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Economy-wide Material Flow Accounting
Introduction and Guide

Version 1.2

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Preamble: The SEC MFA guide

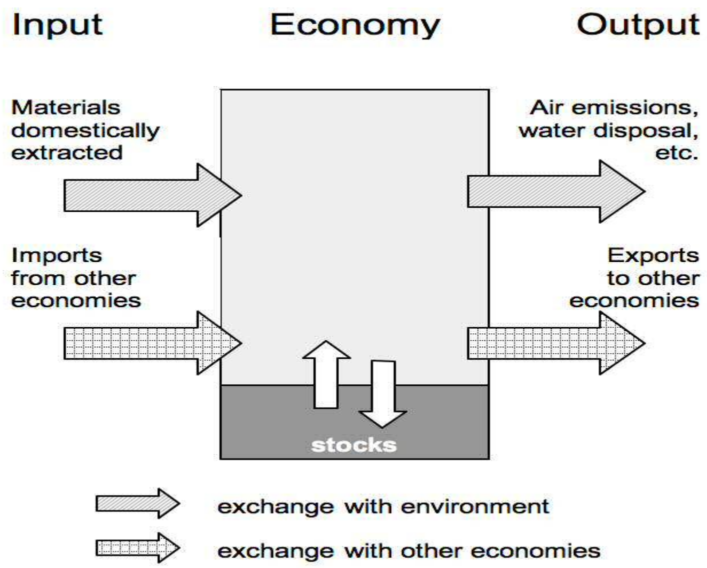
The Institute of Social Ecology (SEC) guide for economy wide material flow accounting (EW-MFA) provides an introduction to accounting principles and practical support for students, statisticians, researchers and all others concerned with material flow accounting. This guide is a revised and modified version of the 2009 draft of the Eurostat MFA compilation guide, which served as a working document in the process of the development of the current Eurostat Guide for EW-MFA.[1] The guidelines have been updated and adapted to fit the needs for a global application and for the reconstruction of historic time series of material flow data. The guide refers to international databases with global coverage and provides suggestions and examples for estimation procedures and coefficients for different world regions and historic time periods. Adaptations to the procedures described in the Eurostat Guide have been made in particular for the estimation of grazed biomass and crop residues, for the estimate of sand and gravel consumption in construction activities and for gross ore estimations. Material flow accounting is a dynamic field and methods and data sources are continuously improved. The guidelines should be seen as work in progress and the methods and estimation procedures described in this handbook represent the state of the art in 2018. Methods and estimation procedures can and should be adapted to country specific situations. Further improvements and adaptation of the methods is strongly encouraged.

[1] Economy-wide Material Flow Accounts (EW-MFA), Compilation Guide 2013, 10 September 2013, European Statistical Office. Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/2013_EW-MFA_Guide_10Sep2013.pdf.

Introduction

In the past years the physical dimension of economic processes, in particular the socio-economic use of materials, was increasingly recognized internationally as a key area for a sustainable development strategy. In 2001 the Gothenburg Council adopted the Sustainable Development Strategy which was revised in 2006 (Council of the European Union 2006). Japanese policy makers already very early focussed on resource use and recycling and Japan was the first country to implement a legal binding policy programme, the 3R action plan, in 2001 (Takiguchi and Takemoto, 2008). The 6th environmental action programme (European Parliament and Council 2002) specifies the sustainable use of resources as one of six priority fields for the period 2002 to 2012. A thematic strategy on a sustainable use of resources was published by the European Commission in 2005 (Commission of the European Communities 2005). An OECD council recommendation on material flows and resources productivity in April 2004 fostered the establishment of an OECD work program on this topic by the OECD working group on environmental information and outlook. In 2007, UNEP initiated the foundation of an international expert panel on a sustainable use of resources. Most recently, the European Commission published the flagship initiative on "A Resource Efficient Europe" (2011) and half a year later the Roadmap to a Resource Efficient Europe (2011) with DMC and resource productivity as headline indicators[2].

Figure 1: Scope of economy-wide MFA



These policy processes substantially increased the need for economy-wide, reliable and comparable time-series data and indicators for material use. The backbone of an environmental reporting system which provides such information is economy-wide material flow accounting (MFA). Economy-wide material flow accounts are consistent compilations of

[2] see http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm and http://ec.europa.eu/resource-efficient-europe/

the overall material inputs into national economies, the changes of material stock within the economic system and the material outputs to other economies or to the environment (Fig. 1).

Economy-wide MFAs, for the sake of brevity referred to as MFA in the following document, cover all solid, gaseous, and liquid materials, except for bulk water and air; the unit of measurement is tonnes (i.e. metric tonnes) per year. Similarly, to the system of national accounts, material flow accounts serve two major purposes. The detailed accounts provide a rich empirical database for numerous analytical studies. They are also used to compile different extensive and intensive material flow indicators for national economies at various levels of aggregation. Economy-wide MFA thereby is to be seen as a satellite system to the system of national accounts which aims at describing the total scale of socio-economic activities in physical quantities.

The first economy-wide material flow accounts, in the contemporary sense, were published in the early 1990s for Austria (Steurer 1992), Japan (Ministry of the Environment, 1992), and Germany (Schütz and Bringezu 1993). Two publications by the World Resources Institute pioneered the comparative empirical analysis of national economies in material terms and the development of internationally comparable MFA indicators, Adriaanse et al. (1997) and Matthews et al. (2000).

A major step towards **methodological harmonization** was the publication *Economy-wide material flow accounts and derived indicators: A methodological guide* (Eurostat 2001). This guide specified the underlying concept of material flow accounting and the design of material flow indicators. Agreements were based on extensive discussion within the Eurostat MFA task force which met twice in 2000. However, the 2001 guide lacks specific information regarding the compilation of MFAs. The report *Materials use in the EU-15. Indicators and Analysis,* published by Eurostat one year later (Eurostat 2002), presented the first official MFA data set for the EU-15 and provided detailed information on a number of practical aspects of the accounting methods in its technical part. In several meetings between 2004 and 2006, the Eurostat MFA task force continued its efforts on methodological standardisation by developing a material flow classification, MFA standard tables, and detailed procedures on how to compile an economy-wide MFA for European Union member states. These compilation guidelines were first published in 2007 (Eurostat 2007) and then revised several times thereafter (Eurostat 2009c, 2012 and 2013). In July 2011 the European Parliament established the Regulation (EU) No 691/2011, which provides a legal base for the compilation of material flow accounts as a key reporting tool in the European Union's environmental and economic accounts. MFA data for the EU Member States are published annually at the Eurostat online portal. At the international level, several global dataset are available covering MFA data (Schaffartzik et al., 2014, Giljum et al., 2014, Schandl and West, 2010, Schandl et al., 2017)[3] with methods strongly based on the Eurostat guidelines. A publication by Fischer-Kowalski and colleagues (2011) and a review by Krausmann et al. (2017a) summarize the state of the art of material flow accounting and research. Most recently, the International Resource Panel of UN Environment, founded in 2007, engaged in the issues of sustainable resource use and

[3] Data compilations are available at: http://www.materialflows.net/, http://www.uni-klu.ac.at/socec/inhalt/1088.htm and http://www.cse.csiro.au/forms/form-mf-start.aspx

published several Assessment Reports based on MFA data (UNEP, 2016, 2011). Supplementing this, UNEP established a global MFA database[4] and is currently preparing an MFA Manual.

Information on the conceptual framework of MFA and how to technically compile the data is spread over several reports and papers. With this guide, we want to provide a concise summary of up to date MFA concepts and methods. The guide strongly builds on the different Eurostat publications, but expands the European centred focus towards a global application. Thus, the **purpose** of this guide is two-fold. First, it documents the **conceptual framework and methodological standards** in economy-wide MFA as they have been, for example, adopted by the European Union. Second, it provides **practical step-by-step procedures** for the compilation of economy-wide international material flow accounts.

Researchers and students from various fields who have an academic interest in MFA will find useful information and methodological guidance in this reference manual, as well as practitioners in the statistical office who may use this guide regardless of the specific reporting schema to which they are committed.

The remaining of the manual is organized as follows. The second chapter **(Fundamentals)** summarizes the fundamental definitions and conceptual principles, applied in economy-wide material flow accounting, and introduces the reader to the various partial accounts and the overall structure of the MFA standard tables. The third chapter 3 **(domestic extraction, Table A)** provides step-wise procedures for the accounting of domestic extraction of biomass, minerals, and fossil fuels, including the description of data sources, crosschecking opportunities, estimation methods, information on conversions and coefficients. The forth chapter **(imports and exports, Tables B, C)** explains the relevant sources and steps in compiling the physical accounts for imports and exports. The fifth chapter **(domestic processed output: DPO, Table D)** covers the analogous accounting information for outputs to the environment. This touches an area of MFA which is less well developed in methodological terms. The information is based on the currently available conventions but has to be considered as work in progress. Likewise, for the sixth chapter **(balancing items and net additions to stock, Table E),** which explains the complex issue of how a consistent material balance for a national economy is completed. The seventh chapter **(Material flow indicators, Table F)** defines and discusses the aggregated extensive and intensive indicators that can be derived from economy-wide material flow accounts and provides some empirical examples.

