QUANTIFYING RESOURCE FOOTPRINTS OF PRODUCTS AND SERVICES AS THE EXERGY EXTRACTED FROM NATURE BY DIFFERENT COUNTRIES.

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Abstract

Although our whole society depends on the use of natural resources, they are not always used in a sustainable way. To achieve a more sustainable development, resource consumption needs to be measured. Therefore, resource footprint frameworks are being developed. These frameworks integrate inventory methodologies, which quantify the specific resources consumed by a system, with resource accounting impact methodologies, addressing the environmental impact of resource consumption, e.g. the Ecological Footprint.

To calculate the inventory of systems at micro-level (processes, products), process-models are generally used, as applied in process-based Life Cycle Analysis (LCA). For systems at meso- and macro-level (sectors, countries), economic input-output/IO-models are mostly used instead of process-models, as applied in IO-analysis and IO-based LCA.

The objective of this paper is the development of a new resource footprint framework called IO-CEENE, in which a world IO-model (Exiobase), providing a global perspective, is integrated with the CEENE methodology (Cumulative Exergy Extraction from the Natural Environment), providing a more complete resource range. CEENE is an exergy-based method, thus it considers not only the resource quantity but also the extent to which consumption removes resource quality. Among the exergy-based methods, CEENE covers the largest number of resource groups: fossil fuels, nuclear resources, metals, minerals, land resources, water resources, abiotic renewable resources and atmospheric resources.

This new framework allows one to calculate resource footprints of products or services consumed in different countries as the exergy extracted from nature. The way the framework is constructed makes it possible to show which resources and countries contribute to the total footprint. This is illustrated by a case study on wheat production.

Keywords

resource footprint, exergy, input-output LCA, hybrid LCA, CEENE

1. INTRODUCTION

Despite the fact that most natural resources are limited, they are not always used in an environmentally sustainable manner. Quantification of the extent of the environmental impact of resource consumption is needed. To do so, resource footprint frameworks are being developed. These frameworks integrate inventory methodologies, which quantify the specific resource amounts consumed by a system, and resource accounting impact methodologies, addressing the environmental impact of resource consumption, e.g. the Ecological Footprint. To calculate the inventory of systems at micro-level (processes, products), process-models are generally used, as applied in process-based Life Cycle Analysis (LCA). For systems at meso- and macro-level (sectors, countries), input-output/IO-models are mostly used, as applied in IO-based LCA.[1]

The scope of this study is the development of a new resource footprint framework in which a world IO-model is integrated with an exergy-based impact method. Exergy is a thermodynamic tool that can be used to evaluate both the resource quantity and quality. Exergy-based impact methods thus have a proper scientific validity.[2]

At meso/macro-level, only two exergy-based methods have been integrated within an IO-model. These are ICEC (the Industrial Cumulative Exergy Consumption) and ECEC (the Ecological Cumulative Exergy Consumption), applied by Bakshi et al. on the 1997 IO-model of the United States.[3] However, this is only a national IO-model, meaning that natural resources embodied in imported and exported products are not taken into account. To avoid this burden shifting, we used a world input-output model.[4] Instead of ICEC and ECEC, the more recent CEENE methodology was chosen, since it covers the largest number of resource types: fossil fuels, nuclear resources, metals, minerals, land resources, water resources, abiotic renewable resources and atmospheric resources.[5] This new resource footprint framework for systems at meso/macro-level (called IO-CEENE) is an addition to the existing one for systems at micro-level (called process-CEENE). Process-CEENE is based on the process-model of the Ecoinvent database.[5]

2. MATERIALS & METHODS

2.2 Selecting a world IO-model

First, a world IO-model was selected. The existing world input-output databases are Eora, GTAP (Global Analysis Trade Project), WIOD (World Input-Output Database) and Exiobase. The natural resources in these databases are typically subdivided into 4 groups: energy use, land use, water use and material use (i.e. fossil fuels, metals, minerals and biomass). However, GTAP does not contain water resources, and both GTAP and EORA are missing material resources. Next to that, the industrial sectors are much more aggregated in WIOD than in Exiobase. Therefore, Exiobase was chosen as world IO-model. This database covers 43 countries and 1 rest of world region combining the remaining 173 countries. Each country is subdivided in 129 sectoral products and services.[4]

