Global Sensitivity analysis in dynamic MFA

Nada Dzubur[1], Hanno Buchner[1], David Laner[1]

[1]Institute for Water Quality, Resource and Waste Management, Vienna University of Technology, Karlsplatz 13, 1040 Vienna, Austria

Material flow analysis (MFA) is a tool to quantify the flows and stocks of materials in arbitrarily complex systems. Dynamic MFA is a frequently used method to assess past, present and future stocks and flows of materials in the anthroposphere (Müller et al. 2014). In contrast to static MFA, where material flows are determined for one balancing period and therefore time independent, material stocks and flows in a dynamic material flow model can potentially depend on all previous states of the system (Baccini and Bader 1996). Recently, dynamic MFA has become increasingly popular with the primary focus on the investigation of material stocks in society and associated end-of-life flows (cf. Laner and Rechberger, in press). Since models represent a simplification of the real metabolic system and because of data limitations in terms of quality and quantity, uncertainty is inherent to material flow analysis (MFA) (Laner et al. 2014). Therefore, uncertainty is a basic aspect of material flow modelling and needs to be explicitly considered to reduce uncertainties and inconsistencies as far as possible, thereby allowing for reliable decision support (Gottschalk et al. 2010, Laner et al. 2015). With respect to dynamic MFAs, the in-use stocks and end-of-life (EOL) material flows are typically estimated according to a top-down approach (i.e. accounting of the net flows into or out of the stock over time), where substantial uncertainty exists concerning model parameters such as average product lifetimes or historical material use patterns. In order to understand the effect of limited data quality and model assumptions on MFA results, the use of sensitivity analysis methods in dynamic MFA studies has been on the increase. So far, the usual sensitivity analysis in dynamic MFA is a One-at-a-time method, which is testing parameter perturbations individually and observing the outcomes on output. In contrast to that, variance based global sensitivity analysis decomposes the variance of the model output into fractions caused by the uncertainty or variability of input parameters (Saltelli et al. 2008). The process of recalculating outcomes under alternative assumptions to determine the impact of variables using global sensitivity analysis can be useful to identify model inputs that cause significant uncertainty in the output in order to increase robustness of the model and understanding of the relationships between input and output variables (Panell 1997). Interaction and time-delayed effects of uncertain parameters on the output of an archetypal input-driven dynamic material flow model using a sample based approach for variance based global sensitivity analysis proposed by Saltelli et al. (2008) are investigated in this study. The results show that determining the main (or first-order) effects of parameter variations is often sufficient in dynamic MFA, because substantial effects due to the simultaneous variation of several parameters (higher-order effects) do not appear for classical set ups of dynamic material flow models. Higher order effects may be relevant for secondary raw material production flows considering sorting and upgrading processes in advance because the probability density function for the respective sector split is located close to zero and several other parameters are multiplied with the sector split ratio to calculate the flow of interest. For models with time-varying parameters, time delay effects of parameter variation on model outputs need to be considered, potentially boosting the computational cost of global sensitivity analysis. The implications of exploring the sensitivities of model outputs with respect to parameter variations in the archetypical model are used to derive model- and goal-specific recommendations on choosing appropriate sensitivity analysis methods in dynamic MFA. Dynamic material flow models will gain in complexity in the future due to the consideration of various material quality layers (e.g. Buchner et al. 2015) or the requirement of closed mass balances applied to the model (i.e. recycled material flows have to (exactly) correspond with the quantities used in secondary production). Because higher order effects are expected to become more prominent in such models, the investigation of parameter interaction effects and parameter dependencies (e.g. Mara et al. 2015) will become a major field for extending the use of sensitivity analysis in dynamic MFA.

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