Material Flow Accounting and Analysis (MFA)

A Valuable Tool for Analyses of Society-Nature Interrelationships

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1. Introduction

This paper aims at summarizing methodological foundations and the state of the art in the rapidly emerging field of material flow accounting and analysis (MFA). Sections 1 to 8 give a short description of the method starting with the historical development, presenting a general model of economy-wide material flow analysis, illustrating indicators that can be derived from MFA accounts, and explaining methods for the calculation of so-called "ecological rucksacks". Section 9 illustrates main areas of applications of MFA, and section 10 describes the shortcomings of this method. Section 11 presents an overview of the state of the art of existing studies. Section 12 discusses selected empirical results taken from recently published MFA studies for the European Union. Finally, section 13 gives an outlook on possible extensions and future methodological development.

2. Historical development of MFA

Material flow analysis builds on earlier concepts of material and energy balancing, as introduced, for example, by Ayres (1978).[1] The first material flow accounts on the national level have been presented at the beginning of the 1990s for Austria (Steurer, 1992) and Japan (Environment Agency Japan, 1992). Since then, MFA has been a rapidly growing field of scientific interest and major efforts have been undertaken to harmonise the different methodological approaches developed by different research teams. The Concerted Action „ConAccount" (Bringezu et al., 1997; Kleijn et al., 1999), funded by the European Commission, was one of these milestones in the international harmonisation of MFA methodologies. The second important co-operation was guided by the World Resources Institute (WRI), bringing together MFA experts for 4 (5 for the second study) countries. In their first publication (Adriaanse et al., 1997), material inputs of four industrial societies have been assessed and guidelines for resource input indicators have been defined. The second study (Matthews et al., 2000) focused on material outflows and introduced emission indicators.

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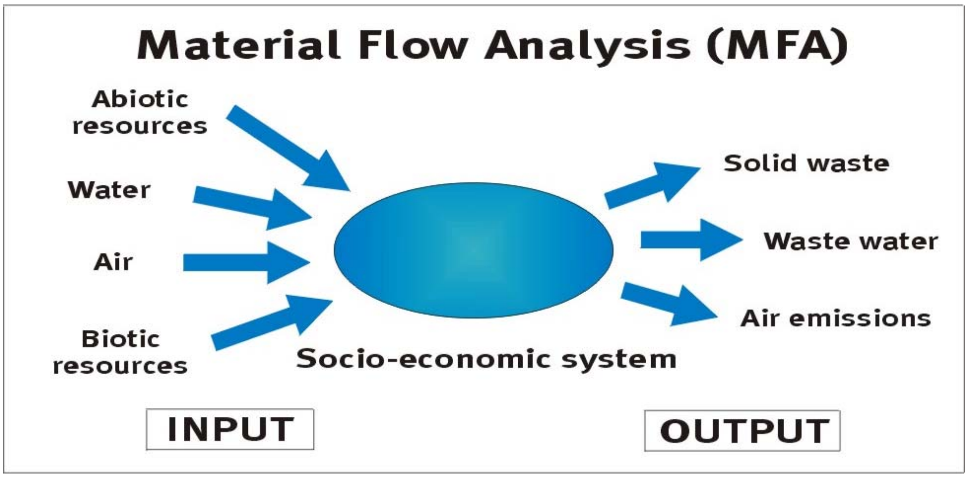
[1] For a comprehensive review on the history of the development of MFA see Fischer-Kowalski (1998b) and Fischer-Kowalski and Hüttler (1999).

In an international working group on MFA, standardization for economy-wide material flow accounting was for the first time achieved and published in a methodological guidebook by the European Statistical Office (EUROSTAT, 2001).

3. Methodological foundations

The principle concept underlying the economy-wide MFA approach is a simple model of the interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment and – similar to living beings – dependent on a constant throughput of materials and energy. Raw materials, water and air are extracted from the natural system as inputs, transformed into products and finally re-transferred to the natural system as outputs (waste and emissions) (see Figure 1). To highlight the similarity to natural metabolic processes, the terms "industrial" (Ayres, 1989) or "societal" (Fischer-Kowalski, 1998a) metabolism have been introduced.

Figure 1: The basic model of material flow accounting and analysis (MFA)



According to the first law of thermodynamics (the law of the conservation of mass), total inputs must by definition equal total outputs plus net accumulation of materials in the system. This material balance principle holds true for the economy as a whole as well as for any sub-system (an economic sector, a company, a household).

For a consistent compilation of an economy-wide material flow account, it is necessary to define exactly, where the boundary between the economic and the environmental system is set, as only resources crossing this border will be accounted for. As described in the System of Environmental and Economic Accounts (SEEA) (United Nations, 1993, 2001), the economic sphere is defined in close relation to the flows covered by the conventional System of National Accounts (SNA). Thus all flows related to the three types of economic activities included in the SNA (production, consumption and stock change) are referred to as part of the economic system. On the other hand, the environmental sphere comprises all resources other than products traded within the market system.

Therefore, for MFA at the national level, two main boundaries for resource flows can be defined. The first is the boundary between the economy and the domestic natural environment, from which resources (materials, water, air) are extracted. The second is the frontier to other economies with imports and exports as accounted flows.