2.2 Integrating the IO-model with CEENE

The integration of the Exiobase IO-model with CEENE was done in two steps: First, resource flows were selected from Exiobase. Second, exergy characterisation factors (X-factors) of the CEENE methodology were determined for and linked to each resource flow. A distinction can be made between generic and country-specific X-factors: generic X-factors only consider the quantity and properties of resources, while country-specific X-factors also take the influence of the location into account. Indeed, the extent of the environmental impact may depend on the location where it occurs. In this study, the country-specific X-factors of Alvarenga et al.[6] were used for land occupation, e.g. 49.2 MJ_{ex}/m^2.year in Indonesia and 19.5 MJ_{ex}/m^2.year in Norway.

3. RESULTS AND DISCUSSION

When multiplying the inventory with the exergy characterisation factors, it is possible to calculate the IO-CEENE resource footprint. This can be done for each of the 129 sectoral products of the 44 countries in Exiobase. It is thus possible to calculate country-specific footprints for 44 countries, which is one of the main advantages of IO-CEENE. Indeed, the resource footprint of a certain product depends on the country in which it has been produced, because the upstream supply chain differs from country to country. This country-specific characterisation is illustrated by a case study, in which the footprint of 1 kg wheat is investigated, see Figure 1.

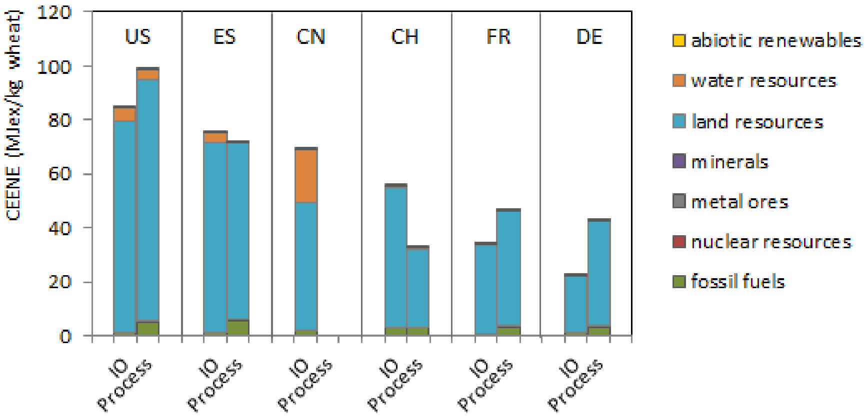

Figure 1: IO-CEENE and process-CEENE for 1 kg wheat in the United States (US), Spain (ES), China (CN), Switzerland (CH), France (FR) and Germany (DE)

While IO-CEENE footprints can be calculated for 44 countries, process-CEENE footprints (based on Ecoinvent v2.2) are only available for 5 regions: Spain, Switzerland, France, Germany and the United States. In this case study, IO-CEENE footprints were calculated for the same countries as in process-CEENE, plus one additional country, China. The IO-CEENE results were originally expressed in exergy (MJ_{ex}) per euro wheat and they had to be converted into exergy per kilogram, using the producer prices of the year 2000.[7]

When looking at the IO-CEENE results, the overall conclusion is that the United States, Spain and China have a much higher footprint than Germany and France. This can be explained by the more intensive agriculture of Germany and France, resulting in higher yields.[7] Because the output (1 kg wheat) is the same everywhere, a higher resource efficiency is obtained by a lower footprint, leading to the conclusion that France and Germany are more resource efficient than the United States, Spain and China.

When comparing the IO-CEENE to the process-CEENE results, one can notice that for the United States, Spain and France, these are quite similar. For China and Germany, there are larger differences. This shows the influence of using different inventory methodologies and databases. Also, there are no process-CEENE results for China, which implies that China should be approximated by one of the other countries, e.g. the United States, when using process-CEENE. However, when looking at the IO-CEENE results, there is a large difference between the United States and China regarding consumption of land resources and water resources. Approximating China by the United States may thus have a large influence on the final results. This illustrates one of the main advantages of IO-CEENE, namely the availability of country-specific CEENE values for each product. Further, having both IO-CEENE and process-CEENE available, it is also possible to perform hybrid LCA studies.

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