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The Waste Absorption Footprint (WAF): A methodological note on footprint calculations

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ABSTRACT

For a better understanding of human demand on the biosphere's capacity to assimilate wastes, this paper introduces a new footprint-based indicator, which is named the 'Waste Absorption Footprint' (WAF). The proposal of the WAF is inspired by the idea of building footprints on nature's multiple ecological functions. Within this framework, the WAF is built upon the waste absorptive capacity of the land and water area. This methodological approach is not confined to a particular waste product, but is able to include a variety of wastes generated by human activities. With this method anthropogenic emissions of wastes are translated into absorptive land and water areas. The results can be expressed in units of average hectares by scaling different land-use types in proportion to their relative absorptive capacity. The utility of the ecological footprint in sustainability evaluation can be greatly strengthened by combining the WAF to fully capture environmental effects induced by anthropogenic emissions of wastes. This paper also discusses the relationships of the WAF with other footprints and is intended to inform future debate on footprint accounting.

1. Introduction

The ecological footprint (EF) measures the amount of biologically productive land and water area required to support the demands of a population or an activity. Since its introduction by Rees and Wackernagel in the early 1990s (Rees, 1992; Wackernagel and Rees, 1996), the EF has been applied in various studies and analyses across geographical regions, spatial scales and time series (Bicknell et al., 1998; Van Vuuren and Smeets, 2000; Ferng, 2001; Bagliani et al., 2003; Wachernagel et al., 2004; Medved, 2006; Moran et al., 2008; Galli et al., 2012b). Analysts apply the EF to understand a population's or an activity's demand for the planet's limited capacity to provide a range of ecosystem goods and services. Given it is relatively easy to calculate, understand and communicate to the public, the EF has been widely acknowledged as one of the most effective evaluation tools to emerge in the sustainability debate.

As with all the tools that evaluate sustainability, the EF has also received a number of critiques (Van Den Bergh and Verbruggen, 1999; Moffatt, 2000; Ayres, 2000; Lenzen and Murray, 2001; Wiedmann and Lenzen, 2007; Fiala, 2008). One of the most heated debates emanates from the calculation of the footprint required to absorb wastes, generally known as the footprint of CO_2 sequestration in most footprint studies. Some of the most common arguments revolve around whether more land-use types than forests should be included (Siche et al., 2010), or whether other waste products (besides CO_2) should be taken into account (Walsh et al., 2009). Moreover, one problem with the carbon footprint, which has been pointed out more than once (Van Den Bergh and Verbruggen, 1999; Fiala, 2008), is that it accounts for more than 50% of the total footprint of most high and middle income nations. In a situation where CO_2 is considered the only waste product, human demand for waste absorption has already taken up half of the total allotment. Is that true?

Although this paper may not be the complete answer to such a yes-or-no question, it does provide a refined and thoughtful way to measure human demand for land-use types that assimilate wastes. This way of thinking is inspired by the idea to build footprints on nature's capacity to provide a variety rather than one single type of ecosystem services. Within this framework, the EF (except the carbon footprint) is in effect a footprint model based on the biologically productive capacity of the land and water area. The footprint model presented here, although also linked to area, is built upon the waste absorptive capacity of nature rather than its capacity to supply biological products. To avoid confusion with the EF, we name our concept the 'Waste Absorption Footprint' (WAF) – a measure of the demand of a given population or activity for the land and water area to absorb the wastes it generates.

The WAF and the EF are two equal footprint models within such a framework, as they are built upon nature's capacity to provide

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two different, but equally important, ecosystem services. Therefore, the WAF and the EF are regarded as two complementary methods, especially when they are applied to evaluate environmental sustainability. The utility of the EF in evaluating environmental sustainability can be largely increased by combining the WAF to fully capture the impacts of anthropogenic emissions of wastes.

2. Methodology

From the viewpoint of the WAF, the wastes generated by human activities require to be absorbed by natural ecosystems, such that the human demand for such waste absorptive capacity can be traced back to the land and water area that provides waste absorption services. Therefore, the WAF is defined as a measure of how much land and water area is required by a given population or activity to absorb the wastes it generates. This methodological approach is not confined to a particular waste product such as CO_2 emitted primarily from burning fossil fuels, but is able to include many other kinds of waste products released from human activities, such as surplus N or P resulting from the overuse of fertilizers for example. Yet, waste products that cannot be absorbed or broken down by any biological process are excluded from this accounting, such as heavy metals and their compounds. The WAF can also track human demand for waste absorption in terms of several land-use types, such as forest, cropland, grassland and inland water. This provides an alternative to assigning certain types of land use for waste absorption, such as forest for carbon sequestration as in the EF.