4. Categories of material flows

Before outlining a comprehensive material balance scheme on the national level, we have to explain the differences between the different types of material flows. In its methodological guide, EUROSTAT (2001) advises to distinguish the various types of material flows according to the following scheme: [2]

Direct versus indirect

Direct flows refer to the actual weight of the products and thus do not take into account the life-cycle dimension of production chains. Indirect flows, however, indicate all materials that have been required for manufacturing (up-stream resource requirements) and comprise both used and unused materials (see also Section 5 and 6 of this thesis for a discussion on direct and indirect flows and their relevance for analyses of international trade).

Used versus unused

The category of used materials is defined as the amount of extracted resources, which enters the economic system for further processing or direct consumption. All used materials are transformed within the economic system. Unused extraction refers to materials that never enter the economic system and thus can be described as physical market externalities (Hinterberger et al., 1999). This category comprises overburden and parting materials from mining, by-catch and wood harvesting losses from biomass extraction and soil excavation as well as dredged materials from construction activities.

Domestic versus Rest of the World (ROW)

This category refers to the origin and/or destination of the flows. Combining these three dimensions to one table shows the 5 categories of material inputs relevant for economy-wide MFA (Table 1):

Table 1: Categories of material inputs for economy-wide MFA

Weight	Economic treatment	Origin	Term to be used
Direct	Used	Domestic	Domestic extraction (used)
(Not applied)	Unused	Domestic	Unused domestic extraction
Direct	Used	Rest of the world	Imports
Indirect	Used	Rest of the world	Indirect input flows associated to imports
Indirect	Unused	Rest of the world	

Source: modified from EUROSTAT, 2001

A standard material flow account focuses on flows of solid materials. This group is further classified into 3 main subgroups of material inputs:

- Minerals (metal ores and non-metallic minerals like stones, clays, etc.),
- Fossil energy carriers (coal, oil, gas), and
- Biomass (from agriculture, forestry and fishery).

The material stock

From the viewpoint of physical accounting, the accumulation of a large physical stock is one main characteristic of modern industrialised societies. Stocks in the MFA framework mainly

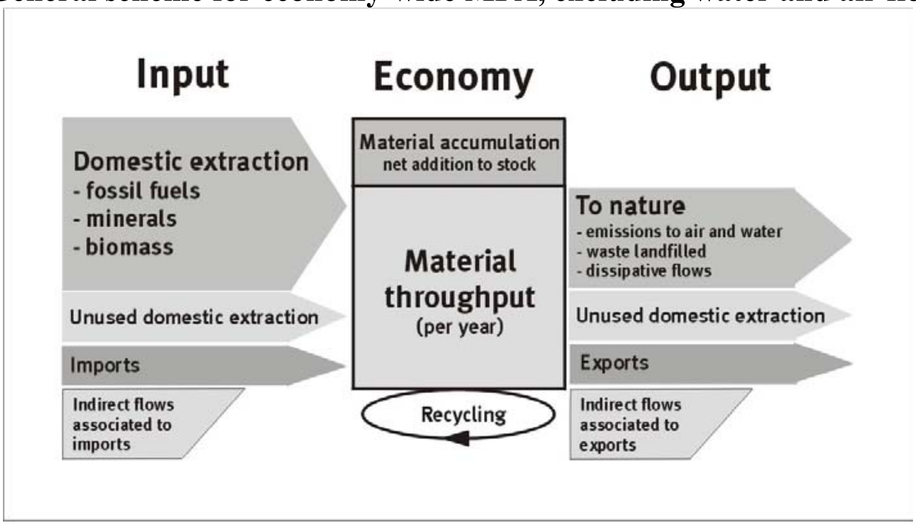
[2] For the categories of unused and indirect material flows, the terms „ecological rucksacks“ (Schmidt-Bleek, 1994) or „hidden flows“ (Adriaanse et al., 1997) have also been used in the literature.

comprise man-made assets: infrastructure and buildings on the one hand and durable consumption goods (like cars, household equipment) and investment goods (machinery) on the other hand. Forests and agricultural plants are considered part of the environmental system and are therefore not included in the physical stock, whereas harvests of timber and crops are accounted as inputs to the socio-economic system. EUROSTAT (2001) suggests treating waste deposited in controlled landfills as outputs of the economy to the environment rather than a physical stock.

5. A general scheme for economy-wide MFA

After having explained the various categories of material flows and the importance of the physical stock, a general balance scheme including all relevant input and output flows can be presented (Figure 2). The material balance reveals the composition of the physical metabolism of an economy and depicts domestic material extraction, imports and exports in physical units, the physical growth of its infrastructure as well as the amount of materials released back to nature.

Figure 2: General scheme for economy-wide MFA, excluding water and air flows



Source: EUROSTAT, 2001

Material inputs to the economic system comprise used domestic extraction of various material groups (fossil fuels, minerals and ores, and biomass). In addition, material inputs include so-called "unused domestic extraction (UDE)". UDE comprises materials that had to be moved during extraction activities, but do not enter the economic system for further processing (such as cover material or overburden from mining and residuals from harvest in agriculture). Consequently, unused flows do not have an economic value. These flows have been termed "hidden flows" in earlier MFA publications, as they are not "visible" in the monetary economy (for example, Adriaanse et al., 1997). Finally, material inputs include physical imports and indirect flows associated with them.

