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Survey

A review and comparative assessment of existing approaches to calculate material footprints☆

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ABSTRACT

Effective implementation of resource policies requires consistent and robust indicators. An increasing number of national and international strategies focussing on resource efficiency as a means for reaching a “green economy” call for such indicators. As supply chains of goods and services are increasingly organised on the global level, comprehensive indicators taking into account upstream material flows associated with internationally traded products need to be compiled. Particularly in the last few years, the development of consumption-based indicators of material use – also termed “material footprints” – has made considerable progress. This paper presents a comprehensive review of existing methodologies to calculate material footprint-type indicators. The three prevailing approaches, i.e. environmentally extended input–output analysis (EE-IOA), coefficient approaches based on process analysis data, and hybrid approaches combing elements of EE-IOA and process analysis are presented, existing models using the different approaches discussed, and advantages and disadvantages of each approach identified. We argue that there is still a strong need for improvement of the specific approaches as well as comparability of results, in order to reduce uncertainties. The paper concludes with recommendations for further development covering methodological, data and institutional aspects.

1. Introduction

Economic development in the past decades was characterised by steadily increasing levels of global resource use and rising human pressures on the environment (UNEP, 2011; Giljum et al., 2014b; Krausmann et al., 2009). Issues related to material consumption and resource productivity have rapidly increased in importance in European and international policy debates in the past few years (European Commission, 2011; OECD, 2011a; UNEP, 2011). Given the increased demand for robust indicators from the policy sphere, discussions on the most suitable indicators to measure material use and material productivity are intensively ongoing. In recent years, awareness generally increased regarding the significance not only of materials and products directly used by a national economy, but also of indirect resource use required along supply chains and embodied in internationally traded products. Consideration of all indirect effects leads to a consumption – or footprint – perspective, allowing illustrating the global impacts related to final demand of a country or region.

The concept of Material Flow Accounting and Analysis (MFA) is the most important methodological framework that allows deriving indicators of material extraction, trade and consumption. MFA as standardised and applied by the European Statistical Office (EUROSTAT, 2013a) and the OECD (2007) constitutes a description of the economy in physical units (Fischer Kowalski et al., 2011). On the basis of the MFA data system a large number of indicators can be calculated (EUROSTAT, 2001; Femia and Moll, 2005; OECD, 2007). Some of them take a fully territorial perspective and account all domestically extracted raw materials. Other indicators consider the mass of internationally-traded products, such as the indicator Domestic Material Consumption (DMC), which is calculated as domestic material extraction plus direct imports minus direct exports.

DMC is currently the most widely used material flow indicator and is at the core of national reporting by EUROSTAT. Also the European Commission's “Roadmap to a Resource Efficient Europe” (European Commission, 2011) identifies GDP/DMC as the headline indicator for measuring resource productivity. The DMC indicator is also part of OECD's Green Growth Indicators (OECD, 2014). It is widely available for countries across all continents, including all OECD countries (OECD, 2011b, 2015a), the Asian and Pacific region (e.g. Schandl and West, 2010; UNEP, 2013a), Latin America (e.g. UNEP, 2013b; West and Schandl, 2013) and Africa (UNCTAD, 2012). Several studies provide comparative assessments of DMC across all countries worldwide (Dittrich et al., 2012b; Giljum et al., 2014a; Steinberger et al., 2010, 2013).

However, in recent years, the necessity to develop and apply indicators that account upstream material flows associated with internationally traded products, i.e. the material footprint, has been articulated by a large number of stakeholders, including policy makers, civil society

☆ Surveys

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and academia. The material footprint illustrates the amount of materials required for specific products along their entire supply chains from resource extraction to final demand. The main point of critique on the DMC indicator is that countries can apparently reduce their national material consumption and improve material productivity by dislocating material-intensive industries to other countries and substituting domestic material extraction by imports. Material footprint indicators are therefore of growing relevance, as supply chains of goods and services are increasingly organised on the global level. Hence, indicators taking into account indirect flows accommodate these new circumstances and allow understanding to what extent global value chains influence a country's economy, the environment, and the resource efficiency performance of goods and services.

As a response, various methodological concepts have been developed which aim at calculating economy-wide indicators embracing direct as well as indirect material flows related to international trade. Examples for such indicators are Raw Material Input (RMI) and Raw Material Consumption (RMC); the latter indicator has also been termed material footprint (Giljum et al., 2014b; Wiedmann et al., 2013). The Raw Material Input indicator is calculated as used domestic extraction plus imports accounted for in Raw Material Equivalents (RME), i.e. the gross weight of imports including all upstream (indirect) material flows. For the calculation of Raw Material Consumption exports in terms of RME are deducted from (i.e. OECD, 2008).

