Environmental footprints: assessing anthropogenic effects on the planet's environment

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Chapter 4

Life cycle assessment: Nice to have or essential for environmental footprints?

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Abstract

The role of life cycle assessment (LCA) in footprinting has been a popular subject of discussion in the literature. The satisfactory performance of LCA on environmental impact assessment (EIA) could allow many footprint topics to be addressed under an LCA framework, in particular those that can be measured in relation to a functional unit. The carbon and abiotic resource footprints are presented as two examples of such LCA-based footprints, in which a variety of inventory flows associated with human disturbance are compiled and translated into impact scores on the basis of science-based characterization modeling. On the other hand, however, narrowing environmental footprints down to an LCA context is found to create blind spots, where exhaustive inventory data for compiling or consensus models for characterization of impact pathways are unavailable. Besides, there are certain important types of questions for which a footprint-type representation is desirable but for which a life cycle perspective is not or only partially appropriate. The organization environmental footprint (OEF) is an obvious example of this. As a result, we argue that footprints are not to be interpreted as a new name for the impact category indicators defined in LCA and, more importantly, that LCA does not substitute but complements footprint analysis. Further investigation into the relationship between environmental footprints and LCA would be critical to the development and refinement of both tools.

4.1. Introduction

The communities of environmental footprints and life cycle assessment (LCA) have lived separately for a long time, but with the advent of the carbon footprint as an LCA tool, the two worlds seem to assimilate. However, there is a tremendous amount of ambiguity, confusion, and controversy surrounding the relationship between environmental footprints and LCA. Is an impact category indicator in LCA the same as a footprint? Is a life cycle perspective indispensable for every footprint accounting? In this chapter, we will discuss some of the points where environmental footprints and LCA agree, but also some of the points where they disagree.

4.2. On the strengths of LCA for environmental footprints

In this section, the strengths of LCA to support the measurement of specific impact categories accounted in environmental footprints are illustrated with two examples: the carbon footprint and the material footprint.

4.2.1. The role of impact characterization in the carbon footprint

The ever-accelerating growth in atmospheric carbon emissions poses the greatest anthropogenic disturbance to the Earth's climate system. As a result, mitigating global warming through reduction of carbon emissions receives top priority among climate-engineering strategies (Cusack et al., 2014). In the pursuit of transitioning to lower carbon output, the concept of the "carbon footprint" was born, with the intention to raise consumer and stakeholder awareness by attributing the responsibility for carbon emissions to products, individuals, organizations, industries, or nations. Although the carbon footprint is internationally recognized as a measure of anthropogenic climate impacts, particularly in the field of LCA (Hellweg and Milà i Canals, 2014), confusion surrounding its meaning still exists.

Of particular concern is what the carbon footprint actually measures and how it deviates from the "ecological footprint" (Borucke et al., 2013). The carbon footprint follows the logic of the LCA framework, in which activities are first translated into the inventory of emissions (resource extractions can be treated on the same level of life cycle inventory) and further processed in a subsequent characterization step, in which the inventory results (emissions or extractions) are modeled quantitatively and expressed as impact scores according to their relative contributions to a specific impact category. By contrast, the ecological footprint translates a given activity into emissions and extractions that are then aggregated into land area required for absorption and regeneration, by a simple conversion that does not involve any characterization modeling. Having recognized probably the most important difference between the carbon and ecological footprints, Hammond (2007) unexpectedly argued that the term "footprint" implies a form of area-based indicator, and that the carbon footprint should thus be renamed "carbon weight" due to its mass unit. This may appear to be an argument over semantics, but underneath is a deeper issue that may indicate a misinterpretation of the term "footprint" and of the rationale behind the carbon footprint calculation. We discuss these issues below.

The carbon footprint assesses not only carbon emissions but also non-carbon greenhouse-gas (GHG) emissions by using substance-specific factors: namely, global warming potentials (GWPs) that account for the relative global warming effects of a mass unit of each GHG. The GWP is determined by sophisticated atmospheric models and set by the equivalence principle, representing the integrated radiative forcing over a specific time horizon (e.g., 100-yr) with a reference to carbon dioxide (CO_2). Subsequently, these comparable results of GHGs are aggregated into a single impact indicator expressed in a CO_2-equivalent mass unit (e.g., kg CO_2-eq.). As such, likening carbon footprint to a mass or weight would be akin to equating blood pressure with a distance because of its unit of measure (mm Hg). This comparison overlooks the distinction between the physical unit of a phenomenon (in this case, infrared radiative forcing) and the accounting unit in which we happen to express something (in this case, the mass of CO_2 that would have to be released to cause an equivalent impact).