Material inputs are (a) accumulated within the socio-economic system (net addition to stock, such as infrastructure and durable consumer goods), (b) consumed domestically within the accounting period (in most cases one year) and thus crossing the system boundary as waste and emissions back to nature or (c) exported to other economies.

6. Indicators derived from economy-wide MFA

Within the internationally harmonised classification systems for environmental indicators, like the pressure-state-response (PSR) framework of the OECD (1994) or the extended Driving Forces-Pressures-State-Impact-Response (DPSIR) system of the European Union (EUROSTAT, 1999), material-flow based indicators are part of the pressure indicator group. These indicators identify and describe socio-economic activities, which cause pressures on the environment. However, their ability to provide information on the actual environmental *impacts* is very limited (see below).

A large number of resource-use indicators can be derived from economy-wide material flow accounts as illustrated in Figure 2, providing a comprehensive description of the biophysical metabolism of societies. These indicators can be grouped into (a) input, (b) output and (c) consumption indicators and have been developed in international co-operations in the course of the last 5-10 years (see, for example, Adriaanse et al. 1997, Matthews et al. 2000).

The following section lists the main indicators of each indicator group and is based on the suggestions in the methodological guide, published by EUROSTAT (2001).

Main input indicators:

- **Direct material input (DMI)** comprises all materials, which have economic values and are directly used in production and consumption activities. DMI equals the sum of domestic extraction plus imports.
- **Total material input (TMI)** is the DMI plus the unused domestic extraction.
- **Total material requirement (TMR)** includes - in addition to TMI - the indirect (used and unused) flows associated to the imports of an economy. TMR thus is the most comprehensive material input indicator, comprising all input flows illustrated in Figure 2.

Main output indicators:

- **Domestic processed output (DPO)** equals the flow „outputs to nature“ in Figure 2 and comprises all outflows of used materials from domestic or foreign origin. DPO includes emissions to air and water, wastes deposited in landfills and dissipative flows. Recycled materials are not included in the DPO indicator.
- **Total material output (TMO)** includes additionally to the DMO also the unused domestic extraction thus comprises all three categories of output flows shown in Figure 2.

Main consumption indicators:

- **Domestic material consumption (DMC)** measures the total quantity of materials used within an economic system, excluding indirect flows. Thus DMC is the closest equivalent to aggregate income in the conventional system of national accounts. DMC is calculated by subtracting exports from DMI.
- **Total material consumption (TMC)** includes, in addition to DMC, also the indirect flows associated to imports and exports and can be calculated using either LCA-oriented or input-output techniques (see also below). TMC equals TMR minus exports and their indirect flows.

Physical Trade Balance (PTB): A PTB expresses whether resource imports from abroad exceed resource exports of a country or world region and to what extent domestic material consumption is based on domestic resource extraction or on imports from abroad. A physical trade balance is compiled in two steps. A PTB for direct material flows equals imports minus exports of a country or region. A comprehensive PTB can also be calculated including indirect flows associated to imports and exports.

Net addition to stock (NAS) describes the annual accumulation of materials within the economic system and thus could also be termed „physical growth of the economy". Materials forming the stock mainly consist of construction materials for new infrastructure and durable goods, such as cars and industrial machinery.

7. The LCA-oriented method for calculating indirect material flows

Two main approaches for assessing the indirect flows associated with imports and exports can be identified. The first approach is based on a simplified life-cycle assessment (LCA) of products or product groups, accounting for life-cycle wide resource inputs. The first approach shall be presented below. The second approach applies input-output analysis on the sectoral level and will be discussed in the next section.

The LCA-oriented method for calculating indirect material flows required in the whole life cycle of a product has been developed at the *Wuppertal Institute for Climate, Environment and Energy* in Germany. The so-called "Material Intensity Analysis (MAIA)" (Schmidt-Bleek et al., 1998) is an analytical tool to assess material inputs along the whole life cycle of a product, including the so-called „ecological rucksack" (Schmidt-Bleek, 1992, 1994). The ecological rucksack can be defined as „the total sum of all materials which are not physically included in the economic output under consideration, but which were necessary for production, use, recycling and disposal. Thus, by definition, the ecological rucksack results from the life-cycle-wide material input (MI) minus the mass of the product itself" (Spangenberg et al., 1998, p. 15).

To use the terms proposed by EUROSTAT, the ecological rucksacks of imported products equal their indirect flows and consist of both used and unused materials. The so-called „rucksack-factor" is the ratio of the materials included in the ecological rucksack and the produced good (expressed in tons/tons).

The Wuppertal Institute today is the most important source for data on indirect material flows. At the website of the Wuppertal Institute, a spreadsheet with a number of „rucksack-factors", mostly for abiotic raw materials, building and construction materials and selected chemical substances can be downloaded.[3] An extensive description of indirect flows for imported products can be obtained from the study „Total Material Requirement of the European Union" (Bringezu and Schütz, 2001c). Detailed lists with „rucksack-factors" for minerals and metals as raw materials and semi-manufactured products as well as some factors for biotic resources are provided. Schütz (1999) and Bringezu (2000) also published good summaries for the calculation of indirect flows with the LCA-based approach.