WAF models are recommended to be established according to specific categories or types of wastes. Different categories of wastes, such as those discharged into the air and to water, are commonly absorbed or broken down through different biological processes, and different types of wastes of the same category may have overlapping impacts on the environment. However, human demand for waste assimilation generally can be calculated by dividing the total amount of the released wastes by the absorptive capacity per hectare. Correspondingly, the Waste Absorption Capacity (WAC) can be calculated as the total amount of land available to absorb the wastes. All the results are expressed in units of hectares. They can be translated into national or global average hectares if conversion factors are available that scale different land-use types for their differences in waste absorptivity.

For any land use type, the footprint of waste absorption (WAF) of a country, in national hectares for example, is given by

$$\mathrm{WAF} = \frac{P}{\mathrm{NA}} \cdot \mathrm{AF} \tag{1}$$

where P is the amount of a waste product discharged; NA is the national average absorptivity for P; AF is the absorptivity factor for the land use type in question.

The capacity of waste absorption (WAC) of a country for any land use type is calculated as follows:

$$\mathrm{WAC} = A \cdot \mathrm{AF} \tag{2}$$

where A is the area available for a given land use type.

Here national hectares are defined as hectares of the absorptive land and water area with national average absorptivity. Absorptivity factors are applied to translate a specific area type (i.e. cropland, forest, grassland and inland water) into a national hectare by capturing the relative absorptivity among various land and water area types within a country. The absorption of a specific land type in a nation can also be translated into a world average hectare, if conversion factors are available that account for differences in absorptivity not only among various land types, but also between a national and the global average.

The choice of land use types in the WAF method is based on the consideration of natural ecosystems that have the capacity to provide waste absorption services. Cropland, forest, grassland and inland water are chosen as the four main land use types, while built-up land that is considered in the EF is excluded from the WAF accounting. However, it is difficult to define each land type according to the waste category or type it can assimilate or its capacity in absorbing a given waste product. In many cases a land type assimilates more than one of the waste products, and its absorptive capacity usually differs among different types of wastes. For example, forest is known as the most absorptive land type for CO_2, but it also assimilates SO_2 and NO_x. In addition, it accumulates nutrients and thus helps reduce non-point source pollution and eutrophication. Therefore, only when specific categories or types of wastes are determined can land use types be adequately defined.

From the above equations, we can see that there are several important questions that need to be resolved in a national WAF calculation: (1) the amount of wastes released into different land-use types; (2) the uptake rates of different land-use types for the wastes; (3) the absorptive factors. The last two questions are closely related to the differences in waste absorptive capacity among different land use types. The calculation of such differences requires to be undertaken at a national scale on a case-by-case basis, and depends on adequate data sets that derive from field research. For the first question, we put forward some possible solutions using the examples of CO_2 and its equivalents below.

As the WAF and the WAC are expressed in the same unit, human demand for waste absorption can be compared directly to absorptive capacity at a local, national or even global scale, from which environmental sustainability of a local area, a nation or the globe, in terms of waste assimilation, can be estimated. If human demand exceeds nature's absorptive capacity, it shows that the environment has been developed in an unsustainable way with a condition of waste absorption deficit. Conversely, if available capacity surpasses human demand on absorptivity, a waste absorption reserve occurs, indicating that the environment currently meets the minimum criteria for sustainability.

The way the WAF is calculated is elaborated in more detail below where CO_2 and its equivalents, surplus N and P are taken as examples.

For CO_2 or its equivalents emitted to the air, the footprint model can be built upon the capacity of the land and water area to sequester carbon. The carbon footprint (tentatively named here) represents the area appropriated for carbon sequestration while the carbon capacity represents the land available for carbon sequestration. Forest is the most absorptive of all the land types, as nearly half of terrestrial carbon is stored in forests (Dixon et al., 1994) and 70% of carbon exchange between the atmosphere and terrestrial vegetation occurs in forests (Schroeder, 1992). Grassland is second to forest, which accounts for about 25% of the terrestrial carbon sink (De Fries et al., 1999). Wetland, as one type of inland water, is another carbon pool where the carbon storage surpasses that of cropland (Parish and Looi, 1999).

For any of the four land use types, the carbon footprint (WAF_C) of a country, in national hectares, is given by

$$\mathrm{WAF_C} = \frac{P_\mathrm{C}}{\mathrm{NA_C}} \cdot \mathrm{AF_C} \tag{3}$$

where P_C is the amount of carbon emitted in a given year (excluding those sequestrated by oceans); $\mathrm{NA_C}$ is the annual national average absorptivity for carbon; $\mathrm{AF_C}$ is the carbon absorptivity factor for the land use type in question.

A country's carbon capacity ($\mathrm{WAC_C}$) for the given land use type is calculated as follows:

$$\mathrm{WAC_C} = A_\mathrm{C} \cdot \mathrm{AF_C} \tag{4}$$