Therefore, the success of the carbon footprint concept should not be attributed only to the fashionable term "footprint", borrowed from the ecological footprint community. Rather, a far more fundamental reason is the scientific underpinning of the characterization models, which allows the GWP to be one of the most established, consensus-based characterization factors. By contrast, the way that the ecological footprint deals with carbon emissions is much less rigorous. So-called carbon hectares, which dominate the overall value of the ecological footprint in many studies, are calculated by adding all energy-related carbon compounds in kilograms, and dividing the sum by a constant carbon sequestration rate (CSR). This procedure disregards the difference of impact strength between different carbon emissions. Carbon hectares are thus proportional to the total carbon weight of the energy carriers (e.g., coal). Furthermore, non-carbon GHGs fall outside the scope of the ecological footprint, even though N_2O, for instance, is one of the most important GHGs that contribute to climate change.

In summary, impact characterization is the key to understanding the carbon footprint concept. There is no need to translate the ecological footprint into land area, as proven by the ecological footprint, which attempts to do so but fails to substantiate the conversion convincingly. Hammond's (2007) uneasiness about mistaking weight for impact is indeed reasonable, although not for the carbon footprint, but rather for the ecological footprint.

4.2.2. Moving from the material footprint to a resource depletion footprint

In view of the success of the ecological, water, and carbon footprints, it is not surprising that an expanding list of indicators with "footprint" in their names will be continuously introduced to the public. The recent appearance of the material footprint is an example (e.g., Schoer et al., 2012; Wiedmann et al., 2015). It is defined as the total mass of materials used for economic processes. By using this mass-based material footprint indicator expressed in absolute terms, one can be clearly aware of the total resource needs of an economy.

However, we argue that computing the material footprint in this way is misleading from a life cycle perspective, because in the goal and scope definition of an LCA, material is treated as an upstream process before the manufacture of a product. This means that the material footprint is an analogous but different concept from product environmental footprint (PEF)—an ongoing European Commission policy initiative (EC, 2015a) assessing a broad set of impact categories to provide a comprehensive picture of the life cycle environmental performance of products, for the sake of product labeling. The material footprint, therefore, is expected to encompass a variety of environmental impacts associated with material extraction through the processing, distribution, storage, use, and disposal or recycling stages.

Rather than furthering the discussion on approaches to a veritable material footprint that has not come up, we call for a shift in focus to scarcity—a critical issue which, in our view, the material footprint practitioners were intended to address. The failure to address scarcity is due to summing up the mass of raw materials with equal weights. To cite an example, we assume that Economy A and B both have a material footprint of 100 kg. This, however, does not mean anything except the total mass, because the truth might be that Economy A consumed 1 kg of Au and 99 kg of sands, and Economy B conversely consumed 99 kg of Au and 1 kg of sands! In that case, misleading decisions can be made as a consequence of neglecting the varying importance of different resources in terms of scarcity.

There are several ways to quantify the scarcity of resources, such as exergy (available energy), surplus energy, and market price approaches. In life cycle impact assessment (LCIA), the impact of resource scarcity is evaluated by so-called resource depletion potential (RDP), a form of characterization factor derived from characterization models reflecting the environmental mechanism of depletion in natural capital stocks (Hauschild et al., 2013). In theory, there are two branches of RDP, namely, abiotic depletion potential (ADP) and biotic depletion potential (BDP) (Guinée and Heijungs, 1995). However, the BDP is normally excluded from LCIA as most biotic resources can be reproduced by a production process. This is why deforestation, for example, would not be regarded as a depletion problem but a production process with its particular environmental impacts such as soil erosion, land degradation, and global warming.

We herein propose a resource depletion footprint (RDF) aimed at addressing abiotic resource depletion. The rationale is that abiotic resources, such as minerals and fossil fuels, are a dominant contributor to the depletion of natural stocks. The RDF is calculated by multiplying the ADP by the extraction of resources, where ADP is specified as the ratio between two estimates, indicating how fast the remaining stocks of resources would be exhausted in comparison to a reference resource (such as Sb), both at the current rate of use. Figure 4.1 compares resource categories for which characterization factor ADPs are derived from Van Oers et al. (2002), which serves as an updated version of the baseline method proposed by Guinée and Heijungs (1995).