This LCA-oriented approach is mainly suitable for the calculation of indirect flows associated to biotic and abiotic raw materials and products with a low level of processing. Applying this method to calculate indirect flows for semi-manufactured and finished products requires the compilation of an enormous amount of material input data at each stage of production. This is a cost- and time-intensive undertaking and makes the definition of exact system boundaries a difficult task (see also Joshi, 2000). Therefore, indirect material flows have only been estimated for a very small number of finished products. A more convenient methodology for calculating the indirect flows on the macro level therefore is to apply input-output analysis. This allows quantifying the overall amount of material requirements stemming from inter-industry interrelations along the production chain (what is similar to the indirect effects in input-output-analysis).

[3] The link: www.wupperinst.org/Projekte/mipsonline/download – document: MI-Werte.pdf.

8. The input-output based approach for calculating indirect flows

An alternative and, to our view, more promising method for calculating indirect flows on the macro level is to apply input-output (IO) analysis, which allows the comprehensive accounting of direct and indirect resource flows activated by final demand. IO-analysis has been introduced by Leontief and carried out for monetary studies since the 1930s (Leontief, 1936). Since the late 1960s input-output methods have also been used to describe and analyse the economy-environment relationship.

One of the most important applications of input-output analysis is the calculation of total input requirements for a unit of final demand. By doing so, one can assess not only the direct requirement in the production process of the analysed sector itself, but also all indirect requirements resulting from intermediate product deliveries from other sectors. Thus the total (direct and indirect) input necessary to satisfy final demand (e.g. private consumption, exports) can be determined (Miller and Blair, 1985). The recently published methodological handbook for economy-wide material flow accounting (EUROSTAT, 2001) also demands for the further development of IO-based approaches for calculating indirect flows associated to imports and exports.

Input-output calculations of resource use can be based on both monetary (MIOTs) and physical input-output tables (PIOTs). PIOTs are, in principal, better suited to calculate indirect resource requirements, as the attribution of direct and indirect resource inputs to the different categories of final demand follows the physical structure of the economy, which differs substantially from the monetary structure (Hubacek and Giljum, 2003; Konijn et al., 1997). By using a PIOT, final demand sectors with the highest material flows (primary sectors, such as agriculture or mining) are also attributed the highest material inputs, whereas by using a MIOT, sectors with high monetary values (high-tech and service sectors) obtain the major share of material inputs in the IO calculation. However, the main obstacle to a broad application is the lack of data, as PIOTs have only been compiled for a few European countries and thus no multi-country models in physical units have been presented so far.

The method how to link monetary input-output models with material flow calculations on the national level has been presented by Femia, Hinterberger and Moll (Femia, 1996; Hinterberger et al., 1999; Hinterberger et al., 1998; Moll et al., 2002). The authors give detailed descriptions how to calculate resource productivities of different sectors disaggregated in monetary input-output tables and to estimate overall (direct and indirect) material inputs to satisfy final demand. This method has also been applied in the project "Work and Ecology", carried out by three research institutions in Germany (Hans-Böckler-Stiftung, 2000). In this project, a dynamic input-output model for Germany ("Panta Rhei", see Meyer et al., 1998) has been extended by material input data, in order to simulate and evaluate sustainability scenarios (Hinterberger et al., 2002; Spangenberg et al., 2002).

The major advantage of this approach compared to the LCA-based calculation is the fact that for studies on the national level only material inputs and physical imports have to be known and linked to the monetary IO table in order to calculate direct and indirect material inputs and resource productivities of all sectors (including service sectors) of the economic system. On the global level, the task becomes even easier, as only material inputs of the primary extracting sectors have to be assessed. Indirect flows of imports are then calculated by the economic model. This shall be explained in more detail in the following section.

Concerning monetary input-output models, a few model systems have been presented, which are closed on the world level, thus covering not only all national economic activities, but also all monetary transactions related to international trade. The most elaborated global input-output model system has been presented by Meyer and Uno (1999) under the abbreviation of COMPASS or GLODYM. The model system distinguishes 66 countries/regions and depending on the type of country model up to 36 economic sectors.

Using the GLODYM model system for calculating indirect material flows (ecological rucksacks) allows the comprehensive assessment of all direct and indirect material flows (domestically extracted or imported) related to production and consumption activities with much less effort and higher consistency than applying the LCA-based method. Less effort results from the fact that only material inputs of those economic sectors have to be collected, which are extracting primary materials (mainly mining, agriculture and forestry, construction).

In the EU-funded project "MOSUS" (Modelling opportunities and limits for restructuring Europe towards sustainability, see www.mosus.net), the GLODYM model system is extended by physical input data (material inputs and land use) in order to quantify European use of resources, including "ecological rucksacks" induced by international trade flows in other regions of the world.