Fundamentals

System boundaries

Economy-wide material flow accounting is conceptually based on a simple systemic model of an economy (referred to as national economy in the following document) as a biophysical and socio-economic system embedded in its socio-economic and biophysical environment. The term embedded indicates that socio-economic systems in general are conceived as materially (and energetically) open systems, i.e. systems that maintain socially organized material (and energy) exchanges with their environment. Such a biophysical understanding of a socio-

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[4] The database is available at UNEP Live: https://uneplive.unep.org/material#.WjxRc_KnTVJ

economic system is commonly referred to as **social or industrial metabolism** (Ayres and Simonis, 1994; Fischer-Kowalski and Hüttler, 1998; Pauliuk and Hertwich, 2015).

For the purposes of EW-MFA compilation, the specific socio-economic system under investigation is the national economy into or from which two types of material input or output flows are possible. On the input side, we distinguish between inputs from the natural environment and material imports from other national economies (the rest of the world (ROW)-economy). Likewise, on the output side, we distinguish between outputs into the environment and material exports to other economies.

EW-MFA is consistent with the principles and system boundaries of the system of national accounts (ESA 95, SEEA)[5]. In EW-MFA two types of material flows across system boundaries are relevant:

1. Material flows between the national economy and the natural environment: This consists of the extraction of primary (i.e., raw, crude or virgin) materials from and the discharge of materials to the natural environment (wastes and emissions to air and water);

2. Material flows between the national economy and the ROW-economy. This encompasses imports and exports.

Only flows that cross the system boundary on the input-side or on the output-side are counted. Material flows *within* the economy are not represented in economy-wide MFA and balances. This means that the national economy is treated as a black box in MFA and e.g. inter-industry deliveries of products are not described.

Used and unused extraction:

Inputs from the natural environment are called "**domestic extraction**". This refers to the purposeful extraction or movement of natural materials by humans or human-controlled means of technology (i.e., those involving labour). Not all materials that are deliberately extracted or moved in the extraction process ultimately enter the economy as marketable goods; and not all materials are moved with the intention of using them in the economy. We therefore distinguish between used and unused extraction.

“Used refers to an input for use in any economy, i.e. whether a material acquires the status of a product. […] Unused flows are materials that are extracted from the environment without the intention of using them, i.e. materials moved at the system boundary of economy-wide MFA on purpose and by means of technology but not for use" (Eurostat 2001: 20). Examples of unused extraction are soil and rock excavated during construction or overburden from mining, the unused parts of fellings in forestry, the unused by-catch in fishery, the unused parts of the straw harvest in agriculture or natural gas flared or vented. The commonly used term "domestic extraction" – abbreviated DE – always refers to "used" extraction if not otherwise specified (some authors also refer to this as “domestic extraction used” with the abbreviation DEU). In some early MFA publications "unused extraction" is also called "hidden flows". This compilation guide does not include any further information on unused extraction.

[5] http://unstats.un.org/unsd/envaccounting/seea.asp

Stocks and flows

The distinction between stocks and flows is another fundamental principle of any material flow system. In general, a **flow** is a variable that measures a **quantity per time period**, whereas a **stock** is a variable that measures a **quantity per point in time**. MFA is a pure flow concept. It measures the flows of material inputs, outputs and stock changes (i.e. inflows to and outflows from stocks) within the national economy in the unit of tonnes (= metric tonnes) per year. This means that in MFA stock changes are accounted for but not the quantity of the socio-economic stock itself.

Although MFA is a flow concept, it is still important to define carefully what is regarded as a material stock of a national economy because additions to stocks and removals from stock are essential parts of the MFA framework. The definition of material stocks is also crucial in identifying which material flows should or should not be accounted for as inputs or outputs: Input flows are those material flows that are required to produce or reproduce the socio-economic material stocks or provide services from them, measured at the point where they cross the MFA specific system boundary. Output flows are discharges into the environment of the focal socio-economic system. This implies that they are measured at the point where society loses control over the further location and composition of the materials.

In MFA, **three types** of socio-economic material **stocks** are distinguished: artefacts, animal livestock, and humans. **Artefacts** (also denoted as manufactured capital or in-use stocks of material) are mainly man-made fixed assets as defined in the national accounts such as infrastructures, buildings, vehicles, and machinery as well as inventories of durable products. Durable goods purchased by households for final consumption are not considered fixed assets in the national accounts but are regarded as materials stocks in economy-wide MFA.

Also the **human population** and **animal livestock** are regarded as socio-economic stocks in national MFA. This means that for a full national material balance not only all food and feed (including non-marketed feed such as grass directly taken up by ruminants on pastures) but also the respiration of humans and animals must be taken into account as material inputs and outputs (most importantly CO_2 emissions).

Theoretically, the calculation of net stock changes should also include the changes in human population and animal livestock. However, experience shows that these stock changes are very small compared to e.g. the stock accumulation through buildings, machinery or consumer durables which typically account for more than 99% of the mass of all stocks. In practice, therefore, the changes in human population and animal livestock are often ignored.

As a consequence of this definition of socio-economic stocks, some material stocks are considered natural and not socio-economic despite the fact that they are part of the economic production system. This applies to **agricultural plants and forests**[6], including cultivated forests, and to **fish stocks** (unless they are cultivated in aquacultures). In MFA, it is indeed not the socio-economic importance of the stock that determines its attribution to the socio-

[6]According to national accounting frameworks (e.g. ESA 95, or SEEA) forests are regarded a socio-economic stock in national accounts; changes in forest stocks are defined as “work in progress”. To allow for consistency between national accounts and EW-MFA it was agreed that net changes in forest stocks should be accounted for as memorandum item in EW-MFA (see section A 1.3 Wood).

economic system but rather the degree of control that a society exerts over the production and reproduction of the stock.

From a more theoretical point of view, it should be kept in mind that humans colonize – in the sense of exercising sustained and organized control over natural processes – more and more elements of the material world of which they are a part of (Fischer-Kowalski and Weisz 2005). The intensity with which humans colonize different parts of their natural environment is not equally distributed though. More or less intensive colonization technologies may be applied to make use of the various material stocks provided by the natural environment. By and large the attribution of stocks to either the natural or the socio-economic system is intended to follow a gradient of colonisation intensities. In this respect the livestock production system can be considered a more intensively colonized system than the plant and timber production system.

There is another more practical reason why cultivated plants are regarded as natural stocks. Treating plants as parts of the national economy would create the necessity to account for water, CO_2, and plant nutrients as the primary inputs from the environment. Effectively, this would mean that the system boundary between a national economy and its environment would have to be drawn at the inorganic level (i.e. plant nutrients, CO_2 and water). Statisticians would be forced to convert rather robust and valid data on annual agricultural and timber harvest to comparably weak estimates of the primary inputs needed to produce these plants. Moreover, all differentiation between different types of crops would be lost. An integration of forests as a socio-economic stock would also imply that an increase in standing timber in forests would represent an increase the socio-economic resource use. From a sustainability perspective, this is counterintuitive and offers another argument for considering forest stocks as part of the natural system.

There are some areas, where the system boundaries are difficult to define, e.g. where the degree of control over material stocks is varying or may change over time. Cases in point are shifts from uncontrolled to controlled landfills and the increasing importance of fish production through aquaculture as opposed to fish catch in uncontrolled settings. Controlled landfills are considered socio-economic stocks, which means that treatment of these stocks is an activity within the socio-economic system. Any leaking of substances in the soil or water vapour exhausting from organic wastes in particular, should be considered as outputs to nature. In practical terms, these flows are considered small and thus negligible. Likewise for aquaculture systems, which are treated as socio-economic stocks. In this case not the fish production but feed and other inputs as well as the outputs in terms of wastes would have to be considered as mass flows crossing the MFA system boundary. In general, we assume that both inputs and outputs of aquaculture systems are already accounted for in domestic extraction (DE), domestic processed output (DPO) and trade flows (for definitions see below). Regarding waste flows it has been agreed upon, that only waste going to uncontrolled landfills should be accounted for in MFA.

Material balance principle

As MFA accounts for materials entering and leaving a system, the **conservation of mass principle** applies, which states that matter can neither be created nor destroyed. Although this principle is not universally true (as nuclear reactions are able to transform mass into energy) it is a sufficiently appropriate formulation for the material exchange relations of macro systems.

