Environmental Science & Policy 54 (2015) 367–376

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

Resource footprint of Europe: Complementarity of material flow analysis and life cycle assessment for policy support

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A R T I C L E I N F O

Article history:
Received 22 December 2014
Received in revised form 10 July 2015
Accepted 21 July 2015

Keywords:
Material resources
Life cycle assessment
Material flow analysis
Resource efficiency
Targets
Resource policy
Resource criticality

A B S T R A C T

The availability and accessibility of natural resources are fundamental for human well-being and the functioning of global economies. International policies have been developed with the aim to ensure resource efficiency and to respond to environmental and socio-economic concerns towards the sustainable management of natural resources. In fact, building effective resource policies requires solid methodologies and indicators for monitoring resource extraction and consumption by the economies as well as all its related environmental impacts. The present study focuses on the European context, assessing current methodologies for resources analysis towards identifying their strengths and weaknesses in supporting policies. The study analyses trends in material resource extraction within Europe and imports over the past 10 years. Three approaches are compared: (i) "mass"-based accounting (i.e. material flow analysis); (ii) "impact assessment"-based, founded on the life cycle assessment methodology, and (iii) "resource criticality"-based, building on assessment of critical raw materials for EU economy. The paper shows through some examples that this methodological choice has relevant repercussions in terms of resource prioritization. Hence, the choice of the accounting methodology and the setting of targets should be guided by the policy objective(s) (i.e. dematerialization, environmental impact reduction and security of resource supply), possibly complementing the different insights coming from the three approaches.

1. Introduction

Availability and accessibility of natural resources are fundamental conditions for ensuring human well-being and the functioning of global economies. Therefore, resources are at the heart of many environmental and socio-economic policies. Several international initiatives and policies are promoting resource efficiency, circular economy and dematerialisation, aiming at the reduction of environmental impact (e.g. UNEP, 2012; EC – European Commission, 2010, 2011a). Moreover, from an economic standpoint, access to natural resources is essential for industrial competitiveness.

Over the years, the EU industrial policy has undertaken several initiatives to ensure a secure and sustainable supply of raw materials (e.g. EC – European Commission, 2008), which include the identification of materials that are critical for the economy, in terms of supply risk and economic importance (EC – European Commission, 2014).

Building effective resource policies and achieving resource efficiency objectives require solid methodologies and indicators for monitoring the extraction and consumption of natural resources – used by the economies – as well as all the related environmental impacts.

Huysman et al. (2015) discuss three different perspectives currently adopted in resource accounting:

1. *mass-based resource accounting*, in which material throughputs between natural and anthropogenic systems are measured, e.g. using material flow analysis (MFA) (Adriaanse et al., 1997; Bringezu and Moriguchi, 2002); or the life cycle inventories (LCI) in a life cycle assessment framework;
2. *impact-based resource accounting*, using e.g. life cycle impact assessment (LCIA) methodologies. This approach entails that inventoried resources are multiplied by factors (so-called characterization factors, CF[1]) representing specific resource-related impacts. Other impact assessment schemes can also be

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[1] Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the impact category indicator (EC – European Commission, 2011b).

http://dx.doi.org/10.1016/j.envsci.2015.07.025
1462-9011/

used, taking into account, for instance, economic considerations leading to define critical raw materials (CRM);
3. *overall environmental impact-based resource accounting* (Huysman et al., 2015), assessing the environmental burden associated to resource extraction and use.

While mass based accounting methods express flows of resources by means of the physical property "weight", impact-based methods consist of a system of CF that translate a physical property into other metrics. These metrics aim to quantify the 'potential' impacts generated on the area of protection "natural resources" and generally build on concepts such as scarcity, depletion, criticality, and cost of production from nature (emergy) or exergy. Similarly, the concept of overall environmental impact-based resource accounting considers the whole set of potential environmental impacts (e.g. climate change, ecotoxicity etc.) associated with the extraction of a resource. This latter approach is not taken into account in this study, which focuses on 1 and 2.

Statistics based on MFA have been widely used to describe global patterns of resource extraction and productivity (Bleischwitz, 2010; Giljum et al., 2014a; Steinberger et al., 2013), relating them to: e.g. population trends and economic performance (Krausmann et al., 2009); income and other socio-economic factors (Steinberger et al., 2010); for defining socio-metabolic regimes (Krausmann et al., 2008). Dittrich and Bringezu (2010) and Dittrich et al. (2012) performed a global assessment of resource use and its implications for regional development and environmental consequences. Watson et al. (2011) provide a fuller picture of the material resource footprint of the European economy, i.e. the net consumption of material including also "hidden flows" of resources both domestically and abroad using a combination of input/output analysis and MFA. Other studies investigate the material footprint at global level (Giljum et al., 2014b; Wiedmann et al., 2013). Resource footprints of final consumption may be evaluated using a global economic-environmental database ground on "Multiregional Environmentally Extended Supply and Use/Input-Output Tables" (Tukker et al., 2014). This has been also applied to assess progress on resource efficiency in different EU economic sectors (EEA, 2014).

