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Analysis

Ecological footprint of nations: Comparison of process analysis, and standard and hybrid multiregional input–output analysis

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ABSTRACT

The ecological footprint (EF) is an indicator of human requirements on bio-productive land, an essential but limited resource, which use is related to environmental burden. In this article, we compare three methods for calculating national EF: a) the process analysis represented by Global Footprint Network (GFN) accounts; b) a standard environmentally extended multi-regional input–output model (EE-MRIOM); and c) a hybrid EE-MRIOM. The process analysis accounts for total domestic production and international trade of selected products. A standard EE-MRIOM further accounts for the upstream footprint of all traded products, but has a low resolution of relevant products in available datasets. The hybrid EE-MRIO method assessed here traces the primary biomass products in physical units through environmental extensions. Our results show that the standard MRIO model might introduce a significant error due to low resolution and poor data quality. The hybrid MRIO approach provides more accurate results than the standard MRIO method since it applies data from additional sources on a more detailed level. The process analysis underestimates the footprint of imports and exports as it ignores trade in services and other products as well as the upstream flows of products included in the analysis.
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1. Introduction

The global socio-economic metabolism has reached unsustainable levels of resource consumption and waste generation (Ellis et al., 2010; Krausmann et al., 2013; Rockström et al., 2009) and requires a continuously increasing amount of environmental resources and absorption capacity for emissions and waste. Consequently, a planetary-scale critical transition is likely to be approaching (Barnosky et al., 2012) and tools are thus needed to detect early warning signs and quantify the effects on ecosystems of a growing human metabolism. Therefore, indicators of environmental sustainability are becoming increasingly important for policy makers who need a basis for measuring progress and setting policy goals to prevent further detrimental effects (BIO Intelligence Service et al., 2012; Eurostat, 2011; Moldan et al., 2012).

Environmental problems are ultimately driven by the consumption of products and services (Tukker and Jansen, 2006), which emphasizes the value of consumption based indicators, often denoted as footprints. Footprint type indicators assign responsibilities for environmental interventions from producers to final consumers. The ecological footprint (EF) has become a popular indicator of socio-economic requirement on bio-productive land (Wackernagel et al., 2002) and it has been widely applied by many researchers and adopted by several governments. Despite its popularity, the standard method for calculating national EF developed by Global Footprint Network (GFN) based on process analysis has been criticized for inconsistent treatment of internationally traded products (Kitzes et al., 2009; Wiedmann and Barrett, 2010). GFN uses data from FAOSTAT (for biomass-based products) and UN COMTRADE (for commodities) and its method thus only tracks primary and derived products captured by these databases. This data serves as a basis to account for the bio-productive land requirements embodied in international trade of the country (imports and exports of bio-productive land requirements) (Kitzes et al., 2008). The traded products consist of all the primary products plus selected secondary and tertiary products, mainly directly derived from the primary products. An inconsistency stems from the fact that only selected products are included in FAO (Food and Agriculture Organization of the United Nations) statistics and thus in the accounting for EF of traded products. Furthermore, another drawback is the limited production chain considered for footprint calculation, which introduces

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potentially significant truncation error, i.e. an error introduced by leaving part of the supply chain out of the analysis (Lenzen, 2001; Majeau-Bettez et al., 2011). For example, the ecological footprint of internationally traded shoes is considered zero in the current version of GFN accounts, since the land requirements related to feeding cows in order to get leather is too far in the supply chain to be considered for the trade analysis under the process analysis.

Environmentally extended multiregional input–output analysis (EE-MRIOA) is the state of the art in the construction of consumption based accounts of national greenhouse gas emissions (national carbon footprints) (Hertwich and Peters, 2009; Peters et al., 2012), since it is capable of accounting for greenhouse gas emissions embodied in all traded products including their nearly complete production chains,[1] and applying country-of-origin production technology on imported products (Wiedmann, 2009). The main disadvantage of EE-MRIOA is its sector and product aggregation, as all products and economic sectors are aggregated into broad groups, which are subsequently assumed to be and treated as homogeneous. Calculating EF through the IO method therefore implies that the several hundred different internationally traded products tracked by GFN would be aggregated into just a few product groups in order to benefit from the inclusion of all traded products. Historically, GFN has opted to maintain the highest possible product resolution, based on the argument that the benefits would not justify the cost (Wiedmann et al., 2007).

Galli et al. (2012) recently defined a footprint family of indicators covering carbon, ecological and water footprints. The authors argued that a common and consistent calculation framework is desirable in the calculation of these indicators. Furthermore, Ewing et al. (2012) proposed a methodological framework to account for ecological and water footprint using EE-MRIO method, but keeping the same level of detail for primary biomass products as the GFN's process analysis. This method was further applied by Steen-Olsen et al. (2012) and Weinzettel et al. (2013). The advantage of this framework covers the possibility to join the footprint family of indicators under the common framework, the application of standard analytical procedures available in IO analysis and alleviate the disadvantage of aggregating the primary products into a few groups (Galli et al., 2013). This method is easier than a full disaggregation of the MRIO dataset, since only the use structures for these products are distinguished and the dimensions of the core MRIO dataset does not increase above a level manageable by a current standard PC.