The mass balance principle can be formulated as:

input = output + additions to stock – removals from stock

= output + net stock changes

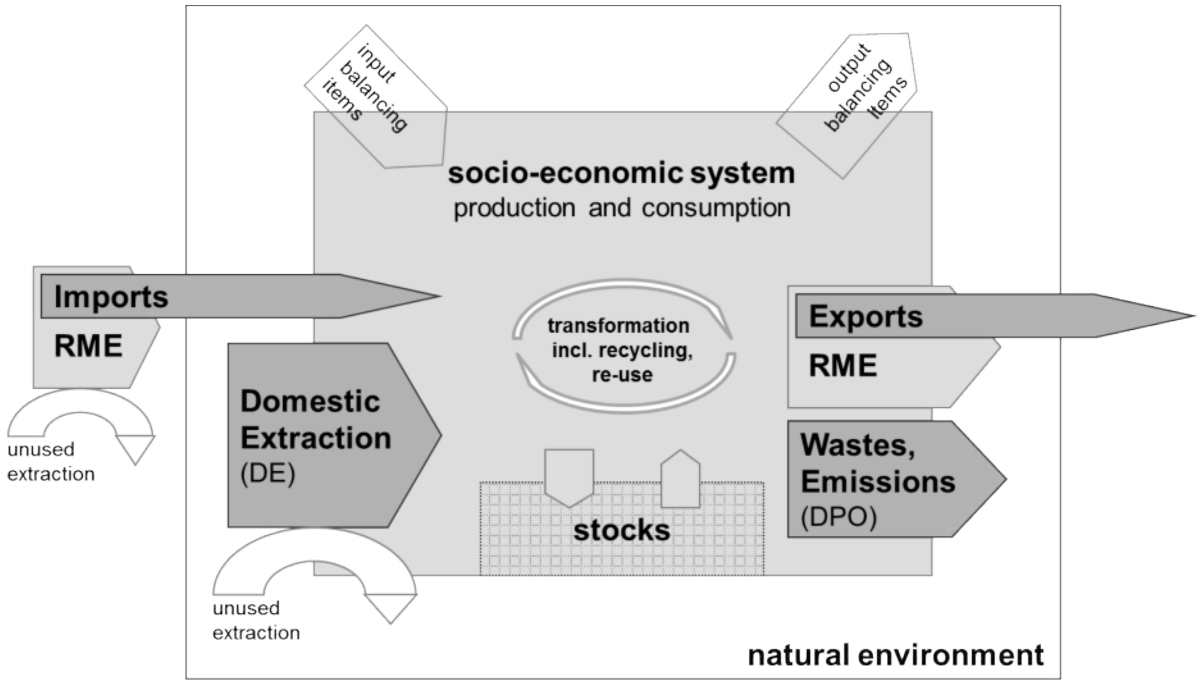
All material inputs into a system over a certain time period equal all outputs over the same period plus the stock increases minus the releases from stock. In principle net stock changes can be positive, indicating net accumulation, or negative, indicating stock depletion.

In MFA, the mass balance principle is used to check the **consistency** of the accounts. It also provides one possibility to estimate the net additions to stock (NAS). It has to be noted, though, that the compilation of a full national material balance is not inevitably the outcome of an economy-wide material flow account. Often partial accounts are compiled, mostly focusing on the input side and trade flows.

Typology of flows

The MFA framework distinguishes between different **material flow categories**. This chapter summarises and completes the description of the general material flow categories and introduces the reader to the relevant terminology. Based on this, we will describe the structure of the economy-wide material flow accounting tables.

Figure 2: Schematic representation of economy-wide MFA



Source: Mathews et al. 2000, modified. Legend: DE = domestic extraction; DPO = domestic processed outputs, i.e. wastes, emissions, dissipative uses and losses; RME = raw material equivalents.

Figure 2 provides a schematic representation of the material flow accounting framework and its main flow categories. All flows that cross the border of the socio-economic system are called direct flows.

On the **input-side**, we distinguish between domestic extraction (used; DE), imports, and the input balancing items comprised of those water and air inflows that must be taken into account in order to complete the material balance. On the **output-side**, we distinguish between exports, "domestic processed output" (DPO), and output balancing items. Finally, inputs to and outputs from stocks are considered, resulting in net-changes of stocks. The main material flow categories are defined as follows:

Domestic Extraction – DE (Table A): The aggregate flow DE covers the annual amount of solid, liquid and gaseous raw materials (except for water and air) extracted from the natural environment to be used as material factor inputs in economic processing. The term "used" refers to acquiring value within the economic system (see Fundamentals > system boundaries). These materials consist of biomass, non-metallic minerals (sometimes also termed construction and industrial minerals), metallic minerals (i.e. gross metal ores), and fossil energy carriers. Concerning the water content of the raw materials, the convention is to account for all raw materials in fresh weight, with the exception of grass harvest, fodder directly taken up by ruminants, and timber harvest. These biomass materials are accounted for with a standardised water content of 15%.

Physical imports and physical exports (Tables B and C): These aggregates cover all imported or exported commodities in tonnes. Traded commodities comprise of goods at all stages of processing from basic commodities to highly processed products.

Net Additions to Stock – NAS: NAS measures the 'physical growth of the economy', i.e. the quantity (weight) of new construction materials accumulating in buildings, infrastructures and of materials incorporated into durable goods with a life time longer than a year such as cars, industrial machinery, and household appliances. Materials are added to the economy's stock each year (gross additions) and old materials are removed from stock as buildings are demolished and durable goods disposed of (removals). Net additions to stock are therefore not calculated by balancing additions to stock and stock depletion (as the arrows in Figure 2 would suggest) but as statistical balance between inputs and outputs. Apart from materials going on stocks in the use phase, also products can be put on stocks before being used or traded. This in particular applies for example to fossil fuels or cereals, where stock inventories can be considerable. NAS can also be negative, i.e. net-removals from stocks. Negative NAS have hardly been observed in any industrialized countries, where stock changes mainly refer to increases in infrastructure.

Domestic processed output – DPO (Table D): DPO measures the total weight of materials, extracted from the natural environment or imported, that have been *used in the national economy* before flowing back to the environment. DPO comprises all waste and emission flows that occur in the processing, manufacturing, use, and final disposal stages of the production-consumption chain. This includes emissions to air, industrial and household wastes deposited in uncontrolled landfills (whereas wastes deposited in controlled landfills are regarded as an addition to the socio-economic stock), material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Also materials that are deployed to ecosystems intentionally, such as fertilizers are accounted for as DPO. Recycled material flows are considered flows within the economy (e.g. of metals, paper, glass) and thus are not considered as output (nor input).

Input and Output balancing items (Table E): Although bulk water and air flows are excluded from MFA, material transformations during processing may involve water and air exchanges which significantly affect the mass balance. Balancing items are estimations of these flows, which are not part of DE, DPO or NAS, because they are not included in the definition of these flows. Balancing items mostly refer to the oxygen demand of various combustion processes (both technical and biological ones), water vapour from biological respiration, and from the combustion of fossil fuels containing water and/or other hydrogen compounds. Also flows of considerable economic importance such as nitrogen which is withdrawn from the atmosphere to produce fertilizer in the Haber-Bosch process or groundwater used in the production of beverages are accounted for as balancing items. These flows are estimated using generalized stoichiometric equations.

Having defined these material flow categories, we now can write a national material balance equation in MFA terms:

DE + Imports + Input Balancing Items = Exports + DPO + Output Balancing Items + NAS

Apart from these direct flows, further flows can be considered in a broader MFA view. These are: unused extraction associated to direct extraction activities, and upstream material use associated with imports and exports (Eurostat 2001). The latter are usually termed raw material equivalents (RME) of imports and exports. Both flows do not enter the focal socio-economic system but the first, unused extraction remains within the natural system, and the second, RME remains in foreign economies. **Unused extraction** comprises materials that are moved or extracted from the environment without the intention of using them in economic processing. This includes, for example, overburden or unused crop residues (e.g. straw that is burned on field or ploughed into the soil. Unused extraction can be associated with the domestic or foreign extraction of raw materials when the latter is attributable to the production of imported goods.

Per definition, materials extracted from the environment are always raw materials. In contrast, imported and exported materials are always products which have already undergone a more or less intensive transformation process before entering or leaving the focal economy. Goods are traded in various stages of processing and the upstream material requirements of imports and exports comprise both used extraction (= raw materials) and unused extraction, together they are referred to as indirect flows. To denote the upstream requirements of used extraction associated with imports or exports the term "**raw material equivalents**" (RME) was coined (Eurostat 2001, Weisz et al. 2004). Raw material equivalents can be used to calculate "material footprints" (Wiedmann et al., 2015), which comprise all material flows associated with domestic final demand, regardless of where on the globe they occur (consumption perspective).

Both the present version of the EW-MFA tables and this compilation guide cover the direct flows only, RME and unused extraction are not included. In the case of RME, methods are still under fast development and results (Wiedmann et al. 2013, Wood et al. 2014, Schandl et al., 2017) are changing significantly depending on the methods used (Schaffartzik et al. 2014, Eisenmenger et al., 2016). In the case of unused extraction, data availability is poor and no sufficiently standardised methods have been developed so far.

Territory and residence principle

Several environmental accounting systems (e.g. air emissions accounts; Eurostat 2009a) follow the residence principle in order to ensure consistency with the System of Economic and Environmental Accounts (SEEA) and national accounts. Also the EU proposes in its EW-MFA guidelines to follow the residence principle, i.e. to consider all material flows associated with transactions attributed to so called resident units in the material flow accounts. In the system of national accounts (ESA 95), resident units are defined as those units whose center of economic interest is located on the national economic territory. A *center of economic interest* is given if the unit is engaged in significant economic activities on the economic territory for a year or more or if it holds ownership of land or buildings on the economic territory. The national *economic territory* encompasses the geographic territory without extraterritorial enclaves and including territorial enclaves as well as air space, territorial waters, deposits over which country has rights, etc.

However, the data compilation process in EW-MFA is usually starting from a territorial perspective that is, from material extraction on the national territory. Most data sources on agricultural harvest, forestry and mining are following the territory principle. In order to transform territorial MFA data to the residence principle, data adjustments are required. In particular, this applies to fuel consumed in international transport (water, air, and road). According to the residence principle, fuel that is consumed by resident units abroad (e.g. bunkering of aviation fuel by domestic airlines in foreign countries) has to be accounted for in EW-MFA, while vice versa fuel provided to non-resident units domestically has to be excluded. These flows, which can be of considerable size in some countries, are usually not captured by production or trade statistics and have to be estimated. Other areas, where standard statistical sources provide data not fully consistent with the residence principle are tourism and activities in extraterritorial enclaves (such as embassies or consulates). However, the related flows are of a comparatively small size in most cases and statistical data are not available and standardized estimation procedures have not been developed. For these reasons, deviations from the residence principle other than for fuel use are currently not considered in most EW-MFA. And even for bunker fuels, many EW-MFAs still ignore these adaptations, because the information required for these estimates are difficult to obtain for most countries and prone to high uncertainty.

