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

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Citation

Fang, K. (2015, November 24). *Environmental footprints: assessing anthropogenic effects on the planet's environment*. Institute of Environmental Sciences (CML), Faculty of Science, Leiden University, Leiden. Retrieved from <https://hdl.handle.net/1887/36421>

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

Issue Date: 2015-11-24

Chapter 7

General discussion

7.1. Answers to research questions

RQ1: Does it make sense to bring together different environmental footprints into a unified framework?

Environmental footprints have now received a lot of attention from academia, the public, organizations and governments; however, none of the existing footprints is able to adequately communicate all aspects of anthropogenic effects on the environment. In addition, focusing on single footprints in isolation runs the risk of shifting the environmental burden to other footprints, as environmental issues within the Earth system are extensively interlinked and interactive and cannot be uncoupled from others. This is particularly true in the context of globalized economy, where a simple product may have a global coverage of resource extractions and hazardous emissions. Without a systemic view of the complexity of human–environment interactions, reducing one type of product environmental footprint (PEF) may induce a remarkable increase in others (see Chapter 2).

Stemming from the firm belief that environmental issues are getting increasingly complex, and that wise environmental policies cannot be formulated without looking at the whole picture, the combination of the ecological, energy, carbon and water footprints takes a fundamental step towards constructing a unified footprint family (see Chapter 2). Although these four footprints differ in more aspects than only in the impacts that are addressed, the footprint family has proved effective in making use of them in a complementary way. The value added of the footprint family lies in its systemic view that allows to provide policy makers with a complete picture of human disturbance associated with the demand for the regenerative and assimilative capacity of the biosphere. By that, one can examine whether or not a reduction in one footprint would lead to undesirable consequences for others. Problem shifting, in this sense, would be avoided to some extent by operationalizing the footprint family concept.

RQ2: How to make use of a selection of environmental footprints to constitute a truly integrated footprint family?

The integration of environmental footprints goes beyond framing a footprint family and requires a deep understanding of the general structure that underlies existing footprint indicators. Defined in simple terms, environmental footprints are indicators that measure anthropogenic effects on the planet's environment by human actions, irrespective of the precise units and dimensions. An investigation into the conceptual and mathematical structure behind different versions of the carbon, water, land and material footprints suggests that there are two broad categories of environmental footprints, namely, the inventory-oriented footprints (IVOFs) and the impact-oriented footprints (IPOFs) (see Chapter 3). The two-category classification captures the inherent distinction between most, if not all, footprint accounts in terms of inventory analysis and impact

characterization; that is, the IVOFs present a physical interpretation of the pressure of resource use which is causing environmental impacts at the inventory level, whereas the IPOFs further link inventory flows to a specific environmental impact and assess the impact category on a scientific characterization basis.

The next step to the categorization is selection. While both footprint categories have their own strengths and weaknesses, the integration of environmental footprints only makes sense if all involved are members of the IPOF category. The foremost reason for choosing the IPOFs rather than choosing the IVOFs is that the former can prevent the process of integration from double counting and double weighting that would undoubtedly compromise the validity of the final composite metric. To meet the policy demands for a single-score, stand-alone metric, a framework for characterization, normalization and weighting of conceivable IPOFs is proposed, whereby the results of inventory analysis are first to be translated into single impact category indicators, and subsequently normalized, weighted and integrated into a composite footprint index (CFI) (see Chapter 3). The three-step framework differs from life cycle impact assessment (LCIA) in that it can be fruitful in life cycle-less contexts as well. Besides, it offers experts without life cycle assessment (LCA)-expertise new insights into how to form a truly integrated footprint family—which remains unsolved and steeped in controversy (see Chapter 4).

RQ3: Is life cycle assessment a necessity for accounting for environmental footprints?

There is no doubt that footprint practitioners and users have learned and borrowed much from the LCA community. The strengths of LCA in assessing environmental impacts could allow many footprint topics (e.g., climate change, resource use) 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 two obvious examples of LCA-based footprints, where a variety of human disturbance is tabulated and translated into the inventory of greenhouse gas (GHG) emissions and abiotic resource extractions and further modeled quantitatively and expressed as impact scores according to their relative contributions to climate change and resource depletion, respectively (see Chapter 4). Given the satisfactory performance of life cycle approaches on scientific robustness, environmental relevance and reproducibility, taking advantage of LCA has now been a fashion trend followed by a growing group of footprint users.

Regardless of the ubiquity of life cycle approaches to footprinting, like any methodologies, however, LCA has its own limitations and uncertainties. Narrowing environmental footprints down to an LCA context potentially creates blind spots, where exhaustive inventory data for compiling or consensus models for characterization of impact pathways are unavailable. Moreover, some of the environmental footprints such

as the classical ecological and water footprints are designed in a way that permits a measure of pressures, not impacts, of anthropogenic activities on the planet's environment, with the belief that this valuable information may get lost if translating into an impact score through characterization modeling. In addition, there are certain important types of questions for which a footprint-type representation would be preferable to a life cycle-type representation, as is the case for organization environmental footprint (OEF). For these reasons, LCA should not be interpreted as a necessity, but rather an option, for defining and computing environmental footprints (see Chapter 4).

