Resources, Conservation and Recycling 95 (2015) 68–76

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Toward a systematized framework for resource efficiency indicators

Sofie Huysman[a], Serenella Sala[b], Lucia Mancini[b], Fulvio Ardente[b], Rodrigo A.F. Alvarenga[a,c], Steven De Meester[a], Fabrice Mathieux[b], Jo Dewulf[a,b,*]

[a] *Research Group ENVOC, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium*
[b] *European Commission – Joint Research Centre, Institute for Environment and Sustainability (IES), Via E. Fermi 2749, 21027 Ispra, Italy*
[c] *Universidade do Estado de Santa Catarina (UDESC), Departamento de Engenharia Ambiental, Centro de Ciencias Agroveterinarias (CAV), CEP 88520-000, Lages, Brazil*

ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form 29 September 2014
Accepted 31 October 2014

Keywords:
Resource efficiency
Eco-efficiency
Indicators
LCA
Waste indicators

ABSTRACT

The transition toward resource efficient production and consumption patterns is currently one of the main challenges in engineering, environmental science and especially in governmental policies. This transition has led to a proliferation of meanings related to the resource efficiency concept, resulting in a wide variety of indicators. In this paper, we propose a systematized framework in which resource efficiency indicators can be structured and comprehensively positioned. The aim is to provide a proper understanding of the scope and limitations of particular existing resource efficiency indicators in order to assist policy makers and the scientific community in the application and further development of indicators. This framework covers all different resource use-related aspects evaluated in existing approaches, including simple accounting of resource extraction and use; environmental impact assessment due to resource extraction and use; accounting and environmental impact assessment of specific processes and of full supply chains; analyses at micro-scale and macro-scale; and analysis of both natural resources versus waste-as-resources. To illustrate the potential application of the framework, a set of currently used indicators was selected, whereupon these indicators were structured and evaluated within the framework.

1. Introduction

In the last years, policy awareness has grown about the increasing competition for natural resources and its possible consequences for economies, human well-being and the environment.

International initiatives, e.g. the Resource Panel of the United Nations Environment Program, have been launched to support policies with scientific assessments in order to achieve a more sustainable use of resources (UNEP, 2014). Japan has been promoting resource efficiency since the 1990s through policies focusing on resource productivity and waste management: the fundamental law for establishing a sound material-cycle society promotes the “3R (reduce, reuse, recycle)” principle and the cascading use of resources (Takiguchi and Takemoto, 2008). US policies have instead focused more on energy efficiency through the Energy Star program, which is a voluntary labeling scheme for the identification and promotion of energy-efficient products to reduce greenhouse gas emissions, introduced in 1992 (Brown et al., 2002). At European level, the challenges related to natural resources are a main part of the 2020 growth strategy (EC, 2010a) and are addressed in the Flagship Initiative “Resource Efficient Europe” (EC, 2011a). In this context, using natural resources more efficiently is deemed as a necessary step to avoid scarcities and achieve environmental targets, e.g. reducing climate change and preserving ecological assets, but also as an opportunity for economic competitiveness. Natural resources have become a high priority theme also in the EU industrial policy and from a resource security perspective. For example, the access to resources and the security of supply of raw materials have been addressed first in the Raw Materials Initiative and in the context of the Resource Efficiency Initiative (EC, 2008). In order to prioritize the policy actions and avoid supply shortages, a first list of materials facing the highest supply risk with respect to the whole EU economy (i.e. Critical Raw Materials, CRM) has been published in 2010 and will be updated every three years (EC, 2010b, 2014).

The transition toward more resource efficient economies implies the need for quantitative indicators, capable to trace resource consumption and associated impacts with production and consumption systems. Such indicators have historically been developed both in a policy and scientific context, based on

* Corresponding author at: Research Group ENVOC, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium. Tel.: +32 9 2645949.
E-mail addresses: jo.dewulf@jrc.ec.europa.eu, jo.dewulf@ugent.be (J. Dewulf).

http://dx.doi.org/10.1016/j.resconrec.2014.10.014
0921-3449/

different theoretical and conceptual frameworks. However, this leads to a diversity of resource-related indicators that are not univocally defined, generating confusion on the real meaning of adopted indicators.

Indeed, indicators have been developed for systems situated at different levels of economic activity: from the micro-scale of specific processes and products, e.g. the energy efficiency of an ethanol-producing system (Liao et al., 2011), to the meso- and macro-scale of sectors and countries, e.g. the energy efficiency of the Norwegian society (Ertesvag, 2005). At micro-scale, some indicators analyze products and processes in a gate-to-gate perspective, while others consider a full life cycle perspective. The same difference is present at macro-scale: some indicators evaluate resource efficiency in a national or regional perspective, while others consider a more global perspective by including resources that are embodied in imported products (BIO-SEC-SERI, 2012). Another point of attention is the provenience of resources: some studies refer to resources extracted from nature, e.g. the inland water consumption (BIO-SEC-SERI, 2012) while in others waste is also considered as a resource, e.g. the resources obtained from recycling waste of electric and electronics equipment (Ardente and Mathieux, 2012). Further, some indicators refer to the amount of resource consumption, e.g. the ratio of the Gross Domestic Product (GDP) over the domestic material consumption (DMC) as applied in the roadmap to a Resource Efficient Europe (EC, 2011a), while others are based on environmental impacts, e.g. the GDP over the Environmentally Weighted Material Consumption (EMC) as established by Van der Voet et al. (2005).

