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Analysis

What Makes the Difference in Raw Material Equivalents Calculation Through Environmentally Extended Input-Output Analysis?

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ABSTRACT

This article describes an approach to improve the Czech model for raw material equivalents (RME) calculation to meet the standards of the Eurostat RME model. It also critically discusses the approach and suggests that some model features need revision. The improvements include further disaggregation of input-output tables; improvement of life cycle inventory data; hybridization of selected product groups; revaluation of imports at domestic prices; and adding additional information on recycling ratios for metal imports and the energy mix of electricity imports. It is shown that those improvements have a significant impact on RME of imports and exports (a decrease by 48% and 38%, respectively). The article further compares results for RME of imports and exports from the improved Czech RME model and the Eurostat RME country tool. These results differ by 24% and 16%, respectively, on an aggregated level, but the difference is much larger for particular material categories. Further improvements of the Eurostat country tool, such as a correction for unit prices of exports, are therefore recommended.

1. Introduction

The consumption of energy and materials is an indispensable prerequisite for the production of goods and services and for maintaining and increasing standards of living (Ayres and Warr, 2009). Materials are not only an important growth factor for the economy; their utilization is also connected to environmental pressures (Ayres and Simonis, 1994; Fischer-Kowalski and Haberl, 1993; Van der Voet et al., 2009; Weizsäcker et al., 2009). Materials first have to be extracted from the environment, then they are used for the production of goods and services to satisfy human needs; and finally they are released back into the environment in the form of emissions and waste. Environmental pressures occur at all stages of material processing.

Economy-wide material flow analysis (EW-MFA) focusing on the whole economy has been established to provide indicators that contribute to the management of resource use and output emission flows from both economic and environmental points of view (Eurostat, 2001; Fischer-Kowalski et al., 2011; OECD, 2008). The two most recently developed and applied EW-MFA indicators include raw material input (RMI) and raw material consumption (RMC) (Schoer et al., 2012b). RMI is the sum of domestically extracted raw materials, domestically harvested biomass and imports in terms of raw material equivalents (RME), while RMC is calculated as RMI minus RME of exports. RME or materials embodied in imports and exports represent the vector of raw materials needed world-wide to provide the product at the border (Eurostat, 2001). RMI and RMC are thus coherent in the sense that both domestic extraction and traded goods are considered as raw materials. On the other hand, the production-based EW-MFA indicators, direct material input (DMI) and domestic material consumption (DMC), are composed of two inconsistent parts: domestic extraction in terms of raw materials and traded weight of imports/exports, which presents a mixture of raw materials and manufactured products (Eurostat, 2001). Since the total weight of raw materials needed to produce manufactured products is usually several times greater than the weight of the products themselves (Kovanda and Weinzettel, 2013), a decrease in material consumption measured by DMI and DMC can be achieved by substituting the domestic production of manufactured products with imports. For instance, a country does not need to extract raw materials for the production of cars, but instead imports cars. As a result DMI and DMC decrease, since part of the extracted raw materials accounted for in DMI and DMC are transformed to wastes during car production and thus are not included in the car itself. DMI and DMC are therefore reduced by this waste transformation when the cars are imported instead of being produced domestically. Moreover, in an increasingly globalized world economy, a focus on domestic production processes provides only a segment of total production. Addressing the total resource

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used which can be attributed to European final consumption and considering European consumer responsibility requires rethinking the approach to raw material equivalents of foreign trade. This is the reason RMI and RMC are planned to soon complement DMI and DMC in policy-making, e.g. in the indicator scoreboard of the Resource Efficiency Roadmap, which is a part of the Resource Efficiency Flagship of the Europe 2020 Strategy (European Commission, 2011, 2016).

There are currently three groups of input-output approaches for calculating RME of imports and exports: 1) An approach working with the "domestic technology assumption" (DTA), 2) Hybrid life-cycle inventory input-output approach (LCI-IO), and 3) An approach that applies multi-regional input-output tables. For a detailed description of these three groups of approaches see Schoer et al. (2013). Weinzettel and Kovanda (2009) calculated RME of imports and exports for the Czech Republic through a hybrid life-cycle inventory input-output approach in their case study for the Czech Republic (CZ 2009 model). Their approach was taken as one of the starting points for development of the Eurostat model for RME calculation of the European Union (Eurostat, 2016a), which in turn served as a basis for development of the Eurostat country tool for RME calculation (Eurostat, 2016b).

Development of the Eurostat model for RME began in 2009, and since then it has become much more elaborate than the CZ 2009 model. A main aim of this article is to upgrade the Czech model to a standard comparable with that of Eurostat. It also critically discusses the approach used by the Eurostat RME model and suggests that some of its features might need revision. Moreover, the work is not significant only for the Czech Republic; it can serve as an example for other countries on how to develop similar models. The second goal is the comparison of results from the improved Czech RME model with results from the Eurostat RME country tool. This comparison can serve as a validation of the Eurostat country tool and suggest if any improvements to the tool are needed. As the Eurostat country tool is intended to be used for all EU countries, quite a lot countries will benefit from these improvements. From these reasons we believe that our article is significant and interesting for a large audience.