This handbook applies the territory principle. However, we highlight, where differences to the residence principle will commonly apply and how to estimate flows according to the residence principle. The adjustments that are required in order to ensure consistency with the residence principle are discussed in the section dealing with trade flows.

Data sources and quality of the accounts

Economy-wide materials flow accounts are meta-compilations of data from various official statistics, most of which are regularly provided and updated by national statistical offices. DE is mainly based on data from agricultural, forestry, fishery production, mining (including geological surveys), and energy statistics. DPO is mainly based on emission inventories (including NAMEA of Eurostat) and waste statistics. Import and export data are taken from foreign trade statistics.

Basically, three types of data sources are useful for compiling MFAs. Data provided by the national statistical offices of the country for which the MFA is complied, international databases (such as those from Eurostat or different UN bodies such as the FAO or IEA, Minerals statistics offered by different geological services such as the USGS or BGS, etc.) and third, data from scientific reports, case studies, and other non-periodical data compilations. Additionally, "educated guesses" by experts may occasionally turn out to be the only means to complete the accounts.

National databases usually have the most reliable data for individual countries because they dispose of the best primary sources and knowledge on national structures and individual characteristics. However, international data sources can provide high quality data which have the advantage of being standardized across countries and thus provide a good basis for cross country comparisons. Often it is necessary to combine national and international data sources in order to close data gaps or for cross checking. In this guide we refer mainly to international databases.

One particular important quality criterion for MFA is its consistency. This includes ensuring that the following general requirements are met.

(1) Only those data must be included which comply with the system boundary definition of MFA.

(2) All data are measured in the same unit of tonnes (i.e. metric tonnes). If data are reported in units other than tonnes they must be converted using appropriate coefficients.

(3) The compilation must be free of double counts. This means that each relevant flow is accounted for only once.

(4) The compilation must be comprehensive. Often there are relevant material flows for which statistical sources provide no or no appropriate data. The compilation of an MFA therefore also involves estimated missing data. As such estimations are a common source of incomparability, we particularly emphasise the description of possible estimation methods, here. Whereas these estimation methods should provide some guidance as to how to complete data gaps, they are not intended to represent the one solution that works best. Different and possibly more accurate estimation methods may be applied based on national data and national expertise.

(5) It must be ensured that the data are of sufficient quality. This is probably the most difficult task. Judging the quality of statistical and other data requires profound knowledge and sufficient experience in the respective fields. Moreover, the specific nature of the problems typically varies across statistical data sources, countries, and points in time. For these reasons it is hardly possible to provide standardised methods to judge the quality of all data which are relevant for MFA.

The following chapters describe the most common and partly standardized methods based on the guidelines developed for Eurostat (Eurostat 2013) but adapted to better fit a global rather than a European perspective that we suggest for the evaluation of some of the most common and quantitatively most severe data quality problems.

The future value of economy-wide material flow accounting will depend largely on its internal consistency, its international comparability, and its potential to reflect a large variety of real world processes. These are at times conflicting goals.

The MFA tables

Together with this manual, we provide a set of different tables that help compiling economy wide Material Flow accounts. These tables are designed to facilitate data organisation, they represent a structuring of material flows and thus are an important tool in the process of MFA compilation. Six tables (A through F) and annexes (0 through 6) form a file in spreadsheet format into which the collected MFA data can be entered according to the type of aggregate to which they belong. These tables and especially the annexes provide valuable information on the individual items to be included in an MFA, including their assigned codes in different systems of notation. The MFA Tables have a hierarchical structure and differentiate between four levels of detail.

Data on **domestic extraction** (DE) of biomass, metal ores, non-metallic minerals, and of fossil energy carriers must be entered into **Table A**. The individual items which make up each of these kinds of domestic extraction are listed under the respective heading. DE of biomass, for example, consists of primary crops (A. 1.1), of used crop residues, fodder crops and grazed biomass (A.1.2), wood (A.1.3) and of the biomass extracted through fish capture (A.1.4) and hunting and gathering (A.1.5). For reasons of consistency, all tables are organized in the same way and along the same number of items.

Tables B and C are designed for the organisation of data on **trade flows (imports and exports)**. In **Table B** (imports) and **Table C** (exports) data on total trade flows are requested. All trade data is organised into similar categories as the data on domestic extraction, the major difference being that the items traded comprise not only primary but also processed material. The latter may consist of either biomass, metal ores and concentrates, non-metallic minerals, fossil energy carriers, or waste imported for final treatment or disposal. Products which cannot be clearly identified as belonging to one of these four categories should be included under “other products”. The procedure for determining where a given trade flow should be entered is described in annexes of the MFA tables for different trade classification systems (CPA, SITC and HSCN).

Data on discharges into the environment are organised in **Table D** as **domestic processed output** and may consist of emissions to air (D.1.) or water (D.3.), landfilled waste (D.2.) or discharges that result from the dissipative use of products (D.4.) as would be the case in the application of fertilizer, for example. Additionally, data on dissipative losses (D.5.) are entered into this table.

Finally, **balancing items** are represented in **Table E**. These data are organised according to whether they comprise those gases required on the input side (E.1.) to balance an output which is already accounted for or gases which must be considered on the output side (E.2.) to balance a given input.

All of the data collected and organised in Tables A through E can then be aggregated permitting for the derivation of **indicators** in **Table F**. Based on known volumes of domestic extraction (F.1.), imports (F.2.), and exports (F.3.), the direct material input (F.4.), domestic material consumption (F.5.), and the physical trade balance (F.6.) can be calculated. By additionally considering domestic processed output (F.7.) and balancing items (Table E), net additions to stock (F.8.) may be determined.

In order to facilitate the proper organisation of data from different sources within one harmonious system, a set of annexes in spreadsheet format provides information on the correspondence between the various statistical codes used to designate relevant items. In **Annex 0** the **structure of Tables A to F** is shown in correspondence with the structure of the MFA tables. **Annex 1 and b** show the **Classification of Products by Activity** (CPA 2002 and 2008) in its correspondence to domestic extraction and trade flows. Domestic extraction of biomass may also be labelled with **FAO** codes; the according correspondence is provided in **Annex 2**. In **Annex 3a and b** the trade flows (Tables B and C) are presented in correspondence with the **Standard International Trade Classification** (SITC) rev. 1, rev. 3 and rev. 4 codes as well as CN and HS classification. Annex 4a and b provide information on the correspondence between MFA classification and FAOSTAT classification of trade with agricultural and forestry products. Annex 5 is a correspondence table between MFA categories and the fossil energy carrier classification according to IEA. Annex 6 contains a correspondence table for mineral and fossil materials as listed in the United Nations Industrial Commodities Production Statistics and material flow groups.

Table A: Domestic extraction

Biomass

Table 1: Domestic extraction of biomass

1 digit	2 digit	3 digit	
A.1 Biomass			
	A.1.1 Primary crops		
		A.1.1.1	Cereals
		A.1.1.2	Roots, tubers
		A.1.1.3	Sugar crops
		A.1.1.4	Pulses
		A.1.1.5	Nuts
		A.1.1.6	Oil bearing crops
		A.1.1.7	Vegetables
		A.1.1.8	Fruits
		A.1.1.9	Fibres
		A.1.1.10	Other crops (Spices, Stimulant crops, Tobacco, Rubber and other crops)
	A.1.2 Crop residues (used)		
		A.1.2.1	Straw
		A.1.2.2	Other crop residues (sugar and fodder beet leaves, other)
	A.1.3 Fodder crops and grazed biomass		
		A.1.3.1	Fodder crops (incl. harvest from grassland)
		A.1.3.2	Grazed biomass
	A.1.4 Wood		
		A.1.4.1	Timber (Industrial roundwood)
		A.1.4.2	Wood fuel and other extraction
	A.1.5 Fish capture and other aquatic animals and plants		
		A.1.5.1	Fish capture
		A.1.5.2	All other aquatic animals and plants
	A.1.6 Hunting and gathering		

Introduction

Biomass comprises organic non-fossil material of biological origin. According to MFA conventions, domestic extraction (DE) of biomass includes all biomass of vegetable origin extracted by humans and their livestock, fish capture, and the biomass of hunted animals. Biomass of livestock and livestock products (e.g. milk, meat, eggs, hides) are not accounted for as domestic extraction (see below).

In 2010 biomass accounted for 30% of total global DE (Krausmann et al. 2009). Values of per capita biomass harvest average at 3 t and range between 0.5 and 20 t. Typically, the share of primary crops of total harvest amounts to 35%, crop residues 20%, fodder crops and grazed biomass 32%, and wood 10%. Fishing and hunting and gathering are of minor quantitative importance in most cases. The actual quantitative and qualitative structure of biomass harvest may vary significantly depending on the regional characteristics of the land use system. In general, DE of biomass is highest in countries with low population densities or high livestock numbers per capita.

DE of biomass includes a number of raw materials which differ significantly in terms of their technical, economical, and environmental properties, which are reflected in the 2 to 4 digit structure of the MFA Table (see Table 1).