The aim of this article is to compare and analyze the differences between national EF calculation through process analysis (represented by GFN accounts), the MRIO method in which land use is linked to the producing sector (standard MRIO method, applied for example by Yu et al. (2013) and Wilting and Vringer (2009)), and the method proposed by Ewing et al. (2012) in which the environmental extension is composed of primary biomass products, which are linked to consuming sectors (hybrid MRIO, applied by Weinzettel et al. (2013) and Steen-Olsen et al. (2012)).[2] We compare these methods on an example of national ecological footprint in 2004. We further emphasize some advantages of the hybrid MRIO approach in respect to process analysis. While a comparison of a MRIO analysis and process-based analysis has been previously provided by Feng et al. (2011) for the national water footprint, this is to our knowledge the first article performing such comparison for national EF values and constituting land types.

[1] Strictly speaking, the standard input–output analysis excludes consumed capital, as it is part of value added, and therefore the upstream requirements of the capital are not part of the results, if any special treatment is not applied (see for example Peters and Hertwich, 2006. The importance of imports for household environmental impacts. J. Ind. Ecol. 10, 89–109. or Schoer et al., 2012. Raw material consumption of the European union — concept, calculation method, and results. Environmental Science & Technology 46, 8903–8909.)

[2] The names “hybrid” and “standard” MRIO are based on a report by Giljum, Lutter, Bruckner and Aparcana, 2013. STATE-OF-PLAY OF NATIONAL CONSUMPTION-BASED INDICATORS. SERI, Vienna. While there is no standard for MRIO, we use this wording to distinguish MRIO from the hybrid MRIO and refer to MRIO as standard MRIO.

2. Methods

2.1. National Ecological Footprint Through Process Analysis (GFN's Accounts)

2.1.1. General approach

According to GFN, a nation's EF (EF_N) is calculated based on direct requirements on domestic bio-productive land[3] (EF_P, production perspective EF, comprising all land utilized domestically) from which the EF of exported products (EF_{EX}) is subtracted and to which the EF of imported products (EF_{IM}) is added:

$$EF_N = EF_P + EF_{IM} - EF_{EX}. \tag{1}$$

The EF is composed of six different land types (cropland, forest land, fishing grounds, grazing land, built-up land, and carbon uptake land) which are expressed in a common unit of “global hectares” (gha) based on the bio-productivity of each land type (Borucke et al., 2013; Galli et al., 2007). The global hectare is defined as a hectare of land with world-average bio-productivity. The direct requirements on domestic bio-productive land (EF_P) are calculated through “primary products”, i.e. the products directly extracted from nature, e.g. wheat, corn, grass, etc. The ecological footprint (EF_i) of a single primary product i is defined as:

$$EF_i = \frac{P_i}{Y_{Ni}} \times YF_{NL} \times EQF_L. \tag{2}$$

And the direct requirements on domestic bio-productive land (EF_P) are calculated as a sum over all primary biomass products i:

$$EF_P = \sum_i \frac{P_i}{Y_{Ni}} \times YF_{NL} \times EQF_L \tag{3}$$

where P_i is the physical amount of primary product i, Y_{Ni} is the country (N) and product specific yield, YF_{NL} is the country and land type (L) specific yield factor, and EQF_L is the land type specific equivalence factor. Each primary product is associated with one land type. The interpretation of this equation is that P_i/Y_{Ni} converts the physical amount of product into actual land requirements, the yield factor YF converts the actual land into world average land of the respective land type and the equivalence factor then converts that into area of world average bio-productivity, measured in global hectares. The yield factor YF is defined as:

$$YF_L = \frac{\sum_{i \in U} A_{LWi}}{\sum_{i \in U} A_{LNi}} \tag{4}$$

where i is the index over all primary products (set U) of the respective land type produced in the given country, A_{LWi} is the area associated to each primary product i if the world average yield was applied and A_{LNi} is the area associated to each primary product i in the studied country. In other words, the nominator accounts for the area which would be needed to produce all the primary products produced in a given country if they were produced with world average yields, and the denominator presents the total area actually used to grow all the primary products within the country. In this sense, for each of the six considered land types, the yield factor tells us how bio-productive the national land is in comparison to the world average land bio-productivity.

[3] Sometimes denoted as “direct or production footprint” because it is directly used for the domestic production of goods and services. The term “production footprint” is confusing, because it does not refer to footprint (it does not cover any upstream requirements), but it only comprises the direct requirements on bio-productive land within the country in question.

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