9. Main applications of economy-wide MFA

The main purpose of economy-wide MFA is to provide aggregate background information on composition and changes of the physical structure of socio-economic systems. MFA represents a very useful methodological framework for analysing economy-environment relationships and deriving environmental and integrated environmental/socio-economic indicators. Material flow-based indicators can be aggregated from the micro to the macro level. They allow comparisons with aggregated economic or social indicators such as GDP and unemployment rates, thus providing policy makers with information they are used to handle, and can therefore help shift the policy focus from purely monetary analysis to integrating biophysical aspects (Kleijn, 2001). Due to consistent and comprehensive data organisation, MFA can be directly affiliated to existing economic accounting schemes, like the system of national accounts (SNA) and is part of extended environmental and economic accounts, like the SEEA system of the United Nations (Weisz, 2000). In October 2000 the OECD *Working Group on the State of the Environment* has dedicated a special session to MFA, which also reflects the increasing recognition of this concept in international organisations (OECD, 2000).

The main purposes of economy-wide material flow accounts and balances are summarised in Box 1.

Box 1: Main purposes of economy-wide material flow accounts and balances

- Providing insights into the structure and change over time of the physical metabolism of economies;
- Deriving a set of aggregated indicators for resource use, including for the EU-level initiative on Headline Indicators and the United Nations' initiative on Sustainable Development Indicators;
- Deriving indicators for resource productivity and eco-efficiency by relating aggregate resource use indicators to GDP and other economic and social indicators;
- Providing indicators for the material intensity of lifestyles, by relating aggregate resource use indicators to population size and other demographic indicators;
- Through their underlying data structure integrated with the national accounts contributing to organising, structuring and integrating available primary data and ensuring their consistency;
- Reacting flexibly and quickly to new policy demands (for example, related to specific materials) through this data structure which can be adjusted easily and put to additional uses;

- Permitting analytical uses, including estimation of material flows and land use induced by imports and exports as well as decomposition analyses separating technological, structural and final demand changes.

Source: EUROSTAT, 2001

10. Shortcomings of the MFA approach

Several important shortcomings and limits of the standard MFA method can be identified. The two main shortcomings are the aggregation of different qualities of material flows to derive aggregated indicators and the weak links between MFA indicators and environmental impacts.

Big material flows dominate all indicators and bias interpretations of aggregated results. Aggregated MFA indicators can, to a large extent, be dominated by only one material category, which can lead to misinterpretations of results, as detailed information on developments of other material groups or economic sectors is diluted or obscured. The collection and interpretation of MFA data should therefore always be carried out on a level, which disaggregates economic sectors and/or material groups.

Another major point of critique is the fact that weight-based MFA indicators do not tell anything about actual environmental impacts. These impacts are, however, a crucial factor in the evaluation of economic development from the perspective of environmental sustainability. The sole focus on the reduction of aggregated resource use is a necessary, but not sufficient, precondition for achieving environmental sustainability. The question remains as to what exactly has to be reduced to achieve a sustainable resource throughput (see, Reijnders, 1998).

Although problems related to weight-based aggregation are in principle recognized by the MFA community, this procedure has been justified by the intention to create "value-neutral physical accounts that include all materials, regardless of their economic importance or environmental impacts" (Matthews et al., 2000, p. 2). However, small material flows, which might be neglected in aggregated indicators, can have large environmental impacts. Therefore, monitoring changes in the composition of aggregated indicators due to substitution between different materials or between different technologies is of crucial importance for the environmental performance of an economy. Negative environmental impacts are in many cases determined by qualitative characteristics of different material input or output flows and cannot be adequately depicted by quantitative numbers. Suggestions how to weight material outflows according to their different potential of environmental harm have been presented for example by Fröhlich et al. (2000) and Matthews et al. (2000). In the latter publication, the characterisation of different material flows is made on the basis of quantity, mode of first release, quality, and velocity (expressed as residence time). The method also allows estimating outflows to the environment and net additions to stock from input flows based on the velocity, in which material flows pass through the economic system. However, an internationally standardized procedure for considering qualitative differences in the quantitative concept of MFA is so far still missing.

Finally, in most MFA studies carried out so far, the link to the actors responsible for the activation of material flows is not established. Consequently, it is not investigated, which groups of society (consumers, entrepreneurs, etc.) could contribute to what extent to a strategy of dematerialisation for the country under investigation (Hinterberger et al., 1996). So far MFA did not contribute sufficiently to political conclusions to be drawn from its results. MFA studies in most cases focused on methodological issues and the presentation of material balances and aggregated indicators. In general, authors did not take a step beyond the presentation of results, to further reflect on possible policy-related uses of results. This applied policy-related evaluation of MFA results should be one central issue for further development of material flow analysis in the future.