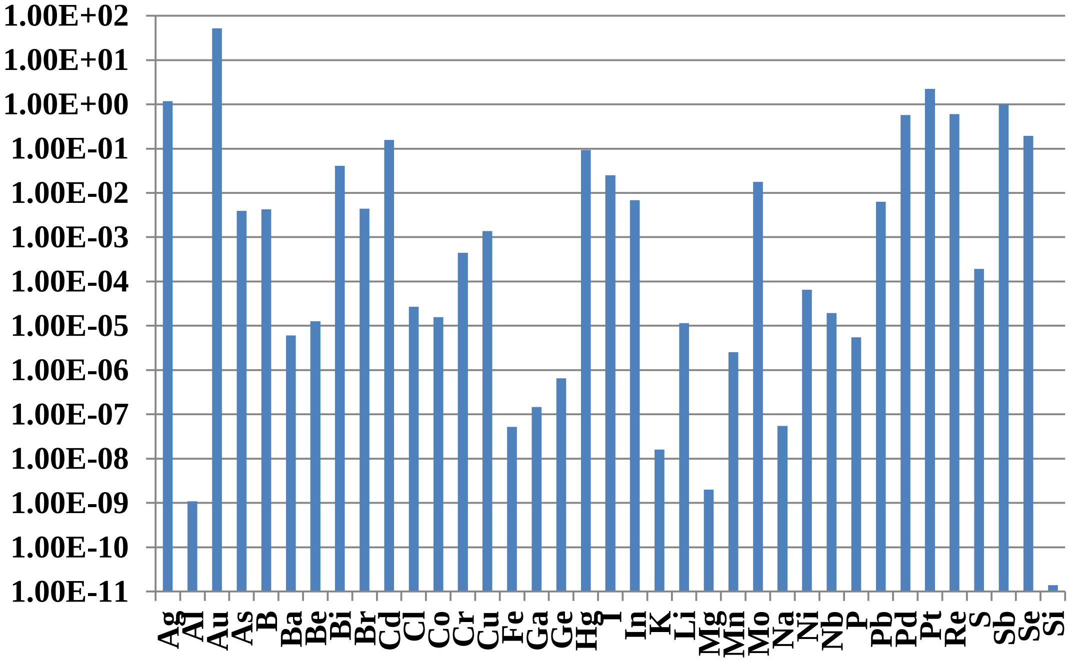

Figure 4.1. ADPs for characterizing abiotic resources against antimony (Sb), based on the estimation of planetary-scale ultimate stocks and the extraction rate for the year 1999. Data derived from Van Oers et al. (2002).

The RDF is distinguished from the material footprint as it uses a set of scientific-based characterization factors as a substitute for arbitrarily equal weights, and the outcome is expressed in relative rather than absolute terms. As a result, it allows one to prioritize abiotic resources with respect to their relative scarcity and to translate the overall risk of abiotic resource depletion into a more understandable measure of kilograms. Moreover, the RDF implies a critical recognition, which has been neglected in many environmental footprints, that human demand for natural capital should be kept within the planetary boundaries of deaccumulation or regeneration, beyond which our planet will be no longer sustainable.

Our proposal enables a harmonization of the RDF and carbon footprint, in the sense that they both aggregate different components based on scientific characterization instead of subjective weighting. The carbon footprint has a broader base of acceptance than other existing environmental footprints, because it is based on GWP—the most complete and accurate characterization factor quantifying the contributions of an emission to climate change. To make transparent the role of characterization in footprinting, we provide a comparison among the carbon footprint, RDF, and an imitating water depletion footprint (WDF) (Table 4.1).

Table 4.1. A proposal for RDF in comparison to the existing carbon footprint and an imitating WDF.

Footprint	Environmental concern	Input/output flow	Impact characterization factor
Carbon footprint	Climate change	Greenhouse emission	GWP
RDF	Resource scarcity	Abiotic extraction	ADP
WDF	Water scarcity	Freshwater extraction	WDP

The WDF has much in common with the RDF. Following this idea, one can easily formulate a suite of environmental footprints which characterize the extractions or emissions through their respective contributions to specific impact categories in a consistent manner. However, although the LCA community has taken an important step in characterizing multiple impact categories, the discrepancy between different characterization models for the same substance and impact category is still large. To fill in this gap, a lot of work needs to be done in the future.

