"Supply-Extension versus Use-Extension in Environmentally Extended Input-Output Modelling: Analyzing Physical Flows within the Austrian Economy"

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Keywords: *Environmentally Extended Input-Output Analysis, Material and Energy Flow Indicators, Raw Material Consumption, Environmental Accounting, Model Comparison*

Economy-wide material flow accounting is a methodological framework for the analysis of physical economies in the context of sustainability research. MFA's indicators of direct material flows, first and foremost Domestic Material Consumption (DMC), are characterized by a high degree of international standardization and harmonization. However, due to the fact that particularly high-income countries are increasingly outsourcing environmental burden and resource consumption to other world regions via international trade, the interpretation of trends in direct material flow indicators when evaluating dematerialization and resource efficiency of consumption activities can be misleading. This urges for an extension of the traditional production-based accounts with an additional consumption-based perspective. The consumption-based equivalent to DMC is the Raw Material Consumption (RMC) indicator, which measures the final consumption of products in terms of raw materials extracted world-wide and used in the complete production chain of final products. Environmentally extended input-output (EE-IO) models are increasingly deployed for the quantification of raw material consumption of countries. In general, monetary-based EE-IO models use inter-sectoral trade flows which are reported in monetary units for the allocation of material flows.

The overall goal of this study is to evaluate and compare the effects that two distinct construction principles (i.e. compilation approaches) of the environmental extension have on the allocation of physical flows to final demand categories and products when applying them to (identical) monetary IO structures. Results derived from two IO model calculations are compared where the first extension is constructed following a supply-logic and the second extension is constructed following a use-logic. Due to the fact that material use data are usually not available on a sector level, this study uses energy statistics, which are much more detailed with regard to industrial or sector uses as well as final consumption. First, the *Supply-Extension*, which represents the standard approach for the calculation of the RMC indicator, allocates energy to the energy producing sectors only and the further allocation to intermediate use and then final demand is done by the monetary IO construct. Second, the *Use-Extension* takes advantage of the detailed energy consumption data and allocates energy to the consuming sectors and final

demand categories directly. This represents the standard approach in energy accounting. By comparing the two model results this work seeks to shed some light on the effects stemming from the application of the supply-logic for the compilation of the environmental extension in consumption-based material flow accounting which becomes necessary due to data scarcity. This research lies at the core of the debate about material flow indicators estimated with monetary IO-Models and has been discussed theoretically in a large number of studies. The analysis is based on a detailed dataset on the supply and use of energy carriers and a single region Input-Output Model (SRIO) of Austria.

In general, the results indicate that the variations of the aggregated footprints of final demand categories are in a range of about 10%. For 2007, which is the most recent year of the time series, the variation for exports was highest with 7% of the total environmental extension. The footprints of the domestic categories of final demand derived from the *Supply-Extension* are higher than those of the *Use-Extension*. Consequently, the *Use-Extension* allocates more energy to the export category than the *Supply-Extension*. Nevertheless, we find the variations of the categories of final demand to be highly sensitive to its product mix. On the one hand, footprints of the *service* sectors are higher when calculated by the *Supply-Extension* in comparison to the results obtained from the *Use-Extension*. While on the other hand, the footprints of sectors producing primary goods are relatively smaller when applying the *Supply-Extension* instead of the *Use-Extension*. We find that the two extensions yield similar product footprint results for *manufactured mineral and metal products*.

In a further step, this study applied structural path analysis (SPA) and production layer decomposition (PLD) in order to analyze and identify structural supply chain patterns of the Austrian economy that contribute to the observed differences. Based on this, the study found that *manufactured mineral and metal products* have the 'longest' or most complex supply chains. Variations in the footprints of different products or product groups appear to correlate with the number of paths (i.e. inter-sectoral trade flows which ultimately deliver final products) contributing to the overall footprint. In general, the more paths or the more complex the production of a final product the higher the similarity of the product footprints derived from the *Supply-* and the *Use-extension*. We presume this is above all the effect of differences on the path or supply chain level which cancel each other out on the higher aggregated product level. Therefore, we propose the hypothesis that the application of monetary IO models for the calculation of RMC, when applying a supply-logic for the compilation of the environmental (material) extension, increases in accuracy as the relevance of international inter-sectoral trade relations increases. Moreover, this hypothesis connects to recent research findings on the effects of sector aggregation. As this study is based on a SRIO model with 57 sectors, it can be assumed that the observed effects will be minor for more detailed IO models. Therefore, we suggest further research through conducting the same analysis deploying an IO model with higher country and product detail. We hypothesize that a detailed representation of the energy sector by energy carrier would have a particularly high effect on the results and would reduce the effect of the construction principle applied to the energy extension.