11. State of the art in economy-wide MFA

The number of countries, which already compiled or currently are in the stage of compiling economy-wide material flow accounts according to the methodological guidelines presented above, is rapidly increasing. So far, full MFAs have been presented for the USA, Japan, Austria, Germany and the Netherlands within the framework of the two MFA projects co-ordinated by the World Resources Institute (WRI) (Adriaanse et al., 1997; Matthews et al., 2000; for calculations of material inputs for Austria see also Schandl, 1998). In addition, MFAs for Italy (de Marco et al., 2001; Femia, 2000), Denmark (Gravgaard Pedersen, 2000), Finland (Muukkonen, 2000), Sweden (Isacsson et al., 2000), the United Kingdom (Bringezu and Schütz, 2001d; Schandl and Schulz, 2000), France (Chabannes, 1998), the Czech Republic (Scasny et al., 2003) and Australia (Poldy and Foran, 1999) exist. For Poland (Mündl et al., 1999), Hungary (Hammer and Hubacek, 2002), Chile (Giljum, forthcoming) and China (Chen and Qiao, 2001) studies on the economy-wide material inputs have been presented. The calculation of the indicator „Total Material Requirement (TMR)“ for the European Union (EU-15) (Bringezu and Schütz, 2001b) as well as the first material balance of the European Union (EU-15) (Bringezu and Schütz, 2001a) have been published by the European Environmental Agency (EEA) and the European Statistical Office (EUROSTAT), respectively. EUROSTAT (2002) recently also published updated material input and consumption indicators for all member countries and the EU-15.

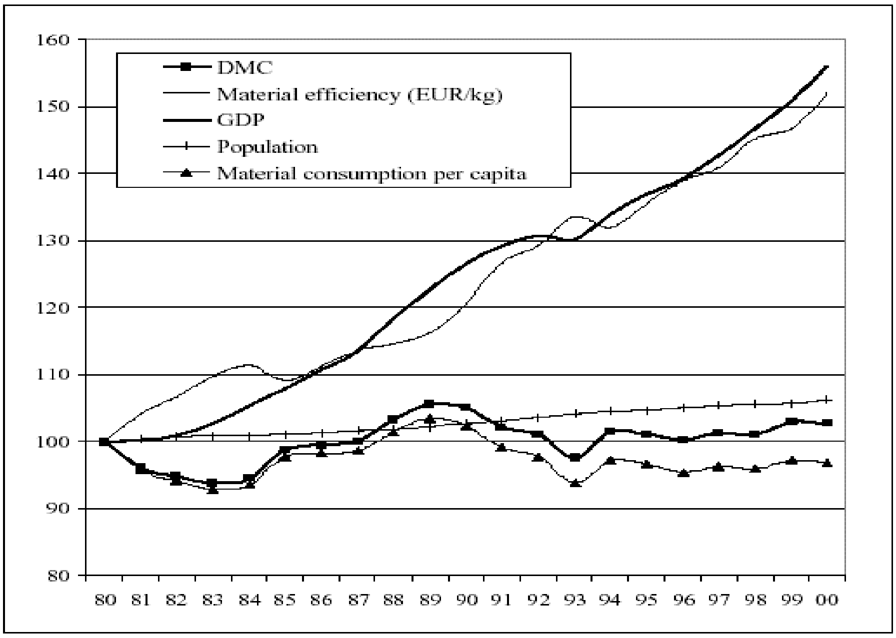
Within the framework of two research projects funded by the European Commission, MFAs for Brazil and Venezuela (Amann et al., 2002; Castellano, 2001; Machado, 2001), Thailand, Laos, Vietnam and the Philippines have been or are being compiled under methodological consultation of the Institute for Interdisciplinary Studies of Austrian Universities (IFF) / Department of Social Ecology.

12. Selected empirical results

As listed above, a rapidly growing number of country studies exist in the literature. The empirical results presented in this section can therefore only provide examples on how MFA data can be depicted and analysed.

Recently, the European Statistical Office published revised data for natural resource use in the European Union. Figure 3 illustrates the indicators of direct material consumption (DMC), material efficiency, GDP, population and DMC per capita in indexed form.

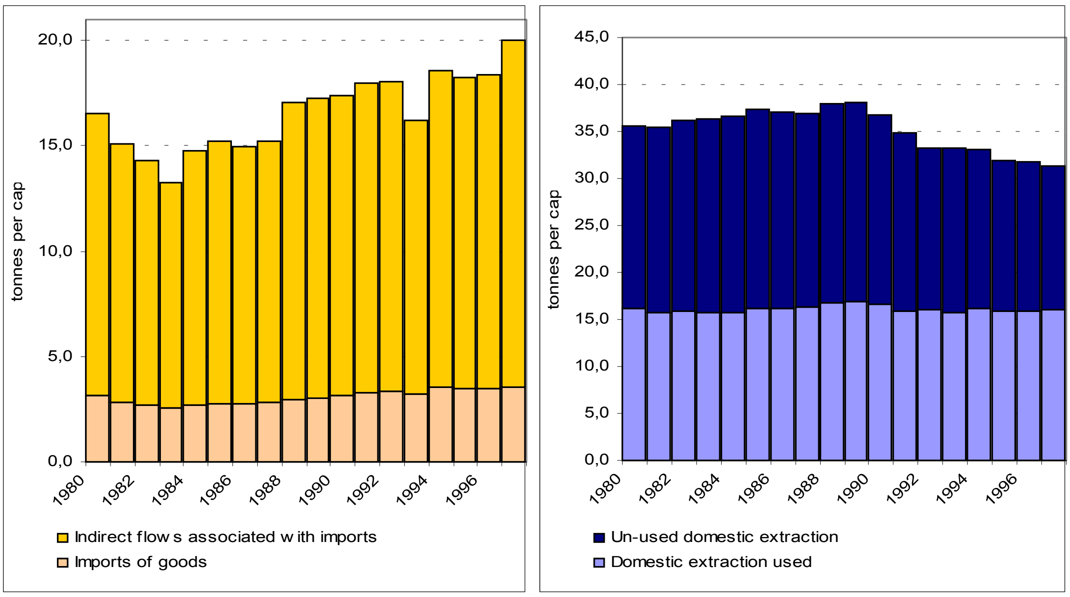
Figure 3: DMC and material efficiency for the European Union, 1980-2000



