debt (GCD) and the total Carbon Debt (CD) of a country, according to the two models introduced in the paper. For model 1, we start from defining the total Carbon Debt, then indicating how it can be split up into a Historical and a Generational Carbon Debt. In the case of model 2, we go the other way around, beginning with definitions for the HCD and GCD which taken together make up the total CD.

Model 1

The total Carbon Debt (CD)

In the case of model 1, the *Carbon Debt* is the cumulative amount of CO₂ a country has emitted over time above the sustainable level. In a more formal way, the carbon debt of a country c , CD_c , can be expressed as

$$CD_c = \sum_{i=\sigma}^{\varepsilon} \left[e_c(i) - \frac{\text{Pop}_c(i)}{\text{Pop}_w(i)} s_w(i) \right] \quad (1)$$

where σ is the start year, ε the end year of accounting, $\text{Pop}_c(i)$ is country c 's population for year i , $\text{Pop}_w(i)$ is the world year i population, $e_c(i)$ is country i 's CO₂ emissions from year i and $s_w(i)$ is the world sustainable level for year i . The carbon debt can be positive or negative. Countries with a positive CD are debtors, those with a negative CD are creditors. Summing the CD_c over all countries gives the carbon debt of the world as a whole, CD_w , i.e.

$$\sum_c CD_c = \sum_{i=\sigma}^{\varepsilon} \left[\sum_c e_c(i) - \frac{\sum_c \text{Pop}_c(i)}{\text{Pop}_w(i)} s_w(i) \right]$$

which immediately gives

$$CD_w = \sum_{i=\sigma}^{\varepsilon} [e_w(i) - s_w(i)]. \quad (2)$$

The Historical Carbon Debt (HCD)

In model 1, splitting the CD_c of a particular country in a HCD_c and a GCD_c is based on the $HCD_{\text{debtors}}/CD_{\text{debtors}}$ ratio of all debtor countries as a whole, and the latter is determined as follows. Consider all carbon creditors, i.e. all countries which have a negative CD_c . According to model 1, these countries should be compensated for exactly the amount of carbon credit they total. Also according model 1, this total amount of carbon credit equals the total amount of HCD_{debtors} of all debtor countries together, i.e.

$$HCD_{\text{debtors}} = - \sum_{\text{creditors}} CD_{\text{creditors}}.$$

In this way, the $HCD_{\text{debtors}}/CD_{\text{debtors}}$ ratio is determined for all debtor countries as a whole. This ratio can then be used to determine the HCD_c for every individual debtor country; every debtor country thus having the same HCD_c/CD_c ($= HCD_{\text{debtors}}/CD_{\text{debtors}}$) ratio.

$$HCD_c = \frac{HCD_{\text{debtors}}}{CD_{\text{debtors}}} CD_c. \quad (3)$$

The Generational Carbon Debt (GCD)

The rest of a debtor country's CD_c is then regarded as carbon debt towards future generations, i.e. the GCD_c .

$$\text{GCD}_c = \text{CD}_c - \text{HCD}_c.$$

HCD_c being determined according to Eq. 3. In this model, carbon creditors will have a negative HCD_c (credit) and no GCD_c ; carbon debtors will have a positive HCD_c and a positive GCD_c adding up to a positive CD_c ; the HCD_c/CD_c ratio of an individual country being determined by the $\text{HCD}_{\text{debtors}}/\text{CD}_{\text{debtors}}$ ratio of all debtor countries together. The sum of all HCD_c over all countries is of course equal to zero.

Model 2

The Historical Carbon Debt (HCD)

In this model, the HCD deals with over-emissions with respect to the world average per capita emissions. The *Historical Carbon Debt* is thus the amount of CO_2 a country has emitted over time in excess of the world average per capita emissions. In a more formal way, the Historical Carbon Debt of a country c , HCD_c , can be expressed as:

$$\text{HCD}_c = \sum_{i=\sigma}^{\varepsilon} \left[e_c(i) - \frac{\text{Pop}_c(i)}{\text{Pop}_w(i)} e_w(i) \right] \quad (4)$$

where σ is the start year, ε the end year of accounting, $\text{Pop}_c(i)$ is country c 's population for year i , $\text{Pop}_w(i)$ is the world year i population, $e_c(i)$ and $e_w(i)$ are country i 's and world CO_2 emissions from year i .

It should be mentioned that the HCD can be positive or negative. Countries with a positive HCD are considered to be in debt with countries that have a negative HCD. Note that the sum of HCD over all countries is equal to zero.

The Generational Carbon Debt (GCD)

The Generational Carbon Debt concerns that part of over-emissions with respect to a sustainable level that does not fall under the historical carbon debt. The *Generational Carbon Debt* is thus the cumulative amount of CO_2 a country has emitted over time above the sustainable level, taking into account only that part of CO_2 emissions that does not overshoot the world average per capita emissions (as that part is contained in the HCD). In a more formal way, the Generational Carbon Debt of a country c , GCD_c , can be expressed as

$$\text{GCD}_c = \sum_{i=\sigma}^{\varepsilon} \text{GCD}_c(i) \quad (5)$$

with:

$$\text{GCD}_c(i) = \frac{\text{Pop}_c(i)}{\text{Pop}_w(i)} (e_w(i) - e_{\text{sust}}(i))$$

where σ is the start year, ε is the end year of accounting, $\text{Pop}_c(i)$ is country c 's population for year i , $\text{Pop}_w(i)$ is the world year i population, $e_c(i)$ and $e_w(i)$ are country i 's and world CO_2 emissions from year i , and $e_{\text{sust}}(i)$ is the sustainable level for year i . Note that in this case, every country has a positive $\text{GCD}_c(i)$ in proportion to its share in the world's

population. This is in line with the argument made in the paper that once the $HCD_c(i)$ is compensated for, we deal with a notional average consumer.

The total Carbon Debt (CD)

The total Carbon Debt of a country, CD_c , is of course determined by the sum of the HCD and GCD, i.e.

$$CD_c = HCD_c + GCD_c. \quad (6)$$

Making use of Eqs. 1, 4, 5 and 6, it is easily verified that the total carbon debt calculated according to model 2 is identical to the total carbon debt according to model 1.

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