With the current increasing awareness of the role of natural resources and the current multiplication of resource efficiency indicators, a clear systematization of these indicators is needed, in order to increase their capability of giving insight into efficiency issues and to promote their proper use among the broad range of applications for ‘resource efficiency’: from technical indicators in engineering to macro-scale indicators in governmental policies.

The objective of this paper is hence to propose a systematized framework in which resource efficiency indicators can be structured and critically analyzed. The aims are: (1) to provide a proper understanding of the theoretical foundation of existing resource efficiency indicators highlighting scope and limitations, allowing more consistency and comprehensiveness; (2) to support a meaningful application of indicators in environmental policies and (3) to pave the way for the further development of indicators, either by improving existing indicators or by creating new indicators where no indicators are available. The article is organized as follows: Section 2 describes how the systematized framework was established. In Section 3, potential applications are illustrated by structuring several key indicators in practice today according to the framework. In Section 4, some pending challenges are presented.

2. Establishing a systematized framework

So far, a generally accepted definition for ‘resource efficiency’ does not exist yet. The resource efficiency platform of the European Commission describes resource efficiency as “using the Earth’s limited resources in a sustainable manner while minimizing impacts on the environment” (EC-OREP, 2014). To be able to establish a systematized framework in which resource efficiency indicators can be classified, several terms and concepts need to be clarified.

2.1. Defining resources

First, it is important to have a clear definition of what resources are. The Earth’s resources are natural resources, defined by Udo de Haes et al., 2002 as “objects of nature which are extracted by man from nature and taken as useful input to man-controlled processes, mostly economic processes”. Different categorizations are possible, splitting natural resources differently, as mentioned in the International Reference Life Cycle Data System (ILCD) handbook (EC-JRC, 2011). We will here refer to the categorization of Dewulf et al. (2007): fossil fuels, minerals, metals, nuclear energy, water resources, land resources (biomass and occupation), abiotic renewable energy (including hydropower, wind, tidal, wave and geothermal energy) and atmospheric resources. Apart from these natural resources, also industrial resources and waste-as-resources should be considered. This is further explained in Section 2.3.

2.2. Defining efficiency

Second, it is essential to have a clear view on how efficiency can be defined. In literature, two types of metrics are being used to characterize efficiency, here referred to as level 1 and level 2 efficiencies.

Efficiency at level 1 originates from thermodynamics-assisted engineering (Heijungs, 2007). It is defined as the ratio between the useful outputs (or benefits) and the inventoried flows (Eq. (1)).

$$\text{efficiency at level1} = \frac{\text{benefits}}{\text{inventoried flows}} \tag{1}$$

Efficiency at level 2 is derived from the original eco-efficiency concept (Heijungs, 2007). In the first definition by Schaltegger et al., 1990), eco-efficiency is defined as the ratio between the intended effects (or benefits) and environmental impacts, assessed through specific impact assessment models (Eq. (2)):

$$\text{efficiency at level2} = \frac{\text{benefits}}{\text{environmental impacts}} \tag{2}$$

2.3. Defining benefits, flows and impacts

The inventoried flows in Eq. (1) can be natural resources, industrial resources, waste-as-resources or emissions. These flows are schematically presented in Figure 1. When natural resources are extracted from the natural environment, they enter the industrial system, consisting of a production and consumption part. Within the production system, natural resources are transformed into industrial resources (IR) (e.g. energy carriers, semi-finished products, chemical building blocks . . .), used further on in the primary, secondary and tertiary economic sectors. The output of the production system consists of products and services that are supplied to the consumption system. These products and services are thus the useful outputs or benefits (B) of the production system. Both the production and consumption system generate emissions (EM) and waste materials. Emissions are released to the environment, while waste materials can be transferred to the waste treatment sector. From this sector, waste materials can be utilized as waste-as-resources (WR) and supplied to the production system. If not, they are disposed without any recovery. These flows and benefits can be expressed in biophysical metrics (e.g. mass, volume, energy or occupation) or in monetarian metrics (e.g. euros, dollars). These quantification metrics are given in Table 1. As this study rather focuses on an environmental than an economic context, the emphasis will be mainly on biophysical metrics further on.

To allow a better interpretation of what these flows exactly mean, several attempts are made by environmental scientists and policy makers to relate these flows to potential benefits and impacts (Eq. (2)). A commonly used methodology that converts the inventoried flows that are directly exchanged with the environment, i.e. natural resources and emissions, to environmental impacts is Life Cycle Assessment (LCA) (ISO, 2006). To evaluate the environmental impact of these flows, characterization factors can be applied