Economic value: The economic value of biomass ranges from very low (less than 10€/t, e.g., crop residues) to medium high (e.g., spices, stimulants, fish catch); the vast majority of extracted biomass is comprised of bulk raw materials with low value (10-100€/t, e.g., cereals, roundwood).

Socio-economic use: Biomass provides raw materials for the food system, but also energy carriers and industrial raw material for a wide range of processes and products (e.g., fibres, chemical compounds, construction material, industrial raw material).

Environment: The extraction of biomass materials can be related to specific land use and land cover types (cropland, grassland, and woodland) and environmental pressures (deforestation, soil erosion, ground water pollution, biodiversity loss, overfishing).

Data sources

Statistical reporting of biomass extraction has a long tradition. Most fractions of biomass harvest are reported by national statistical offices (or national offices concerned with agriculture and forestry) in their series of agricultural, forestry, and fishery statistics. Additional information useful for biomass accounts may be provided by national food, feed, and wood balances. The accounting frameworks are well established and show a high degree of international standardisation and accuracy. Both national and international data sources generally cover the harvest of all types of primary crops (1.1) and wood (1.4), and biomass extraction by fishing and hunting activities (1.5 and 1.6). In some cases crop residues (1.2.1) and harvested fodder crops and biomass harvested from grassland (1.2.2.1) are reported in statistical accounts as well, but grazed biomass (1.2.2.2) is usually not estimated by official statistics. For these items, which usually are of considerable quantitative significance, this guide provides standard estimation procedures.

The most consistent international source of data on biomass extraction is the statistical database FAOSTAT provided by the United Nations Food and Agricultural Organization. The FAO database covers a huge range of data concerning agriculture, forestry, and fishery, and the food system on the level of nation states in time series since 1961. The structure of the EW-MFA tables is compatible with the data provided by the FAO (see Annex 2 for a detailed correspondence table).

In discussing the aggregation and estimation procedures, the guide follows the two and three digit level of the MFA tables.

Conventions

Terminology and classification: The terminology and classification of biomass items and aggregates used in this guide by and large follow the terminology used by the FAO and may differ from the terminology used in national statistics.

Moisture content: A characteristic feature of all types of biomass is its considerable moisture content (mc), which may account for more than 95% in the case of fresh living plant biomass. However, the moister content is very variable across plant parts and species and vegetation periods. In many cases, biomass is harvested at low moisture content (e.g., cereals) or dried during the harvesting process (e.g., hay making). In accordance with agricultural statistics, biomass is accounted for at its "as is weight" at the time of harvest. Few crops may be harvested at different water contents (fresh weight (80-95% mc) or air dry (15% mc)); in these cases, moisture content has to be standardised according to MFA conventions. This applies only for the categories A.1.2.2.1 fodder crops, A.1.2.2.2 grazed biomass, and A. 1.4. wood.

Primary harvest and crop-residues: In many cases, primary harvest (i.e. the used fraction accounted for in MFA) is only a fraction of total plant biomass. However, the remaining crop-residue or a certain fraction of it may be subject to further socio-economic use and is accounted for in MFA. The most prominent example for this is (cereal)straw, which may either be used as bedding material for livestock, feed stuff, for energy generation or as raw material used for other purposes (crop residues which are ploughed into the field or burnt are not accounted for as DE). This also applies to wood harvest, where fellings and removals are distinguished.

Livestock: According to MFA system boundaries and conventions, livestock is considered an element of the physical compartment of the socio-economic system. Consequently, all direct biomass uptake by livestock is accounted for as domestic extraction, whereas livestock and livestock products are considered secondary products and not accounted for as domestic extraction. Exceptions are hunted animals and fish capture, which are considered an extraction from the natural environment and, therefore, are accounted for as DE. Biomass uptake by livestock consists of market feed (cereals, food processing residues, etc.), fodder crops (fodder beets, leguminous fodder crops, etc.), crop residues used as feed (straw, beet leaves, etc.), and grazed biomass. Domestic extraction of market feed is included in the extraction of primary crops (item A.1.1), crop residues used for feed in item A.1.2.1 and fodder crops, grassland harvest and grazed biomass in item A.1.2.2.

Data Compilation

A 1.1 Crops

Harvest of primary crops is comprised of primary harvest of all crops from arable land and permanent cultures. This includes major staple foods from crop- and garden land such as cereals, roots and tubers, pulses, vegetables as well as commercial feed crops, industrial crops and all fruits and nuts from permanent cultures. The FAO's crop production database distinguishes roughly 160 different types of primary crops (including fruits and nuts from permanent cultures). In most countries, the numbers of primary crops will be much smaller; for European countries, it typically ranges between 30 and 50.

Data on the extraction of primary crops are provided in good quality by national and international statistical sources and can be used directly for MFA compilation without further processing. With respect to aggregation of the harvest of individual crops to the 3 digit level of the standard tables, we follow the classification scheme suggested by the FAO which is also compatible with CPC classification. The table in the Annex 2 of the EW-MFA tables lists all common crop types according to the 3 digit level of the standard tables (A.1.1.1 to A.1.1.10). Crops not identified in this list, but reported by national statistics should be classified with regard to the 3 digit level or, if this is not possible, subsumed under A.1.1.10 (other crops) (e.g. flowers or nursery products).

A 1.2 Crop residues

In most cases, primary crop harvest is only a fraction of total plant biomass of the respective cultivar. The residual biomass, such as straw, leaves, stover etc., often is subject to further economic use. A large fraction of crop residues is used as bedding material in livestock husbandry but crop residues may also be used as feed, for energy production or as industrial raw material. The used fraction of crop residues is accounted for as DE. In many countries this is a considerable flow which may account for 10-20% of total biomass DE. Residues which are left in the field and ploughed into the soil or burned in the field are not accounted for as DE.

MFA accounts distinguish between two types of crop-residues:

A.1.2.1 Straw of cereals: all harvested straw of cereals including maize

A.1.2.2 All other crop-residues: This can, for example, include tops and leaves of sugar beets or residues from sugar cane.

In some cases, all or some harvested crop-residues are accounted for in national agricultural statistics. However, neither FAOSTAT nor national agricultural statistics in most countries report any data on harvested crop-residues. In case national statistics provide data on the used fraction of crop-residues, these can directly be used for MFA compilation without further processing. For most countries, however, crop-residue production and the fraction recovered for socio-economic use will have to be estimated:

Step 1: Identification of crops which provide residues for further socio-economic use. In most cases this will include all types of cereals (A.1.1.1), sugar crops (A.1.1.3) and oil bearing crops (A.1.1.6), only in exceptional cases will other crops have to be considered.

Step 2: Estimation of available crop residues via harvest factors

The procedure to estimate the amount of crop residues available is based on assumptions on the relation between primary harvest and residues of specific crops. In agronomics, different measures for this relation are used: the most prominent are the harvest index, which denotes the share of primary crop harvest of total aboveground plant biomass, and the grain to straw ratio. This relation is typical for each cultivar, however, subject to changes over time as plant breeding aims specifically at increasing the harvest index of cultivars. Based on this, we can calculate a harvest factor, which allows for the extrapolation of total residue biomass from primary crop harvest (equation (1)). Typical harvest factors for crops in different world regions, which can be used in absence of national information, are provided in Table 2a.

Note: The harvest factors in Table 2 refer to dry matter of both crop and crop residue. MFA reports crops and crop residues with the moisture content at harvest (as is weight). In most cases the moisture content of crop and crop residues is equal (e.g. cereal straw and grain both have a mc of roughly 16%). In this case the factors in Table 2a can be applied without modification; if the moisture content between crop and crop residue differs, however, corresponding adjustments have to be made. In the case of sugar cane, for example, average moisture content of harvested cane is 72%, that of residues in 59%.

(1) Available crop residues [t (as is weight)] = primary crop harvest [t (as is weight)] * harvest factor

Table 2: Standard values for harvest factors (a) and recovery rates (b) for common crop residues.

	E. Asia	E. Europe	Latin America	N. Africa W. Asia	N. America Oceania	S. and C. Asia	Subsaharan Africa	W. Europe
a) Harvest factors. Crop residue [g dry matter (DM) per year] = primary crop harvest [g DM/yr] * harvest factor.								
Wheat, other cereals	1.5	1.5	1.5	1.5	1.2	1.7	2.3	1.0
Rice, Paddy	1.0	1.2	1.2	1.2	1.2	1.5	1.5	1.2
Maize	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Millet	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Sorghum	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Roots and Tubers	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Cassava	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sugar Cane	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sugar Beets	0.7	0.5	0.7	0.7	0.5	0.7	0.7	0.5
Pulses	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Soybeans	1.2	1.5	1.5	1.5	1.2	1.5	1.5	1.2
Groundnuts in Shell	1.2	1.2	1.5	1.5	1.2	1.5	1.5	1.2
Oil Palm Fruit	1.5	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Castor Beans	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Rapeseed, oil crops	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9
Permanent crops	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
b) Recovery rates: Used crop residues [g DM] = available residues [g DM] * recovery rate.								
Cereals incl. rice and maize	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Roots and Tubers	0.75	0.25	0.75	0.75	0	0.75	0.75	0
Sugar Cane	0.52	0.47	0.4	0.47	0.47	0.52	0.47	0.47
Sugar Beets	0.75	0.25	0.75	0.75	0	0.75	0.75	0
Sugar Crops nes	0.8	0.3	0.8	0.8	0	0.8	0.8	0
Beans, Dry	0.5	0.5	0.5	0.5	0	0.5	0.5	0
Other pulses	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Other oil crops	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Oil Palm Fruit	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sunflower Seed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rape seed	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Source: based on data provided in Krausmann et al. 2013 and Wirsenius 2000. For sugar cane see Buchberger (2017).