The rest of the article is structured as follows: Section 2 first briefly describes the basic features of the CZ 2009 model and then introduces its improvements and the overall design of the improved model on a more detailed level. It also provides information on the approach for a comparison of the model results with the results from the Eurostat country tool. Section 3 shows how various model improvements altered the original results and in what ways the improved results differ from results of the tool. Section 4 discuses reasons for the differences found, while Section 5 concludes that the differences between the CZ 2009 model and the improved Czech model are significant, thus justifying the elaboration of the original model described in this article. Finally, it suggests some directions for further development of the Eurostat country tool.

2. Material and Methods

2.1. CZ 2009 Model

The hybrid approach for RME calculation is based on the interconnections between the input-output analysis (IOA) introduced by Leontief (1936, 1970) and a life cycle assessment (LCA). The basis of IOA is represented by monetary input-output tables. For the CZ 2009 model these tables in NACE Rev. 2 classification[1], disaggregated by 88 CPA product groups[2], were provided by the Czech Statistical Office (various years-a) (for a list of the product groups see Supplementary Data 1). The hybrid approach allows for a calculation of the raw material equivalents of a group of products comprised in vector $\boldsymbol{y}$ ($\boldsymbol{RMEy}$):

$$\boldsymbol{RMEy} = \mathbf{F}.\,(\mathbf{I} - \mathbf{A})^{-1}.\,\boldsymbol{y} \quad (1)$$

where F is an environmental extension matrix, represented by direct material extraction (Czech Statistical Office, 2012b) per unit of domestic output, I is an identity matrix, A is a technology coefficients matrix and y is the vector of products for which RME is calculated.

The above calculation assumes that imported commodities are produced abroad using the same production technology as corresponding commodities in the domestic economy (sc. domestic technology assumption). Since this assumption need not hold for a range of products (especially when taking into account imports from developing to developed countries), the results can be significantly distorted. To overcome this shortcoming, life cycle inventory (LCI) data are integrated into the model for commodities for which the domestic technology assumption is not expected to hold. These data were retrieved from the Ecoinvent database (Ecoinvent, 2012) for natural gas, crude oil, metal ores and basic metals (CPA 06, 07, 24), which are not produced in the Czech Republic at all or only in minor quantities. For details on the reasons for and the process of data integration see Schoer et al. (2012b) and Weinzettel and Kovanda (2009). RME of imports (RME_{IM}) and RME of exports (RME_{EX}) can be calculated by replacing the vector y in Eq. (1) with vectors for total imports ($\boldsymbol{IM}$) and total exports ($\boldsymbol{EX}$), respectively.

$$\boldsymbol{RME_{IM}} = \mathbf{F}.\,(\mathbf{I} - \mathbf{A})^{-1}.\,\boldsymbol{IM} \quad (2)$$

$$\boldsymbol{RME_{EX}} = \mathbf{F}.\,(\mathbf{I} - \mathbf{A})^{-1}.\,\boldsymbol{EX} \quad (3)$$

For other details on the CZ 2009 model see Weinzettel and Kovanda (2009, 2011) and Kovanda and Weinzettel (2013).

2.2. Improvements to the Model

The CZ 2009 model was further developed for 2010 for which the Czech Statistical Office produced detailed input-output tables. We applied an approach which was almost fully based on the Eurostat RME model method (Eurostat, 2016a; Schoer et al., 2012a) and comprised the following steps:

a) Further sectoral disaggregation of input-output tables

As shown by various studies (Lenzen, 2011; Schaffartzik et al., 2015; Schoer et al., 2013), the level of disaggregation of input-output tables has a significant impact on RME results. This is because the calculation approach assumes the homogeneity of product groups which cannot be assured at a low level of disaggregation. It especially holds for extraction and primary processing product groups, which are responsible for 80% of RME of imports. The detailed input-output tables published by the Czech Statistical Office contained 184 product groups in total (Musil, 2016). Compared to the Eurostat RME model, they were less disaggregated for the extraction sector, at a similar level of disaggregation for manufacturing sector and at a higher level of disaggregation for construction and services. As a high level of disaggregation is crucial for a thorough consideration of extraction activities, the tables were further disaggregated for extractive industries up to the level of the Eurostat RME model. Relationships from the 182 × 182 monetary input-output table (MIOT) were used, which is the foundation of the Eurostat model (Eurostat, 2016a). The detailed Czech model thus contained 245 product groups in total (for a list of the product groups of the improved Czech model and the Eurostat RME model see Supplementary Data 1). The disaggregation procedure followed similar rules as the Eurostat RME model, details of which are described in Section 2.3 of its documentation (Eurostat, 2016a). The use of EU-wide data for disaggregation of the Czech input-output tables can be justified by Lenzen (2011): even if the data used for disaggregation are not for that specific country the quality of results can be significantly improved when different production technology (in this case the Czech Republic and in the EU) is maintained at the aggregate level

[1] NACE: statistical classification of economic activities in the European Community
[2] CPA: classification of products by activity