Source:
EUROSTAT, 2002

The figure illustrates that DMC and DMC per capita stayed more or less constant in this period of 20 years, while GDP grew steadily. As a consequence, a relative de-coupling (or de-linking) between GDP growth and resource use could be observed in the EU, indicated by a significant increase in material efficiency (or material productivity). However, as stated above, DMC only includes direct material flows and leaves the categories of unused domestic extraction and indirect flows associated with imports unconsidered. To complete the picture of resource use in the EU, Figure 4 presents foreign and domestic shares of EU total material requirement (TMR).

Figure 4: TMR of the European Union, 1980-1997, in tons per capita



Source: Moll, 2003

In this calculation, the so-called ecological rucksacks were taken into account. It can clearly be taken from the figure that these flows hold a significant share in total material requirement. Furthermore, an apparent trend can be observed towards an increasing foreign share of TMR (due to rising indirect flows associated with imports), while the domestic share (in particular the category of unused domestic extraction) is decreasing. In 1997, around 2/5 of Europe's TMR was provided by other countries. This trend can be explained by the reduction of domestic extraction of metals and fossil fuels (especially coal) and increasing imports in these categories from other world regions, which highlights the importance of including ecological rucksacks in the evaluation of the environmental performance of a country or world region within a global context.

13. Extensions and further methodological development of MFA

In this final section, four areas for extensions and further methodological development of the MFA approach shall be discussed. They comprise the consideration of qualitative aspects of different material flows, the sectoral disaggregation in so-called physical input-output tables (PIOTs), MFA applications on the regional level and the links between material flow accounting and land use accounting.

13.1. Valuation of material flows according to environmental impacts

One major point of critique of the MFA approach is the fact that weight-based MFA indicators do not tell anything about actual environmental impacts (see above). In life cycle assessment (LCA), the development of a common framework for environmental impact assessment has been a major issue in the past 10 years and today there is general agreement on the most relevant impact categories and corresponding indicators (for example, de Haes et al., 1999). The system of relevant categories comprises extraction of biotic and abiotic resources and land use on the input side and a number of impact areas on the output side (such as climate change, human toxicity and eco-toxicity, acidification and nitrification). Furthermore, a number of evaluation methods have been developed which allow aggregating different effects into an overall judgment of alternative options (for example, Notarnicola et al., 1998).

Further development concerning the qualitative evaluation of MFA data could adapt these existing valuation methods, in order to come up with alternative procedures to weight-based aggregation. Some authors (Brunner, 2002) even state that MFAs are of no use, if data presentation is not followed by a critical assessment of the meaning of results in a policy context. Additional procedures are therefore needed to perform an evaluation of MFA results.

Weighting approaches based on a distance-to-target determination represent one group of valuation methods and have been applied in a large number of LCA studies (Seppälä and Hämäläinen, 2001). These methods would be in particular appropriate to be performed with MFA data, as valuation starts from physical flows. The "Ecoscarcity" of "Ecofactor" method (Ahbe et al., 1990) relates the critical load of a substance to the actual load of anthropogenic emissions of that substance, with the critical load being derived from national agreements on the limits for environmental load of a certain flow. This procedure has been criticized, as results depend on national political priorities, which implies that there will be different ecofactors for every country. This fact would make international comparisons of "Ecoscarcities" impossible (Notarnicola et al., 1998). In other distance-to-targets methods, such as the "Eco-Indicator 95" approach (Goedkoop, 1995), targets are determined from ecological critical loads deriving from environmental science.

So far, distance-to-targets methods have mainly been applied on the level of products or product systems within LCA. On the macroeconomic level, a similar approach has been introduced under the term "sustainability gap" (Ekins and Simon, 1999). The "sustainability gap" can be defined as the difference between the current level of environmental impact from a particular source and the sustainable level of impact according to sustainability targets derived from scientific considerations. "Sustainability gaps" have been estimated for a number of air pollutants for the UK and Netherlands (Ekins and Simon, 2001).

All distance-to-target methods presented so far have their focus on material outflows (waste and emissions) of production and consumption activities. In order to apply this approach for the evaluation of MFA data, further methodological development of this type of assessment framework is needed to consider equally the extraction of biotic and abiotic resources.

13.2. Physical Input-Output-Tables (PIOTs)

Physical input-output tables (PIOTs) provide the most comprehensive description of anthropogenic material flows. A PIOT describes the material and energy flows between the socio-economic system and the environment (thus providing the same information as economy-wide material flow accounts described above) and in addition the flows between the different sectors within an economic system. Furthermore the net-accumulation of materials in the economic system is accounted for.