Step 3: Estimation of fraction of used residues

In most cases, only a certain fraction of the totally available crop-residue will be harvested and subject to further use. The actual fraction of residues used (recovery rate) can be estimated based on expert knowledge or specific studies. If no reliable information on the country-specific share of used residues is available, recovery rates provided in Table 2b can be applied; but it has to be noted that these are only rough approximations and actual rates may vary considerably across countries and over time. The amount of used crop residues can be calculated using equation (2).

(2) Used crop-residues [t (as is weight)] = available crop-residues [t (as is weight)] * recovery rate

A.1.3 Fodder crops (incl. biomass harvested from grassland) and grazed biomass

This category subsumes different types of roughage including fodder crops, biomass harvested from natural or improved grassland (meadows) and biomass directly grazed by livestock. Coverage of these large flows in statistics is usually poor. The most important types of fodder crops may be reported in harvest statistics (e.g. maize for silage, leguminous fodder crops, hay) and for some countries national feed balances exist from which data on biomass harvested from grassland and grazed biomass can be derived. In case no reliable data for both fodder crops (A 1.3.1) and grazed biomass (A 1.3.2) exist, formula (5) (see section A 1.3.2 below) can be used to estimate the total amount of biomass subsumed under A 1.3. In this case, the calculated total requirement for roughage is assumed to be equal to the total amount of harvested fodder crops and grazed biomass (A 1.3).

A.1.3.1 Fodder crops (incl. harvest from grassland)

This category includes all types of fodder crops including maize for silage, grass type and leguminous fodder crops (clover, alfalfa etc.), fodder beets and also mown grass harvested from meadows for silage or hay production. All commercial feed crops such as barley, maize, soy bean etc. which may also be used for food production or as industrial raw material are not included in this category. Fodder crops are typically reported by national agricultural statistics. In some cases, standardisation of moisture content is required:

Step 1: Fodder crops which require a standardisation of moisture content must be identified: All grass type fodder crops and biomass harvested from meadows (FAO codes 638-643 and 857-859, see Annex 2 of the EW-MFA tables) can be harvested and used either fresh (i.e. with a high moisture content; for immediate feeding or silage production) or at air dry weight (hay). According to MFA conventions, these crops are accounted for at air dry weight, i.e., at a standardised moisture content of 15%. In case no information on the moisture content of the reported data on fodder crops is available, a rough check can be made by looking at yields per area unit: The yield of grass type fodder crops at air dry weight [t/ha/yr] is typically in the range of 2-3 times the yield of cereals (e.g., wheat or barley). Fresh weight yields are significantly higher and are 5-15 times the yield of cereals.

Step 2: The weight of fodder crops which are reported in fresh weight (i.e., at a moisture content of 80%) has to be reduced to a moisture content of 15% by applying equation (3) and by using a factor, defined in equation (4):

(3) Air dry weight (at 15% mc) = fresh weight (at 80% mc) * $Factor_{mc}$

(4) $Factor_{mc} = (1-mc_{fresh}) / (1-mc_{air\ dry}) = 0.2 / 0.85 = 0.235$

A.1.3.2 Grazed biomass

According to MFA conventions, biomass grazed by livestock is a flow crossing the system boundary and thus considered in the accounts. This type of biomass extraction is not reported in standard agricultural statistics. In some cases, information on grazing is available from national feed balances or can be obtained from local agricultural experts. These data can be used for MFA accounts, eventually quantities given in other units (e.g. dry weight or digestible energy) have to be converted to air dry weight (15% mc) with the support of information from feed composition tables or expert knowledge or by using equation (4).

Different methods are available to estimate the amount of biomass grazed by livestock: One method uses the number of animals, which is well documented in agricultural statistics, and calculates an average feed or roughage demand by using information on daily feed intake per head. This approach is described in detail as method A in this manual. The second approach, method B, uses data on the amount of animal products (meat, milk, eggs) produced and information on the ratio of feed required to produce one unit of output (feed conversion rate). Both methods have been used in material flow accounts and allow for a rough estimate of biomass uptake by grazing.

Method A: Demand-driven feed balance to identify grazing gap.

Information on livestock numbers are typically well reported in national and international agricultural statistics. Based on information on roughage requirements of ruminants and other grazing animals and the number of livestock, the demand for grazed biomass can be estimated. Daily biomass intake by grazing depends on the age and live weight of the animal, animal productivity (e.g., weight gain, milk yield), and the feeding system (e.g., feed composition) and therefore may vary considerably within one species even within a country depending on the prevalent livestock production systems. The procedure described here is a simplified version of a feed balance model used in estimates of global biomass harvest (see Krausmann et al. 2008 and Krausmann et al. 2013 for more information and detailed feed balances). Table 3 provides information of average roughage uptake by livestock species in different production systems (3a) and averages for different world regions over time (3b). The values refer to air dry weight (i.e. at a moisture content of 15%) and already take into consideration that part of the overall feed demand is met by market feed and crop residues (the share of market feed and crop residues in feed ratios (dry matter basis, average across all species) ranges between 5 and 50%). The coefficients in Table 3 can be used to calculate total roughage requirement (equation (5)).

Table 3: Typical roughage intake by grazing animals

	Annual intake Traditional livestock system [t/head and year]	Annual intake Industrial livestock system [t/head and year]
Cattle (and buffalo)	1.5	5.5
Sheep and goats	0.43	0.64
Horses	3.0	4.3
Mules and asses	1.8	2.6

Values represent annual intake of air dry biomass (15% mc) in t / head and year. Sources: The values are derived from national feed balances and literature (Wirsenius 2000; Hohenecker 1981; Wheeler et al. 1981; BMVEL 2001).

Table 4: Estimate of annual intake of roughage by cattle and buffalo in 1960, 1990 and 2005

t/head/y	South & Central Asia	East Europe	North Africa & West Asia	North America & Oceania	West Europe	Sub-Saharan Africa	Latin America & Caribbean	East Asia	World
1960	1.6	2.3	2.3	3.4	3.3	2.4	3.1	2.0	2.5
1990	1.5	2.9	2.6	5.1	4.5	2.4	3.4	2.6	2.9
2005	1.6	2.8	2.5	5.6	5.1	2.3	3.8	3.8	3.3

Roughage intake includes grazed biomass, hay and forage crops. Values are given in t (at 15%mc) /head and year. Intake of market feed and crop residues is already discounted for. Source: derived from Krausmann et al. 2013.

(5) Roughage requirement = livestock [number] * annual feed intake [t per head and year]

Roughage requirement may be covered from grass type fodder crops, hay or silage or from grazing. To estimate biomass uptake by grazing, total roughage requirement has to be reduced by the amount of available fodder crops and biomass harvest from grassland (item A.1.3.1, equation (6)).

(6) Demand for grazed biomass = roughage requirement [t at 15% mc] – fodder crops [t at 15% mc].

Method B: Extrapolation from animal production (feed conversion efficiency):

National and international agricultural statistics also report data on primary animal products such as meat and milk. From this information and appropriate feed conversion coefficients (feed demand per unit of product) the demand for feed and subsequently also grazed biomass can be extrapolated. It is important that the applied feed conversion coefficients take the demographic structure of the herd into account. This means, for example, that not only the feed consumed by the cows which produce milk is taken into account, but also the feed required for the calves, heifers and steers that maintain the herd of cows. Data on domestic production of animal products should be corrected for trade with live animals: an imported steer which is slaughtered after import will be recorded in production statistics, but the feed required to produce the steer was not consumed in the importing but in the exporting country. Therefore, the slaughter weight of imports and exports of live animals has to be subtracted or added, respectively, from domestic meat production. FAOSTAT commodity balances also report "meat indigenous" which is corrected for traded live animals. Another source of underestimation of this method concerns livestock services other than meat and milk. In particular, in low income countries, a significant share of the total livestock may be used primarily to provide draught power (e.g. horses, oxen, buffaloes) or wool (sheep). The feed demand to provide these services will not be accounted for with the feed conversion coefficients reported below and needs to be estimated separately (e.g. using method A).

Method B has been applied for example in the MFA accounts of the CSIRO and UNEP Asia-Pacific Material Flows database (CSIRO 2010) using coefficients derived mainly from Wirsenius 2000. We here present a simplified version of this method: In a first step the amount of feed energy (digestible energy) required to produce each type of primary animal product (meat or milk by animal species) is calculated using conversion coefficients given in Table 5 (equation (7)). Meat should be reported in terms of carcass weight (slaughter weight), and milk in terms of whole milk production. The share of grazed biomass in total feed is calculated using equation (8) using information on the region specific share of roughage in feed (Table 6). The requirement for grazed biomass is converted from digestible energy into mass at 15% moisture content using an average value of digestible energy per unit of roughage of 10.4 MJ/kg dry matter (DM) (Wirsenius 2003) and the moisture content coefficient of 0.85 (equation (9). In case information on the harvest of forage crops (grasses, legumes, corn for silage) is available and reported under A1.3.1, these have to be subtracted from total roughage demand. Roughage demand of grazers other than cattle, sheep and goats (i.e. of horses, mules, asses, camels etc.) has to be calculated based on the estimation procedure and coefficients described in method A. Since the method is prone to considerable uncertainty, the plausibility of the results derived from this estimation procedure should be cross-checked by calculating the average per capita forage demand per head of cattle/buffalo and sheep/goats. This can be done by dividing the estimated roughage demand for meat and milk of, for example, cattle and buffalo by the total number of stock of the species (e.g. cattle and buffalo). The results can be compared to the average demand values provided in Table 3 or Table 4 (see also Cordova et al. (1978)).

