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

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Summary

Introduction

Attention to develop indicators of anthropogenic interference with ecosystems in a footprint context is shared by a wide range of research communities, especially in the fields of ecological economics and industrial ecology. The concept of environmental footprint has now been broadly recognized as a proxy for human-induced pressure or impact on the planet's environment. A substantial number of publications released in recent decades have contributed to establishing the scientific underpinning and communication standards of environmental footprints. Meanwhile, the widespread diffusion of footprint indicators that employ disparate or conflicting hypotheses, principles and methodologies is increasingly facing the challenge of finding ways to achieve harmonization between different footprint studies. Despite the emergence of the footprint family concept, the related knowledge is still scarce and fragmented. Moreover, there remains a lack of exploration of the common ground and individual characteristics of various environmental footprints, which significantly restricts the policy-oriented use of footprint indicators.

Research questions

As a starting point for clearing the footprint jungle, this thesis aims to present, for the first time, a comprehensive investigation into the theoretical and methodological aspects of environmental footprints and the disciplinary relationship with the latest science in defining planetary boundaries for human activities. Research questions have been condensed into five items:

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

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

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

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

RQ5: How to allocate planetary boundaries to nations and how does this relate to nation-specific environmental sustainability assessment?

Answers to research questions

Answers to RQ1: Chapter 2 brings together the ecological, energy, carbon and water footprints into a footprint family. It shows that the four footprints differ in more aspects than only in the impacts that are addressed. Although there is some overlap and there are some inconsistencies between these footprint accounts, the footprint family established as a whole has proved effective in offering an overall picture of anthropogenic effects on some major compartments of the Earth system. Our study provides a strong conceptual and visionary basis for discussion on the integration of different environmental footprints, which remains one of the most meaningful and challenging academic tasks for the current footprint community. Without this systemic view, problem shifting is likely to occur and trade-offs cannot be implemented in a convincing way.

Answers to RQ2: Chapter 3 develops a stepwise approach to uncover the conceptual and mathematical structure hidden in existing versions of the carbon, water, land and material footprints. The differing elements allow most, if not all, environmental footprints to be classified into two broad categories: the inventory-oriented footprints (IVOFs) and the impact-oriented footprints (IPOFs). While both footprint categories have their own strengths and weaknesses, the integration of environmental footprints is found to be feasible only if all involved are members of the IPOF category. Furthermore, a unified framework is proposed to integrate different IPOFs into a composite footprint index in support of environmental decision-making. Our study touches upon a fundamental issue which is the key to making sense of the footprint concept.

Answers to RQ3: Chapter 4 discusses the pros and cons of applying life cycle assessment (LCA) to environmental footprints. On the one hand, the strengths of LCA in assessing environmental impacts could allow many footprint topics to be addressed under an LCA framework, as exemplified by the carbon and abiotic resource footprints which are subject to life cycle approaches. On the other hand, narrowing environmental footprints down to an LCA context may create blind spots where exhaustive inventory data for compiling or consensus models for impact characterization are unavailable. Moreover, there are certain important types of questions for which a life cycle perspective is problematic, as is the case for organization environmental footprint (OEF). As such, LCA offers an option, not a necessity, to account for environmental footprints.

Answers to RQ4: Chapter 5 departs from the position of challenging the isolation of environmental footprints and planetary boundaries. These two research communities are found to have much in common but with different strengths and weaknesses. Our analysis demonstrates that the latest scientific knowledge of planetary boundaries is able to provide environmental footprints with a set of consensus-based threshold estimates as reference indicators, and in reverse that the planetary boundaries framework (PBF) could benefit from well-grounded footprint models which allow for more accurate and reliable measurement of current human disturbance. For these reasons, we propose a framework for complementary use of the footprint and boundary metrics, where the concept environmental sustainability assessment (ESA) is defined in a novel and explicit way.

Answers to RQ5: Chapter 6 performs a practical implementation of the footprint–boundary ESA (F–B ESA) framework to assess the environmental sustainability of 30 nations primarily from a production point of view. The downscaling of planetary boundaries to nations is fulfilled by a top-down approach based on population, as is the case for carbon emissions, or by a bottom-up approach based on natural endowments, as is the case for water and land use. On the national scale, the sustainability gaps of the above three environmental issues are determined in relative terms, explaining how far countries approach or exceed their respective environmental boundaries for sustainable development. Through this work that provides concrete evidence of the validity of the F–B ESA framework, policy makers can be adequately informed of national performance on environmental sustainability both at the disaggregate and aggregate levels.

Main conclusions

- Environmental footprints are defined as measures of anthropogenic pressure or impact on the planet's environment irrespective of their precise units and dimensions.
- The IVOFs and IPOFs that address environmental exchange (extractions and emissions) at the inventory and impact assessment levels respectively offer two competing paradigms for footprint indicators.
- The framework for integration of the IPOFs provides policy makers with a unified approach to assessing overall environmental impacts and has a broader scope of applicability than LCA.
- While footprint users have learned and borrowed much from LCA, some limitations encountered suggest that LCA cannot be interpreted as a versatile tool for accounting for all possible environmental footprints.
- Latest science in planetary boundaries is found to complement environmental footprints in assessing environmental sustainability that is a critical prerequisite for the economic and social pillars of sustainable development.
- The sustainability gap between the converted footprint and boundary metrics plays a central role in understanding the national performance on individual and collective environmental issues.

Outlooks

- Theoretical fundamentals of environmental footprints should be strengthened in support of the establishment of footprint science.
- It is necessary to improve the performance of individual footprints on conceptual transparency, methodological robustness, data availability and policy relevance.

- There is a need for the development of systematic and dynamic frameworks where a well-defined footprint family is quantified and integrated in a uniform way.
- It may be appropriate to further clarify the pros and cons of LCA-based footprint accounting with more examples.
- Enhancing consistency and compatibility of the footprint and boundary metrics are of great importance to the operationalization of ESA.
- There seems to be room for use of environmental footprints in combination with other analytical tools both from production-based and consumption-based points of view.