Concerning the flows of intermediary products within the economy (1st quadrant), PIOTs are directly comparable to monetary input-output tables (MIOTs), but with the products of the intra-industry trade listed in physical units (tons) instead of monetary (value) terms. The most wide-ranging extension of PIOTs compared to MIOTs is the inclusion of the environment as a source of raw materials on the input side (3rd quadrant) and as a sink for residuals (solid waste and emissions to air and water) on the output side of the economy (2nd quadrant) (Stahmer et al., 1997). Thus also the resource flows, which have no economic value, are integrated into the system of PIOTs.

Like economy-wide MFA, a PIOT lists the overall amount of materials flowing into and out of the socio-economic system. In addition, the sectoral disaggregation of data allows analyses of resource intensities of the different branches and highlights the correlation of material inputs, produced goods and residuals in each sector, thus providing information on the resource efficiency in production processes. As the symmetric physical input-output table is directly comparable to the MIOT, various possibilities for parallel studies of material and monetary flows as well as the correlation of the physical and monetary data arise. Residuals, such as air or water emissions, can thus be directly connected to the MIOT and scenarios on the impacts of specific policy strategies can be developed and analysed (Stahmer et al., 1997). Apart from the accounting of direct material inputs of economic activities, the application of input-output analysis enables the calculation of indirect material flows activated in production chains. These indirect flows can then be attributed to categories of final demand (e.g. private consumption and exports).

However, since the compilation of a full set of a PIOT is a very work- and time-intensive task and requires the availability of highly disaggregated production and trade data as well as data on domestic material extractions and water use, only a few economy-wide PIOTs have been presented until today (for example, Gravgaard Pederson, 1999; Statistisches Bundesamt, 2001b; Weisz et al., 1999).

13.3. Regional MFA

Several empirical MFA studies on regional or local levels have been carried out in the past. However, compared to the large number of MFA studies on the national level, published studies on the regional or local level are still very limited and a standardised method such as presented by EUROSTAT (2001) for the national level does not exist yet.

One main difference between regional and national MFAs concerns the data sources. On the national level most of the data needed can be obtained from publications from statistical offices directly in published form. Almost all material input and trade data in physical units is accessible. On a regional level, data availability in general is much smaller. Data may have to be gathered in a more time consuming process as it may be dispersed among several institutions and not be available centralised (like on national levels at national statistical offices or from the United Nations). Furthermore, data may not be available in physical units at all for a number of material flows and therefore may have to be estimated from more general data. Two main methodological differences between the national and the regional level concern import (and export) flows and confidentiality of data. On national levels trade flows for the whole country are reported by official statistics. On a regional level trade flows have to be separated into interregional or intranational trade flows (physical flows between the region and the rest of the country) and international trade flows (physical flows between the region and the rest of the world outside the country). For both kinds of flows different statistical sources and methods of estimation may have to be used.

Confidentiality of data on a regional level could be a problem if the production structure in a certain branch within the region is dominated by a small number of firms. In that case data for the whole region could allow conclusions on the production quantities or technologies of single firms and could than be confidential. For a more detailed description on the issue of regional MFA see Hammer et al. (2003).

13.4. Linking MFA and land use accounting

It is generally agreed among ecological economists that – together with energy and material flows – land use is the third important natural resource input category of economic activities (see for example, Spangenberg and Bonnoit, 1998).

The so-called "ecological footprint" is regarded as one of the most influential approaches for the communication of the concept of environmental sustainability and uses the limited availability of biologically productive areas on the planet as a symbol for the limited carrying capacity for anthropogenic environmental stress. However, a number of critical points concerning the calculation procedure of EFs have been raised (see, for example,van den Bergh and Verbruggen, 1999).

In our opinion, the most suitable approach for including land use aspects in physical accounts is to use land cover data, available from land use statistics (for example, Statistisches Bundesamt, 2001a) or from Geographical Information Systems (GIS) (for example, European Environment Agency, 2000). A parallel but separate analysis of the two categories of material flows and land use reduces the communicability of information by increasing complexity. However, problems connected to the conversion of one category into the other and the related loss of information are avoided, which significantly increases scientific transparency and credibility of the approach (Spangenberg et al., 1998).

On the product (micro) level, the definition of an indicator, which relates the intensity of land use to the service provided has been discussed (Schmidt-Bleek, 1994). This procedure would follow the approach of "MIPS" (material intensity per service unit) developed for the category of material use.

If material flow and land use data can be allocated to economic sectors (for example, within the framework of input-output tables), parallel analysis of resource intensities and land intensities of different economic activities can be carried out. This type of analysis can clarify the relation between material flows and land use and provide answers to the question, whether the most material intensive sectors are also the sectors with the highest intensity of land use.

To our knowledge, no empirical study has been published so far addressing questions of the spatial distribution of material flows and the implications of changes in the metabolic profile of regions for regional land use changes. Future research should focus on the possible trade-offs between reductions of material intensity and land intensity, respectively and the question, whether land intensity could be one possible criterion to evaluate different types of material flows.

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