4.2.3. Summary

As such, we underline the wide application and good performance of LCA in footprint studies and, conversely, of the usefulness of footprint principles in LCA studies. It is widely accepted that the product carbon footprint (PCF) or a broader PEF should be based on LCA (Wiedmann and Minx, 2008). LCA is typically an integrative approach in two ways: it covers many types of impact, and it covers the full life cycle. The full life cycle is analyzed to make sure there is no problem shifting from the use phase to the production phase or the disposal phase. The same is true for the broad spectrum of impacts: it is needed to ensure a more complete picture and prevent sub-optimization. Restricting an LCA to a PCF potentially creates blind spots where problem shifting can occur. Extending a PCF with more impact categories to obtain a full PCF is therefore a natural step.

4.3. On the limitations of LCA for environmental footprints: a case study of OEF

In their recent article, Ridoutt and Pfister (2013) call for an integrated family of footprint indicators, for which they highlighted the imperative of a "universal" footprint definition that is entirely based on LCA. That is to say, footprints which are not consistent with a comprehensive LCA (including the description of the goal and scope, inventory analysis, impact assessment, and the interpretation of the inventory and impact assessment results) should be disqualified from the footprint family. We believe that Ridoutt and Pfister overestimated the necessity of LCA to support the establishment of footprints in general or of a footprint family. There are more footprints than product footprints and national footprints. An important and upcoming type is the footprint of an organization (such as a company or an enterprise). In a policy context, the OEF has been described as based on a life cycle (Chomkhamsri and Pelletier, 2011; European Commission (EC, 2015b), without any motivation. We are concerned that such unfounded claims are reinforced by Ridoutt and Pfister, again without a proper justification. It is our conviction that a life cycle-based OEF is likely subject to overcounting. We illustrate this with a brief example. Suppose we calculate the life cycle-based OEF of a copper wire manufacturer. It will be based on cradle-to-gate impacts of its copper wire. Just a few street blocks further, a manufacturer of electrical equipment is using copper wire from the first company. The life cycle-based OEF of the second company will include all cradle-to-gate impacts of its materials, so also of the copper wire. This means that the OEFs of the two plants add to a too big number, because we are double counting the impacts of copper wire. The sum of the parts is bigger than the total; that is a truly holistic LCA! A similar argument was made in the context of product LCAs by Cullen and Allwood (2009).

If one includes the upstream impacts in an organization's footprint, a retailer's footprint will be very high. Likewise, a company that just transports or sells energy (such as a transmission network company or a gas station) would have an excessively large footprint. On the other hand, a flexible permission given by the EC (2013b) either to include or exclude downstream activities could perhaps avoid double counting, but also add uncertain and arbitrary results. There is a need to understand the risks to the environment and investors while recognizing that multiple stakeholders have different needs (Marland et al., 2013). This illustrates a very important point, where LCA can be used only for the final consumers in an economy (Lenzen et al., 2007), rather than for those which serve as both upstream consumers and downstream producers. The solution is to look at the added footprint instead of the life cycle footprint, much as an economist looks at the added value. To find the added footprint of an organization, we must subtract the cradle-to-gate impacts of the inputs from the cradle-to-gate impacts of the outputs, just like a business economist calculates the value added by subtracting the cost of the inputs from that of the outputs. Thus, we can elegantly formulate our framework as:

$$OEF = \sum PEF_{out} - \sum PEF_{in} \tag{4.1}$$

Notice that this formula contains two LCA-based expressions to calculate the OEF. In this sense therefore, the OEF could be argued to be based on LCA or even doubly so. But notice well that the OEF is defined as a difference between two PEFs, so all overlapping parts of the life cycle are effectively removed.

In conclusion, there is still room for a footprint family without a life cycle approach. Obviously, the definition of the indicators, in terms of how resources and/or emissions are combined into footprints, needs to be aligned between life cycle-based and non-life cycle-based footprints, so between the PEF and the OEF. It would be strange to have a different global warming potential list when doing a PEF and an OEF. In fact, by defining the OEF in terms of a difference between life cycle-based PEFs, a natural harmonization, in terms of method and scope, is achieved.

4.4. Rethinking the relationship between environmental footprints and LCA: a concluding discussion

Over the past two decades, a rapid expansion of footprint-style indicators has been observed by academics, companies, governmental bodies, and nongovernmental organizations, particularly in the arena of environmental and sustainability discourses. Although nowadays footprints have reached worldwide popularity, a dedicated footprint research community is far from being established. The ambiguous relationship with LCA, for which there is such a community, poses a substantial obstacle to achieving that goal.

