Method Précis: Material Flow Analysis

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Material flow accounting (MFA) aims to provide a biophysical representation of society-nature interactions that complements purely monetary economic accounting systems. It quantifies all material flows into and out of a socioeconomic system. MFA accounts for solid, gaseous and liquid materials excluding water and air and is measured in physical units (mass, usually metric tons) (Eurostat 2001; OECD 2008).

MFA represents a broad family of different accounts, from national to local levels or from aggregate materials to single substances (OECD 2008). Similar physical accounts are used to measure stocks and flows of energy, carbon and other relevant substances (see Method Précis on Energy Flow Analysis). Within this broader family, economy-wide material flow accounting (EW-MFA) is most widely applied and is part of standard statistical reporting in the EU (2011). EW-MFA considers all material inputs and outputs to the system, but it treats the socioeconomic system itself and any processes therein as a 'black box'. Methodological harmonization and standardization has been intensely promoted in past few years, resulting in high consistency among available datasets (Fischer-Kowalski et al. 2011).

EW-MFA measures all material flows that are required for the establishment, operation and maintenance of socioeconomic biophysical stocks. By convention, these biophysical stocks include humans, manmade artifacts (infrastructure, buildings, vehicles, machinery, durable goods, etc.) and productive livestock (animal husbandry and aquaculture). It follows that two system boundaries need to be defined: one between the socioeconomic system and its natural environment and another separating it from other socioeconomic systems. Concerning the first boundary, material inputs flows are raw materials extracted from the domestic natural environment (domestic extraction, DE), and outputs are wastes and emissions released to the natural environment (domestic processed outputs, DPOs). Flows crossing the second boundary are imports from and exports to other national economies. Following the laws of thermodynamics, particularly the law of conservation of mass, material inputs equal material outputs corrected by stock changes (for more details, see Eurostat 2001). Stock changes are material flows to socioeconomic stocks with a lifetime exceeding one year, or materials released from physical stocks and transformed to wastes and emissions (Fig. 9.7).

Domestic extraction (DE) is defined as the raw material extracted from nature. It includes agricultural harvest and forestry as well as raw material extraction from mining and quarrying. Material flows are usually grouped along four main material categories:

1. *Biomass* extraction includes all harvested plant-based biomass, that is, all crops, timber, grazed biomass and crop residues further used in socioeconomic processing. In addition, animal biomass from fishing and hunting is included

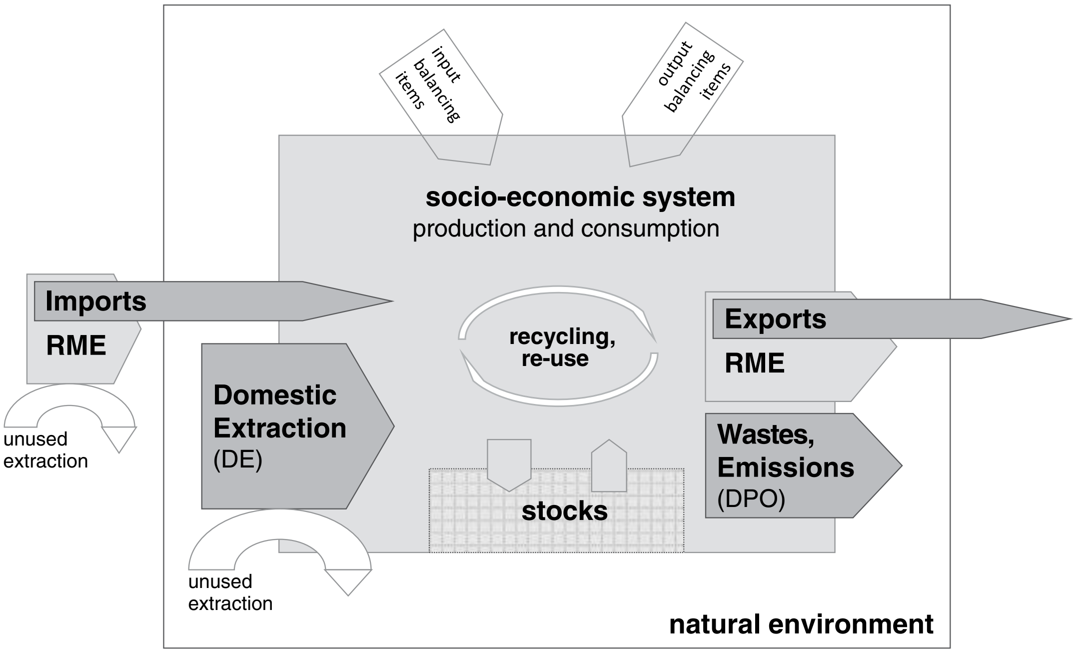

Fig. 9.7 Material flow accounting scheme. Legend: RME = Raw material equivalent. Input and output balancing items: to have a closed material balance, so-called balancing items have to be introduced into the MFA framework on both the input and output sides (water vapor, air as entry into combustion processes, etc.) (Eurostat 2001)

if it is extracted from populations of wild-living animals. Biomass production from domestic livestock is not counted as DE.

2. *Metallic minerals* comprise all ores accounted for as the mass leaving the mine, including the waste rock ('run-of-mine' approach).
3. *Nonmetallic minerals* comprise all minerals used in industrial processing and in construction, such as sand, clays, phosphate, salt and diamonds.
4. *Fossil energy carriers* include all coal, crude oil, natural gas and unconventional energy sources (such as gas hydrate, shale gas).

