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ANALYSIS

Ecological footprint accounting in the life cycle assessment of products

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ABSTRACT

We present and discuss ecological footprint (EF) calculations for a large number of products and services consumed in the western economy. Product-specific EFs were calculated from consistent and quality-controlled life cycle information of 2630 products and services, including energy, materials, transport, waste treatment and infrastructural processes. We formed 19 homogeneous product/process subgroups for further analysis, containing in total 1549 processes. Per group, the average contribution of two types of land occupation (direct and energy related) to the total EF was derived. It was found that the ecological footprint of the majority of products is dominated by the consumption of non-renewable energy. Notable exceptions are the EFs of biomass energy, hydro energy, paper and cardboard, and agricultural products with a relatively high contribution of direct land occupation. We also compared the ecological footprint results with the results of a commonly used life cycle impact assessment method, the Ecoindicator 99 (EI). It was found that the majority of the products have an EF/EI ratio of around 30 m^2-eq. yr/ecopoint ± a factor of 5. The typical ratio reduces to 25 m^2 yr/ecopoints by excluding the arbitrary EF for nuclear energy demand. The relatively small variation of this ratio implies that the use of land and use of fossil fuels are important drivers of overall environmental impact. Ecological footprints may therefore serve as a screening indicator for environmental performance. However, our results also show that the usefulness of EF as a stand-alone indicator for environmental impact is limited for product life cycles with relative high mineral consumption and process-specific metal and dust emissions. For these products the EF/EI ratio can substantially deviate from the average value. Finally, we suggest that the ecological footprint product data provided in this paper can be used to improve the footprint estimates of production, import and export of products on a national scale and footprint estimates of various lifestyles.

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1. Introduction

The need for more sustainable products, processes, and ultimately lifestyles, has triggered the development of a large number of environmental assessment tools (e.g. Azar et al., 1996; Hertwich et al., 1997; Robèrt, 2000; Robèrt et al., 2002). These tools measure environmental performance and identify improvement potentials from an environmental point of view. One group of assessment methods focuses on the direct and indirect resource inputs and/or emissions from the "cradle to grave" of products. The underlying philosophy is to take into account all environmental impacts during the whole life cycle of products. These environmental product assessment methods are also called life cycle assessment (LCA) methods.

For the interpretation of product-specific life cycle resource use and emissions, two classes of LCA methods can be identified that produce one single score for every product assessed. The first class of indicator methods aims at analysing all potential environmental impacts occurring during the life cycle of a product. A commonly applied single-score impact assessment method in LCA is the Ecoindicator 99 (EI; Goedkoop et al., 1998; Goedkoop and Spriensma, 2000). The EI-method focuses on quantifying impacts on human health, ecosystem quality and resources. A single score per product is obtained by applying weighting factors based on panel preferences. The second class of methods produce input-related indicators, for instance based on the cumulative use of land, energy and materials. Inputs can be assessed with relatively high confidence and is considered to be indicative of total environmental performance. One example of this class is the cumulative energy demand (Chapman, 1974; Hirst, 1974) quantifying the energy required during the life cycle of a product.

As shown by Huijbregts et al. (2006), fossil cumulative energy demand (CED) is indeed an important driver of several environmental impacts and thereby indicative for many environmental problems. Although fossil cumulative energy demand (CED) is strongly linked to emission-related impacts as global warming and acidification, correlations of CED to land use are relatively low. Land use plays an important role in relation to the production of renewable energy carriers and less for fossil fuel extraction (Hischier et al., 2005; Jungbluth et al., 2005). In this context, the ecological footprint (EF) may be an appropriate alternative for the CED as a proxy single-score indicator in LCA. The EF integrates (i) the area required for the production of crops, forest products and animal products, (ii) the area required to sequester atmospheric CO_2 emissions dominantly caused by fossil fuel combustion, and (iii) the area required by nuclear energy demand (Wackernagel et al., 2002; Monfreda et al., 2004). The EF has been commonly used to assess human pressure in geographical context, for instance on the level of nations, regions or cities (see e.g. Folke et al., 1997; Wackernagel et al., 2002; Nijkamp et al., 2004). Furthermore, the EF of a number of products, mainly energy carriers and food products, have been calculated (Kautsky et al., 1997; Folke et al., 1998; Chambers et al., 2000; Simmons et al., 2000; Deumling et al., 2003; Stöglehner, 2003; Holdren and Høyer, 2005). Up to now, however, the EF methodology has not been comprehensively applied to assess environmental burdens by a wide range of products (Wackernagel and Yount, 2000).

The current paper fills this information gap by calculating ecological footprints of 2630 products and services in the western economy, including energy generation, material production, transport, waste treatment processes and infrastructure. We formed 19 rather homogeneous product/process subgroups for further analysis, containing in total 1549 processes. Per group, the average contribution of the three types of land occupation (direct, CO_2 and nuclear) to the total EF was derived. Instead of producing another theoretical critical assessment of the ecological footprint method (e.g., van de Bergh and Verbruggen, 1999), we compared the ecological footprint results with the results of a more sophisticated impact assessment method, i.e. the Ecoindicator 99. This helps to identify for which product categories the two approaches will lead to a different ranking of products in practice.

2. Methodology

2.1. Ecological footprint

The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption (Wackernagel and Rees, 1996; Wackernagel et al., 2002; Monfreda et al., 2004). The focus on biologically productive land and water for humans reflects the anthropogenic perspective of the ecological footprint accounts (Wackernagel et al., 2005). In the context of LCA, the ecological footprint of a product is defined as the sum of time-integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO_2 emissions from fossil energy use and cement burning:

$$\mathrm{EF} = \mathrm{EF}_{\mathrm{direct}} + \mathrm{EF}_{\mathrm{CO_2}} + \mathrm{EF}_{\mathrm{nuclear}} \tag{1}$$

For the products included in the analysis, direct land occupation over time (m^2 yr) is defined by (i) built-up area, (ii) forest, (iii) cropland, (iv) pasture and (v) hydropower area. The direct ecological footprint, related to the five land occupation types identified, is calculated by

$$\mathrm{EF}_{\mathrm{direct}} = \sum_a A_a \cdot \mathrm{EqF}_a \tag{2}$$

where $\mathrm{EF}_{\mathrm{direct}}$ is the ecological footprint of direct land occupation (m^2 yr), A_a is the occupation of area by land use type a (m^2 yr) and EqF_a is the equivalence factor of land use type a (–). One important difference with the original ecological footprint approach as described in Wackernagel et al. (2005) is that we apply product-specific yield figures for forestry, pasture and crops to obtain the direct land occupation A_a instead of global average yields (ecoinvent Centre, 2004). As argued by Wiedmann and Lenzen (2007), actual yields better reflect gains in product efficiency which is considered an important aspect in the life cycle assessment of products.