There has been a growing interest in discussing the relationship between footprints and LCA. Many researchers have stressed the unique contributions of LCA to the identification and quantification of footprints, with the intention of legitimizing footprint indicators from a life cycle perspective. The strengths of LCA in assessing environmental impacts could allow many footprint topics (e.g., climate change, water use, biodiversity) to be addressed under an LCA framework, in particular those that can be measured in relation to a functional unit. Examples include the carbon footprint for climate change and the RDF for abiotic resource depletion (Section 4.1).

Nevertheless, footprint practitioners tend to stand alone in some way. One example is the ecological footprint—the ancestor of the footprint family. From an LCA perspective, the classical ecological footprint analysis (EFA), namely, the National Footprint Accounts (NFA), corresponds to a more rough type of inventory analysis in which hundreds of primary bio-products are simply tabulated and converted into the land use elementary flow. The lack of transparency in defining system boundaries and the exclusion to characterize inventory results make the NFA an unsuccessful LCA, at least in the eyes of LCA experts.

Probably the most important thing that LCA users have learned from the EFA is the name—a good name sometimes means everything. Therefore, the advent of the carbon footprint is not surprising. It begins with the task of competing for public and corporate concerns on global warming—an issue that the ecological footprint attempts to address as well but fails to receive due attention. The prosperity of the carbon footprint moves LCA back to central stage, even though Hammond (2007) suggests calling the carbon footprint "carbon weight" with the belief that footprints should be area-based indicators in line with the ecological footprint.

Meanwhile, environmental input–output analysis (EIOA) has proved useful in accounting for the carbon footprint at national and international scales (Hertwich and Peters, 2009). Increasingly, IO methods have also been found suitable for computing the ecological footprint and many other footprints for nations, such as the water, material and biodiversity footprints. These, however, do not diminish the dominant role of LCA in contemporary footprint analysis, especially in the domain of product footprints where a great amount of theoretical and practical work has been done by the LCA community on various environmental issues associated with production and consumption.

In spite of this, saying that footprints must be LCA-based is, to some extent, analogues to saying that footprints must be area-based—both are due to a lack of mutual understanding between different scientific communities in the field. The reality is that non-area-based footprints are now ubiquitous, and that LCA is not the only way to implement an inventory analysis, in addition to which a footprint is not necessarily committed to an impact assessment. Moreover, there are certain important types of questions for which footprints are desirable but for which a life cycle perspective is not or only partially appropriate. Such a methodological limitation has been demonstrated in Section 4.2, with the case of OEF.

The footprint family has been envisaged in such a way that it can be easily extended to capture a broader scope of sustainability issues. Some emerging footprints, such as the celestial, employment and inequality footprints, open the door for footprint developers to establish and measure human well-being in terms of happiness and equality, which remains the ultimate goal of sustainable development. These social and economic dimension–LCA, however, suffer from difficulties in data availability, societal impact assessment, and result interpretation.

One thing that LCA can learn from environmental footprints is the comparison of a footprint and indicator of carrying capacity. The ecological footprint has a tradition of benchmarking man's land occupation with available planetary area and thereby determining whether the situation is sustainable or not. So do the blue water footprint and chemical footprint—the two can be readily compared with blue water availability and chemical boundary, respectively. The convergence of footprints and planetary boundaries makes sense in that it allows for the evolution of environmental impact assessment to environmental sustainability assessment, which is more informative for policy purposes but lacking or at least inconspicuous in current LCA frameworks.

Admittedly, facilitating the calculation of footprints with mature methodological frameworks is preferred, and because of this, many footprint users have learned and borrowed much from LCA, IOA, or a hybrid of both. Even so, narrowing footprints down to an LCA context potentially creates blind spots, where exhaustive inventory data for compiling and/or consensus models for characterization of impact pathways are not available—and vice versa—some typical impact categories (e.g., ozone depletion, ionizing radiation) are out of the scope of the footprint family in its current form.

To sum up, footprints are not to be interpreted as a new name for the good old impact category indicators defined in LCA and, more importantly, that LCA does not substitute but complements environmental footprints. The nuanced ways that footprints and LCA deal with anthropogenic stressors should not be viewed as merely a source of controversy but rather as an opportunity for complementary use, and for development and refinement of these tools. For instance, an initiative has been launched to investigate the possible synergies between classical water footprint and water-use LCA (Boulay et al., 2013). More investigations are needed into the relationship of individual footprints and LCA scopes. Examples include the ecological footprint and land use, chemical footprint and toxicity, as well as nitrogen footprint and eutrophication. This relies on the collaboration between the footprint community—which is ever-expanding but fragmented and the LCA community—which is sophisticated but more fossilized because its members stick to standards by ISO, EPA, EC, and more.

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