(7) Feed requirement for product i [GJ] = kg product i [t] * feed conversion coefficient product i [KJ/kg]

(8) Roughage demand product i [GJ] = Total feed requirement i [GJ] * share of roughage [%]

(9) Grazed biomass [t at 15% mc] = Roughage demand [GJ] / 10.4 [MJ / kg dry matter] / 0.85 - fodder crops [t at 15% mc]

Table 5: Feed conversion coefficients

		South & Central Asia	East Europe	North Africa & West Asia	North America & Oceania	West Europe	Sub-SaharaAfrica	Latin America & Caribb.	East Asia
Cattle meat	MJ/kg carcass	499.0	160.0	151.0	132.0	126.0	373.0	264.0	313.0
Cow milk	MJ/kg milk	13.8	10.0	14.3	6.9	7.4	29.1	13.2	11.0
Sheep and goat meat	MJ/kg carcass	998.0	320.0	570.0	264.0	252.0	746.0	528.0	626.0
Sheep and goat milk	MJ/kg milk	27.6	19.9	28.6	13.8	14.8	58.2	26.4	21.9

Feed energy requirement per unit of animal product (MJ digestible energy per kg of product) by world region. Meat refers to carcass weight (slaughter weight), milk to whole, fresh milk. Based on Table 3.9 in Wirsenius 2000.

Table 6: Share of roughage in total feed energy supply by world region

% of digestible energy	South & Central Asia	East Europe	North Africa & W. Asia	North America & Oceania	West Europe	Sub-Saharan Africa	Latin America & Carrib.	East Asia
Milk cattle	65%	80%	64%	39%	43%	69%	77%	73%
Beef cattle	67%	79%	64%	60%	58%	69%	77%	69%
Sheep and goats	100%	100%	100%	80%	80%	100%	100%	100%

Roughage includes forage crops such as grasses, legumes, corn for silage and grazed biomass. Values in % of total digestible energy. Based on figure 3.28 in Wirsenius 2000 (p. 139), weighted by digestible energy content (table B5 in Wirsenius 2003).

Note: Both methods are strongly simplified versions of full scale feed balances. Results obtained with method A and B for a specific country can differ considerably. Reasons for inconsistency may lie in primary data (inconsistencies between livestock numbers and data on animal production), simplified assumptions on feed requirements, feed composition and energy content of feed stuff and also differences in terms of comprehensiveness (e.g. method B focusses on meat and milk and ignores other services such as draught power). Also limitations in the application of the provided region specific coefficients to individual countries and their temporal variability may cause inconsistencies between the two methods. Both methods have their specific shortcomings and the described procedures provide only rough estimates of grazed biomass. It is recommended to apply both methods, cross check results and then choose the methods that yields the more plausible results. More detailed methods which take national data, information of feeding systems and the full range of animal species and animal products into account are presented in Wirsenius (2000 and 2003), Krausmann et al. (2013) and Herrero (2013).

Cross check: Supply estimate via grazed area and information on area yield.

In many countries, land use statistics provides data on the extent of grazing land (often differentiated by quality or intensity) in their agricultural or land use statistics. Based on information on the extent of pastures and typical biomass yield per unit of area, the potentially available biomass for grazing can be calculated, assuming an optimum utilization of pasture resources. Country or region specific area yields of pastures and rangelands can be estimated based on expert knowledge and literature data. Table 7 provides information on typical grazing yields for different quality types of pastures in Central Europe (based on data for Austria). These data serve only as an example as pasture yields vary largely according to climate, soil conditions and management (irrigation, fertilization). To apply this crosscheck, country specific information is indispensable. Grazing potential can be calculated using equation (10).

(10) Grazing potential [t at 15% mc] = pasture area [ha] * pasture yield [t at 15% mc / ha]

Table 7: Typical area yield of permanent pastures in Central Europe

	Yield range [t at 15%mc / ha]	**Average yield [t at 15%mc / ha]**
Rough grazing, alpine pasture	<1	0,5
Extensive pasture	1-5	2,5
Improved pasture	5-10	7,0

Source: The values are derived from data for Austrian grassland systems given in Buchgraber et al. (1994) and can be assumed typical for Central Europe. Grassland yields in other world regions can deviate significantly from those presented here.

The calculated demand for grazed biomass should be lower or equal to the calculated potential supply of grazable biomass. If this is not the case, two aspects should be considered, which may, after expert consultation, lead to an adaptation of the estimates:

a) the yield factors have been estimated too low

b) the daily intake factors of livestock have been assumed too high.

Other reasons may be an exceptionally high share of market feed and feed concentrate in feed ratios, overgrazing of pasture resources or significant grazing on areas other than those reported as pasture in land use statistics (woodlands, waste lands etc.).

If no revisions are plausible or possible, the lower of the two estimates should be considered.

A.1.4 Wood

This category comprises of timber or industrial roundwood (A.1.4.1) and fuel wood (A.1.4.2). It includes wood harvest from forests and also from short rotation plantations or wood from agricultural land.

Extraction of wood is reported in forestry statistics which usually differentiate between coniferous and non-coniferous wood. Wood from short rotation plantations may also be recorded in agricultural statistics, because short rotation forests are considered cropland in many countries. National wood balances, if available, often provide more comprehensive datasets, because they also include wood harvested from non-forested land.

Wood is usually reported in terms of volume rather than weight. Units used are stacked (or piled) cubic meters and solid cubic meters (scm). One stacked cubic meter is considered equal 0.70 solid cubic meters. For MFA, volume measures have to be converted into weight measures using standard conversion factors given in Table 8.

Table 8: Standard factors to convert quantities given in volume (scm) into weight (at 15% mc) for coniferous and non-coniferous wood.

	Density [t DM / scm]*	Density [t at 15% mc / scm]
Coniferous	0,44	0,52
Non-coniferous	0,58	0,68
EU25 average (80% coniferous)	0,47	0,55

*These factors refer to t DM per scm green volume. Source: Based on factors used in IPCC greenhouse gas inventories (Penman et al. 2003).

Fellings vs. removals, bark:

Forestry statistics, especially forest inventories, sometimes distinguish between fellings and removals. MFA considers only the biomass removed from forests for further socio-economic use, i.e. wood removals. All biomass not removed (branches, root-stock, etc.), i.e. fellings minus removals, is not accounted for in MFA. This differentiation has to be considered.

Special care must be taken concerning the issue of bark, which accounts for approximately 10% of stem wood weight. Wood removals are usually reported in solid cubic meters (scm) under bark (i.e. without bark), although wood is removed including bark and a significant fraction of the bark is subject to further socio-economic use (e.g., energy production). In order to correct wood removals reported under bark for bark, we use an extension factor derived from typical values for the bark fraction of stem wood (equation (11):

(11) wood removals incl. bark [t at 15% mc] = wood removals under bark [t at 15% mc] * 1.1

A.1.5 Fish capture and other aquatic animals/plants

Fish capture and extraction of other aquatic animals and plants is reported in national fishery statistics and by FAO fishery statistics (FISHSTAT; http://www.fao.org/fishery/statistics/en). Fish and seafood production from aquaculture is not considered domestic extraction but a secondary product of the livestock sector (see section fundamentals). Only capture of wild fish (including recreational fishing) and other animals and plants extracted from unmanaged fresh and seawater systems should be reported under item 1.5 in Table A of the EW-MFA tables.

A.1.6 Hunting and gathering

This type of extraction is quantitatively of minor significance and is only accounted for if data are available in national statistics. A conversion from pieces or other physical units into tonnes might be necessary. The 2013 version of the Eurostat MFA compilation guide provides a long list of average weight of hunted animal species (see Eurostat 2013).

Specific issues related to DE of biomass

Biomass production from subsistence agriculture and home gardening: According to MFA system boundaries, biomass harvest from subsistence agriculture and home gardening is regarded as domestic extraction of biomass. In industrialized countries, these flows usually are of minor economic and physical significance and usually not included in agricultural statistics. Currently, for European countries, no reliable data and estimation procedures to quantify these flows exist and they are not considered in MFA accounts for practical reasons. In developing countries, though, this category can be of significant size. Estimation procedures might have to be developed.

Biomass waste from management of parks, infrastructure areas, gardens etc.: A significant amount of biomass is generated as a by-product of management of home gardens, infrastructure areas, public parks, and sports facilities etc. A certain fraction of this biomass flow, which comprises mown grass, woody biomass, residues from pruning and foliage etc., may be subject to further socio-economic use, e.g. for energy generation or the production of compost or it may appear in waste statistics. According to MFA system boundaries, these fractions are regarded as domestic extraction of biomass (domestic processed output, respectively). However, due to lack of reliable data and estimation procedures they are currently not accounted for. Recently, this biomass flow has received increasing attention in the context of strategies for sustainable resource use and might be included at a later stage of MFA method development.