Mass-based accounting underpins the monitoring of the Resource efficient flagship initiative of the European Commission (EC) (2011a). The ratio between Gross Domestic Product (GDP) and a mass-based indicator (Domestic Material Consumption, DMC) was chosen by the EC as leading indicator for tracking progress towards the dematerialization of the economies and the decoupling of the economic growth and resource use (Eurostat, 2010). On the contrary of MFA, the application of LCA methodology to the macroeconomic scale is still at an early stage, and the framework of the Life Cycle based indicators developed by EC-JRC (EC – European Commission, 2012) represents one of the first proposals of impact-based indicators to be used at macro-economic scale (Tukker et al., 2009).

The scope of this paper is to compare and discuss mass-based and impact-based resource accounting and their application for resource policy (Fig. 1). In particular, it aims to evaluate the feasibility and opportunity of using impact assessment methods for supporting resource policy. The results may help understanding the implications associated with resource accounting when adopting methods based on relative share of mass flows as well as relative scarcity/criticality of the resource. Indeed, this study reflects upon proposed targets for resources, e.g. those proposed by (BIO Intelligent Service, 2012), to identify where to prioritize efforts following different perspectives: e.g. promoting dematerialisation based on accounting for mass flows, focusing on specific resources due to their scarcity or to geopolitical considerations that may affect their availability to economy.

In this study, trends in resource extraction (following the accounting of point 1. and 2. in Fig. 1) and related resource depletion impacts (as for point 3. in Fig. 1) are assessed and analyzed for the period 2000–2010. Imports of resources are also taken into account together with domestic extractions in order to estimate the actual requirement of natural resources by the EU economy. Due to limited data availability, only MFA data have been used for the analysis of import. The paper is organized as follows. Section 2 describes the underlying methodologies and the datasets used for the assessment; Section 3 presents the results for each resource typology; in Section 4, we discuss the differences resulting from the analysis of resource trends including also a criticality assessment (point 4. in Fig. 1). The contribution analysis to domestic extractions and impact focuses on metals (year 2010) and highlights the implications of the selection of accounting methods when setting targets as well when assessing the relative contribution of trade over domestic extractions. The conclusion section presents the main strengths and limitations of the three approaches for resource policy support.

2. Methodology[2]

Mass-based and impact-based approaches refer to two well established methodologies, i.e. MFA and LCA. Both methodologies could be used for assessing resource trends. In this section we present some hurdles that these methodologies face in terms of: comparability and consistency; data sources; and integration of resource criticality metrics. More detailed information on data sources and methodological issues are reported in the supplementary material.

2.1. Material flow accounting (MFA)

The term material flow analysis (MFA) refers to a set of descriptive and analytical tools based on the materials balance principle, which can be applied to different levels of detail (from economy-wide to product chains) in order to understand the interaction between human activities and the environment (Bringezu and Moriguchi, 2002; OECD, 2008). Economy-wide material flow accounts (EW-MFA) have been adopted by EUROSTAT to describe the material throughput of the EU economy and to indicate the metabolic performance using a number of aggregated indicators. Within this set of indicators we find the DMC, which measures the amount of materials directly consumed by the economies. It is derived as the annual amount of raw materials extracted from the domestic territory (Domestic Extraction Used, DEU), plus all physical imports minus all physical exports.[3] Raw Material Consumption (RMC) represents a new development of the DMC. It adopts a life cycle perspective for the accounting of import and export, thus considering the upstream flows along the production chain and expressing them in Raw Material Equivalents (RME)[4] (Schoer et al.,

[2] Due to the extensive amount of information provided by the study, some tables and figures cited in the text (numbered with "s") are available in the Supplementary Material.

[3] The main shortcoming of this indicator is that it considers only the direct materials embodied in traded good, while the upstream indirect material flows of traded goods, the so-called "ecological rucksack", are not included. As acknowledged by many authors (Dittrich and Bringezu, 2010; Dittrich et al., 2012; OECD, 2008; Schoer et al., 2012) neglecting the indirect flows associated with traded goods could provide misleading information to governance, since shifting of environmental burden to resource suppliers countries are not disclosed.

[4] "The RME concept takes the perspective of raw materials embodied in products, indicating how much extraction of material was necessary over the whole production chain for manufacturing a specific product, irrespective whether those raw materials where extracted from the domestic or the rest of the world environment. The weight of the consumed raw materials is measured at the point of extraction from the environment. The estimation of RME is based on the Leontief approach, which is a well-established method for environmental economic analysis. That approach applies input–output analysis for assigning direct environmental pressures – measured in physical units – by the individual production activities to the products of final use and of imports" (Schoer et al., 2012).