In recent years, the RMC indicator has received considerable attention in publications by academic and statistical institutions (see Table 1 below). However, also in policy debates, the indicator is being suggested to monitor material use and productivity of a country in a global context. Examples are discussions on setting targets for resource productivity in the context of the EU "Roadmap for a resource-efficient Europe" (European Commission, 2014) or providing demand-based indicators of material flows in the context of the OECD Green Growth Indicators (OECD, 2014). Especially in the latter case, efforts have intensified in the past year to further develop the RMC-type indicators in order to improve its applicability in policymaking. Main areas for improvement are identified as (1) temporal range (time series), (2) geographical (country) detail, (3) sector detail, and (4) capability for detailed analyses of supply chains.

This paper provides a comprehensive review and comparative assessment of the currently existing methodologies to calculate the RMC or material footprint indicator on the economy-wide level. The objective of the paper is to assess the strengths and weaknesses of the various approaches and evaluate them with regard to their state of development and readiness for implementation. Based on this review, we describe key areas for further development and harmonisation regarding methodology and data. Note that we focus our review on indicators of used material extraction and thus exclude those indicators, which also consider unused material extraction, such as overburden from mining or by-catch from fishery.

The paper is structured as follows: In Section 2 we describe the methodology set-up for the review and evaluation of existing approaches. We explain which main groups of approaches to calculate material productivity indicators have been identified and which criteria were used to analyse and comparatively evaluate the different approaches. The following Sections 3 to 5 describe the three main methodologies currently in use, i.e. input–output analysis, coefficient approaches and hybrid approaches. Section 6 provides a comparative assessment of the evaluation results. In the final Section 7 recommendations for further development of the material footprint methodology are provided.

2. Scope of Review and Evaluation Methodology

Three methodologies for the calculation of material footprint indicators are generally distinguished to calculate footprint-type indicators (see, for instance, Chen and Chen, 2013) (Giljum et al., 2013): (1) top-down approaches starting from the macro-economic level in terms of economic structures and material extraction, (2) bottom-up approaches using coefficients on material input per product unit, and (3) hybrid approaches combining the two previous approaches. In this paper, we focus on representatives of these three approaches with regard to methodological development and data availability.

In the case of top-down approaches the prevailing approach is environmentally-extended input–output analysis, which integrates physical data on material use with structural information on the supply and use flows within economies; for bottom-up approaches the prevailing method is to apply coefficient approaches based on process analysis; hybrid approaches combine elements from both input–output analysis and coefficient approaches. Note that with the term "hybrid" we refer to the integration of IO and process-based methods and not to the use of mixed units (i.e. monetary and physical units) in input–output approaches. However, the latter form of hybridisation is also applied within some of the hybrid approaches.

From an overall conceptual point of view, coefficient approaches and IO analysis could be regarded as variations of the same approach (Suh and Nakamura, 2007). Both are applied to assess all required direct and indirect inputs to a specific product, are based on comprehensive input inventories, and compile them drawing on a wealth of often different but generalizable forms of allocation (Majeau-Bettez et al., 2014). Therefore, a full-fletched IO-model with a very high product detail would provide similar results compared to a LCA-based approach, given the availability of country- and time-specific data for all products. What theoretically could be tackled as a pure practical issue, however, in reality is a question of approximation of two schools of thought, as

Table 1
Methodologies and publications considered in the review.

Methodology	Organisation (model name)	Material flow database	Publications
Input–output approaches	WU (GTAP)	SERI/WU database (materialflows.net)	Giljum et al. (2014b)
	JRC et al. (WIOD)	SERI/WU database (materialflows.net)	Arto et al. (2012), Dietzenbacher et al. (2013)
	GWS et al. (GRAM)	SERI/WU database (materialflows.net)	Bruckner et al. (2012), Wiebe et al. (2012)
	TNO et al. (EXIOBASE)	SERI/WU database (materialflows.net)	Tukker et al. (2013)
	University of Sydney (Eora)	CSIRO database	Wiedmann et al. (2013)
	EUROSTAT	Eurostat MFA data	Watson et al. (2013)
Coefficient approach	Wuppertal Institute	Wuppertal database	Dittrich et al. (2012a, 2013), Schütz and Bringezu (2008)
Hybrid approaches	EUROSTAT[a]	Eurostat MFA data	Schoer et al. (2012a, b, 2013)
	ISTAT	ISTAT MFA data	Marra Campanale and Femia (2013)
	CUEC	Czech Statistical Office MFA data	Kovanda (2013), Kovanda and Weinzettel (2013), Weinzettel and Kovanda (2009)
	SEC	Austrian Statistical Office MFA data	Schaffartzik et al. (2013, 2014)
	DESTATIS/UBA	German Statistical Office MFA data	Destatis (2009), Lansche et al. (2007)

[a] Since the publication of a handbook for material footprint calculations for the national level by Eurostat (EUROSTAT, 2015. Handbook for estimating Raw Material Equivalents of imports and exports and RME-based indicators on country level — based on Eurostat's EU RME model. Statistical Office of the European Communities, Luxembourg.) increasingly country studies are published, such as by the Swiss Statistical Agency (BFS, 2015. Der Material-Fussabdruck der Schweiz. Bundesamt für Statisitk BFS, Neuchâtel.)