RQ4: What are the complementarities of environmental footprints and planetary boundaries?

While focusing on the measurement of planetary boundaries for several environmental issues, the ultimately aim of the planetary boundaries framework (PBF) is to identify the remaining safe operating space for humans by comparing planetary boundaries with current environmental states. The sole use of expert knowledge and lack of quantitative methods, however, compromise the reliability of current estimate—a neglected part of the PBF which could have been more rigorous and accurate if appropriate footprint models are employed instead. On the contrary, the lack of comparison to threshold indicators makes many of the environmental footprints (e.g., nitrogen footprint, biodiversity footprint) policy-irrelevant. Even for those which have already been linked to threshold values, the threshold estimates are far from satisfactory and much work remains to be done. As a result, it becomes clear that recent developments regarding planetary boundaries could facilitate the ongoing process of benchmarking environment footprints against the corresponding critical thresholds.

Substantial similarity exists between environmental footprints and planetary boundaries, because almost all environmental issues that the PBF concerns, such as climate change, water use, and land use, can be found in existing footprint accounts. Interestingly, the two research communities are doing something quite similar but with different strengths and challenges and lacking communication and mutual understanding. As they are found to be limited in their own abilities to implement environmental sustainability assessment (ESA), it makes great sense to take advantage of both in a complementary way. To that end, a footprint–boundary (F–B) ESA framework is proposed as a tool for jointly assessing environmental sustainability (see Chapter 5). It challenges the isolation of the footprint community and the planetary boundary community, thus opening the door to collaborative research into ESA. The primary purpose of the F–B ESA framework is to support policy makers in responding to the widening sustainability gap and in finding new ways to prevent the planet's environment from undesirable transitions.

RQ5: How to allocate planetary boundaries to nations and how does this relate

to nation-specific environmental sustainability assessment?

The environmental issues that the F–B ESA framework deals with come in two broad types, namely, the systemic processes and aggregated processes. Climate change, for instance, fits within a systemic process whose unambiguous global nature enables the climate boundary to be one of the few planetary boundaries which can be downscaled to the national level through top-down approaches that seem to be a normative or political issue more than a scientific issue. Water use, conversely, is an aggregated process for which the environmental boundaries at the national level can be quantified by upscaling local and regional water boundaries that are spatially heterogeneous, depending on a great deal of well-documented survey data for site-specific runoff and water availability. The main challenge to allocate planetary boundaries to nations is therefore a mix of downscaling and upscaling, as well as a balance between scientific and political considerations (see Chapters 5 and 6).

One prominent advantage of the F–B ESA framework is its capability to create solutions to this challenge. Converting environmental boundaries from the planetary scale to the national scale can be fulfilled by a series of steps, including the identification of target environmental issues, the selection of suitable footprint metrics, the determination of the level at which specific environmental boundaries rely on, the choice of appropriate methods for boundary metrics, the harmonization of the footprint and boundary metrics, and the measurement of sustainability gaps (see Chapter 6). In the case of climate change, atmospheric CO₂ concentration and radiative forcing—two independent control variables for defining the climate boundary—are integrated in a way consistent with the calculation of carbon footprint—a consensus-based impact indicator describing the current status of the Earth's climate system. On the national scale, the difference between the footprint and boundary metrics, in either absolute or relative terms, offers a straightforward and practical means of nation-specific ESA, explaining how far countries are from their individual environmental boundaries.

7.2. Further reflections

7.2.1. Advances to the establishment of a footprint family

Chapters 2 and 3 are dedicated to the development of a conceptual and methodological framework of the footprint family, with the aim to call for a policy transformation from assessing single environmental footprints in isolation towards an integrated assessment. Each of the ecological, energy, carbon and water footprints involved in the footprint family focuses on limited aspects of human-induced environmental change to the Earth's ecosystems, but in combination they are able to provide an overall picture of anthropogenic effects on the biosphere, atmosphere and hydrosphere. However, there is still a need to avoid overlapping and conflicting messages of the current footprint family. For this concern, we suggest to: (1) exclude the energy-related component from the

ecological footprint accounting and rename the remaining as "land footprint"; (2) reshape the energy footprint to make it relevant for assessing the depletion of non-renewable energy resources in the lithosphere; (3) keep the footprint family systematized and flexible so that emerging environmental footprints could be continuously taken into account; (4) ensure the harmonization of all selected footprint accounts by including them in unified procedures for structuring, categorization and integration; and (5) present the final results both at aggregate and disaggregate levels in keeping with the varying requirements of policy makers and scientists.