Material extraction data can be compiled from official statistics (for details, see Eurostat 2012). Some quantities are reported in units other than metric tons per year and must be converted into mass units. Some flows are only poorly or not at all reported in official statistics. In these cases, missing data have to be estimated using standardized MFA estimation procedures (Eurostat 2012; Krausmann et al. 2014). This applies to crop residues, grazed biomass and nonmetallic minerals used for construction purposes. In addition, gross ores often have to be estimated based on metal concentrates reported in statistics and the corresponding ore grades. Estimation procedures have been developed thoroughly over the years, and they aim to use biophysical data as a basis for the applied estimation procedure (Eurostat 2012).

In addition to materials extracted domestically, EW-MFA accounts for imports and exports (derived from foreign trade statistics, which report physical next to monetary units). Trade flows comprise products at very different stages of processing, namely, primary goods (copper ores, wheat), secondary products (copper wires, wheat flour) and final goods (mobile phones, cakes). This makes trade flows very different from material extraction, and the allocation of traded goods to one of the material categories is often difficult. However, correspondence tables have been developed (Eurostat 2012) that allow for an allocation of trade flows according to the main material content of the traded good.

Within the EW-MFA framework, several indicators can be calculated (Eurostat 2001; Fischer-Kowalski et al. 2011):

- Direct material input, DMI = DE + imports.
- Domestic material consumption, DMC = DE + imports − exports.
- Physical trade balance, PTB = imports − exports.
- Resource efficiency or resource productivity = GDP/DMC

MFA indicators are considered pressure indicators, and they are closely linked to socioeconomic activities—that is, they are indicative of the potential magnitude of environmental burdens related to economic activities. In order to discuss environmental impacts, MFA indicators need to be complemented by other indicators such as those from Life Cycle Assessments (see Method Précis on Life Cycle Assessment). The most prominent EW-MFA indicator is DMC, which is used as a key indicator for material use and, in relation to the GDP, as a proxy for resource efficiency in general (European Commission 2011). DMC represents the materials used within a socioeconomic system in the production process and/or in final consumption that are transformed into wastes and emissions.

Two other flows related to the EW-MFA framework should be mentioned.

In the course of extraction from nature, materials are moved or extracted without the intention of using them in socioeconomic processing or attributing economic value to them. These flows are commonly termed 'unused extraction' and include unused by-products in agriculture (straw and roots left on the fields), by-catch in fishery, overburden in mining and soil and rock excavated during the construction of infrastructure (Dittrich et al. 2012; Eurostat 2001). In most cases, no statistical data are available to account for this unused extraction, and the mass of these flows has to be estimated (Bringezu and Bleischwitz 2009). Obviously, the provision of data of sufficient quality, particularly for comparison across countries and time, is quite a challenge.

In recent years, the demand for indicators addressing the total raw material use of a country's final consumption has been growing. In such an indicator, all raw materials used in the production process of traded goods need to be considered. MFA summarizes these raw material inputs as raw material equivalents (RMEs; Eurostat 2001; Schaffartzik et al. 2014; see also Chap. 10 in this volume) of traded goods. Adding (subtracting) the RME of imports and exports to (or from) the DMC yields the indicator raw material consumption (RMC; Schaffartzik et al. 2014; or Chap. 10 in this volume) or the material footprint (Wiedmann et al. 2015). RMC measures the amount of raw materials extracted and used at the global level to manufacture the products consumed in one particular country. Recent policy documents (European Commission 2011) consider indicators such as RMC to address issues such as outsourcing and its relevance for resource productivity in forging strategies for a more sustainable use of biophysical resources.

References

Bringezu, S., & Bleischwitz, R. (2009). Sustainable resource management. In *Global trends, visions and policies*. Sheffield: Greenleaf Publishing Limited.

Dittrich, M., Bringezu, S., & Schütz, H. (2012b). The physical dimension of international trade, part 2: Indirect global resource flows between 1962 and 2005. *Ecological Economics, 79*, 32–43.

EU. (2011). *Regulation on European environmental economic accounts*. Regulation (EU) No 691/2011 of the European Parliament and of the Council. Official Journal of the European Union.

European Commission. (2011). *Roadmap to a resource efficient Europe*. COM(2011) 571 final. Brussels: European Commission.

Eurostat. (2001). *Economy-wide material flow accounts and derived indicators. A methodological guide* (pp. 1–92). Luxembourg: Eurostat, European Commission, Office for Official Publications of the European Communities.

Eurostat. (2012). *Economy-wide material flow accounts (EW-MFA)*. Compilation Guide 2012. Luxembourg: European Statistical Office.

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., et al. (2011b). Methodology and indicators of economy wide material flow accounting. State of the art and reliability across sources. *Journal of Industrial Ecology, 15*(6), 855–876.

Krausmann, F., Weisz, H., Eisenmenger, N., Schütz, H., Haas, W., & Schaffartzik, A. (2014). Economy-wide material flow accounting. In *Introduction and Compilation Guide*. Social Ecology Working Paper No. 151. Vienna: IFF Social Ecology.

OECD. (2008). *Measuring material flows and resource productivity*. Volume I. The OECD Guide. OECD, Paris; MA, USA.

Schaffartzik, A., Eisenmenger, N., Krausmann, F., & Weisz, H. (2014b). Consumption-based material flow accounting Austrian trade and consumption in raw material equivalents 1995–2007. *Journal of Industrial Ecology, 18*(1), 102–112.

Wiedmann, T., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations. *PNAS,*. doi:10.1073/pnas.1220362110.