7.2.2. Environmental impact assessment vs. environmental sustainability assessment

Chapters 5 and 6 are committed to an investigation into the complementary use of environmental footprints and planetary boundaries, for which there are two leading but disparate communities in the fields of environmental and ecological sciences. The simultaneous assessment of the footprint and boundary metrics not only aims at describing what is happening to the environment, as is done in environmental impact assessment (EIA), but also at determining whether this is deviating away from a state of environmental sustainability—a prerequisite for the economic and social pillars of sustainable development. It builds on the recognition that man should not merely minimize his environmental footprints which many footprint users currently concentrate on, but make sure these footprints stay within the planetary boundaries. As pointed out by Lancker and Nijkamp (2000), an indicator does not provide any information on sustainability unless a reference value is given to it. The F–B ESA framework is, to our knowledge, the first attempt to create synergies between environmental footprints and planetary boundaries, representing an evolution of prognostic and preventive ESA—a step ahead from EIA. To obtain a better understanding of the implications for ESA, further improvements need to focus on the following issues: (1) development of measurable aggregated boundaries at multiple scales; (2) partitioning of systemic planetary boundaries for sub-global assessments; (3) harmonized accounting of the footprint and boundary metrics; and (4) trade-offs between different sustainability gaps.

7.2.3. The role of methodological standards

Chapter 4 gives novel insights into the relationship between environmental footprints and LCA. At present, a series of initiatives have been made or are under way to reach agreement on methodological standards for footprint accounting, such as the PAS 2050 (BSI, 2011) for the carbon footprint, the ISO 14046 (ISO, 2014) for the water footprint, and the Environmental Footprint Analysis (EPA, 2014). More recently, guidelines for Product and Organization Environmental Footprints (PEF/OEF) have been launched (EC, 2015a, 2015b), in the hope that the environmental impacts of products and organizations can be assessed within LCA frameworks. While it is an appealing idea to proceed with the development of footprinting standards from an LCA perspective,

inappropriate and misleading results may be encountered when equating environmental footprints with impact category indicators defined in LCA. This is why until now there is no consensus on the most appropriate footprinting method, and neither is there a clear recognition of the applicability of every conceivable method nor of the compatibility of the results due to varying methods chosen. All this leads to a question about the role of international standards for the calculation and interpretation of environmental footprints: is it a boost or obstacle?

7.2.4. Data quality and uncertainty

This thesis as a whole is not intended to generate new data but to generate new insights obtained by critical reading and contemplation. The contradicting literature and the non-quantitative nature of the analysis make the research distinguished from others. Nevertheless, on the basis of the findings of the thesis, the following remarks can be drawn: (1) in the absence of exhaustive data for life cycle inventory analysis and impact assessment, footprint accounts may be satisfied by using classical footprinting methods, such as National Footprint Accounts (NFA) and the Water Footprint Network (WFN) approach, which provide feasible alternatives to LCA; (2) recent development in environmentally extended multi-regional input–output (MRIO) models offers an opportunity for footprint users to get access to more comprehensive and detailed datasets for macro- and meso-scale studies than previously available; (3) analysis of uncertainty in both raw data and final results is necessary to add to the procedure for interpretation of environmental footprints; (4) there is a need for high-resolution remote sensing data to map the spatial and temporal variations in anthropogenic extractions and emissions; and (5) data availability for a variety of operational control variables is an important limiting factor for the allocation of planetary boundaries to country-specific shares.

7.2.5. Production-based *vs.* consumption-based perspective

A further point of attention concerns the choice between consumption-based and production-based footprint accounts in relation to nationalized planetary boundaries. For environmental footprints, a distinction has been made between production-based and consumption-based accounting (Peters, 2008; Wiedmann, 2009). Production-based footprints refer to the pressure or impact exerted where production of goods and services takes place. Given that more than ever consumers are driving environmental impacts far beyond the geographical borders of their own locations (Moran et al., 2013), there is a growing focus on the consumption-based footprints which ignore the pressures by activities for exported products, but on the other hand include the activities that take place abroad and that are associated with products imported by the region of concern (Chao et al., 2013). Both viewpoints are legitimate and have a policy value, although the precise realms of application of the two are still under debate. But regardless of the

choice for production-based or consumption-based footprints, the environmental boundaries are supposed to be defined along the same principle. In this regard, in Chapter 6 there is a striking inconsistency between data for the footprint metric and data for the boundary metric. That should be resolved in the follow-up work.

7.3. Recommendations for future research

The thesis aims at bringing clarity and transparency to a number of unresolved and important issues regarding environmental footprints; nevertheless, there remain many gaps in our knowledge. In order to proceed with the development of environmental footprints, we come up with a research agenda that includes the following prioritized topics:

- Harmonization of the structure, terminology and notation of environmental footprints.
- Identification of the applicability and limitations of each environmental footprint;
- Evaluation of footprinting methods on scientific quality, policy relevance, and public acceptance.
- Development of approaches for uncertainty and sensitivity analysis of footprint models.
- Development of systematic and dynamic frameworks of the footprint family to integrate other sustainability-related (e.g., social, economic) footprints.
- Exploration of the methodological synergies with LCA, IOA, MFA, energy-based methods (e.g., energy, exergy), etc.
- Improvement in the consistency and compatibility of the footprint and boundary metrics.

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