Biomass harvest from set-aside agricultural land: An increasing amount of agricultural land in the European Union is set-aside. In many cases, this land, however, does not remain uncultivated but is used for the production of renewable resources, such as oil crops or short rotation forests etc. Usually, the biomass from these areas will be considered in national agricultural statistics, in some cases it might be recorded in separate statistical accounts or sources. In any case, it has to be accounted for as domestic extraction and subsumed under the respective item (e.g. under A.1.1.6 oil bearing crops or A.1.4.2 wood fuel).

Metal ores and non-metallic minerals

Table 9: Domestic extraction of metal ores

1 digit	2 digit	3 digit
A.2 Metal ores (gross ores)		
	A.2.1 Iron ores	A 2.1 Iron ores – gross ore M2.1 Iron ores – metal content
	A.2.2 Aluminium ores	A.2.2 Bauxite and other aluminium ores - gross ore M.2.2 Bauxite and other aluminium ores - metal content
	A.2.3 other non-ferrous metal ores	
		M.2.3.1 Copper ores - metal content
		M.2.3.2 Nickel ores - metal content
		M.2.3.3 Lead ores - metal content
		M.2.3.4 Zinc ores - metal content
		M.2.3.5 Tin ores - metal content
		M.2.3.6 Gold, silver, platinum and other precious metal ores - metal content
		M.2.3.7 Uranium and thorium ores - metal content
		M.2.3.8 Other metal ores - metal content

Table 10: Domestic extraction of non-metallic minerals.

1 digit	2 digit	3 digit
A.3 Non-metallic minerals		
	A.3.1 Ornamental or building stone	
	A.3.2 Limestone, gypsum, chalk, and dolomite	
	A.3.3 Slate	
	A.3.4 Gravel and sand	
	A.3.5 Clays and kaolin	
	A.3.6 Chemical and fertilizer minerals	
	A.3.7 Salt	
	A.3.8 Other mining and quarrying products n.e.c.	
	A.3.9 Excavated soil, only if used (e.g for construction work)	

Introduction

Metal ores and non-metallic minerals are the two major groups of minerals that are distinguished at the 1 digit level of the MFA classification. All minerals together accounted for about 51% of the global DE in 2005 (Krausmann et al. 2009), to which metal ores contribute a share of around 17%. Still, a separate representation of metals at the 1 digit level is justified due to their outstanding strategic importance for the industrial metabolism and their comparatively high economic value.

It should be noted that the classification of minerals presented in Tables A.2 and A.3 of the EW-MFA tables does not explicitly distinguish between non-metallic industrial minerals and construction minerals, a distinction that has been applied widely in material flow studies in particular in early years. The reason is that this distinction never was unambiguously and properly defined, as the same mineral often can be used for both industrial and construction purposes. Additionally, construction materials also go through some industrial processing. For a rough indication of the magnitude of minerals mainly destined for the use in the construction sector, the sum of A.3.1, A.3.2, A 3.4, A 3.5 and A 3.9 can be taken. At the detailed level of data compilation, as described below, a more accurate distinction is possible.

It is important to keep in mind that the category "domestic extraction of minerals" does not include the extraction of gases from the atmosphere for industrial purposes, such as the extraction of nitrogen in the Haber-Bosch process. These flows, if quantitatively important, are accounted for as balancing items (see the chapter on table G).

Per capita minerals extraction in Europe averaged at 8 t and ranged typically between 4 and 24 t in 2005. Non-metallic minerals used in the construction industry by far dominate domestic extraction of minerals (e.g. 94% for the EU-15 in 2000). The extraction of industrial minerals and metal ores varies greatly across countries, depending on the availability of exploitable mineral deposits. Only a few large countries like Russia or Australia mine a broad spectrum of ores and industrial minerals, most countries only mine a few of the listed materials.

DE of minerals includes a number of raw materials which differ significantly in terms of their chemical, technical, economic and environmental properties:

Economic value: The economic value of minerals ranges from very low (less than 10€/t, e.g. sand and gravel) to very high (e.g., precious metal ores and diamonds); the vast majority of extracted minerals comprises of bulk raw materials with low value (< 100€/t, e.g., sand, mixed gravel, crushed stone).

Socio-economic use: Minerals provide raw materials for constructing buildings and infrastructures, materials that enter a wide range of industrial processes and final products (e.g., inorganic chemicals, ceramics, salt for food), and metal ores for also a wide range of uses (e.g. constructions, vehicles, machinery, electrical appliances). Most of the minerals accumulate in in-use stocks of artefacts and by that differ from the other two material categories (fossil fuels and biomass), which are mostly transformed to wastes or emissions within one year.

Environment: The extraction of mineral materials can be associated with a number of environmental pressures depending on the kind of mineral and the location and type of mining and quarrying activities (ecosystems destruction, sealing of land, toxic waste emissions). A large fraction of these minerals is accumulated in societal stocks of buildings, infrastructures and durable goods; at the end of their lifetime they turn into wastes and are then a potential source for recycling and reuse of fractions of the disposed good. Any recycling and reuse flows are considered to be a flow within the socio-economic system and do not cross the system boundary between the societal system and nature.

Data sources

Statistical reporting of minerals extraction has a long tradition with regards to statistics of the mining industries. On the national level, these commonly report with high reliability on industrial minerals and metal ores, and should be taken as the primary data source. However, mining statistics often does not include complete accounts of bulk minerals like sand and gravel or crushed stones. Additional information useful for getting comprehensive data on domestic extraction of minerals may be provided by industrial associations (e.g. for the gravel and sand industry or natural stones industry). These may provide figures covering the complete field of activities involved in minerals extraction, for example also small scale enterprises not considered by other statistics. In case statistics of industrial associations or related data sources are used, it should be ensured that these report continuously on the same items. In some cases, however, data for minerals for construction will have to be estimated (see below).

Apart from national mining statistics, useful data for metallic and industrial minerals may also be obtained from international mining statistics which are mainly:

- European Mineral Statistics, a product of the World Mineral Statistics, published annually by the British Geological Survey (BGS) http://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS
- Minerals Yearbook (Volume III: Area Reports: International), by the U.S. Geological Survey (USGS) http://minerals.usgs.gov/minerals/pubs/country/index.html#pubs
- United Nations Industrial Commodity Production Statistics http://unstats.un.org/unsd/industry/ics_intro.asp
- Eurostat statistics on the production of manufactured goods (PRODCOM) http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

The statistics compiled by the **BGS** represent, so far as this is possible, the official data for the countries concerned. BGS reports production as well as imports and exports of a wide range of mineral commodities (including fossil energy carriers). In the case of metals, production data of different steps in metal processing can be selected (mine production, smelter, refining – note, that only mine production is considered an extraction from the natural system, see below), each expressed in terms of metal content. Data are reported for all countries in the world and can be downloaded for free for the years 1980 onwards. The years prior to 1980 are available in pdf files. BGS archives even provide data (in pdf form) from the 1910s onwards.

The **USGS** provides comparable data on the country level along with detailed information on the mineral industry within the studied country, in particular about the structure of the mineral industry in terms of commodity, major operating companies and major equity owners, location of main facilities, and annual capacity. This often provides important detailed information, especially for the metal contents and coupled mining of ores. Time coverage of the data accessible via the internet is usually from 1990 onwards, but only for most recent years (from 2000 on) in a format that directly allows for data processing (earlier publications are available in PDF format only). USGS archives even contain data tables (pdf) that go back to the 1930s.

For longer time series, the **United Nations Industrial Commodity Production Statistics** provide a valuable source of information (from 1950 onward). The UN, however, publishes updates roughly one or two years later than the USGS or BGS. For overlapping long time periods up to the most recent year, compatibility between the different databases has to be ensured by analysing and eventually adjusting the different datasets.

Eurostat provides the **statistics on the production of manufactured goods (PRODCOM)**. It covers data for the 27 European Union member states and a number of additional countries according to the European PRODCOM system, which is largely identical with the CPA classification system. Production data are available for more than 1000 products in physical and monetary units. However, the completeness of the data varies considerably across countries and years.

Note that production statistics reports marketable products, which is often not equivalent to mined minerals as reported in mining statistics. MFA requires accounting for mined ores or minerals, see definition below.

Conventions

Terminology and classification: Mining statistics does not use the same terminology or classification internationally. UN statistics use the ISIC Rev.2-based commodity codes, Eurostat uses PRODCOM and CPA codes respectively, and the BGS and USGS do not refer to standard statistical codes at all. Therefore, some caution is required when working with more than one data base to avoid either incomprehensive or double accounting.

System boundaries: Minerals mining involves the mobilisation of huge amounts of materials. For the compilation of comparable data sets and indicators it is instrumental that the same system boundary is applied. Table 11 gives an overview of the terminology used in MFA with regard to the different flows involved in the extraction of metals.

Table 11: Different system boundaries in metal mining

Description of the material	**Common terminology**	**MFA terminology**
Materials removed to get access to metal reserves	Overburden, interburden	Unused extraction
Metal containing material	Run of mine, gross ore, crude ore	Used extraction
Pure metal	Net ore or metal content	Memorandum item; metal component of used extraction, not specifically referred to in MFA indicators; reported in the MFA tables as metal content for further information.
Processed ores with a higher metal concentration.	Metal concentrates	No DE but an intermediate product along the different stages of metal processing. In MFA terms this is considered an internal flow within the socio-economic system. DE can be extrapolated from data on metal concentrate using appropriate coefficients.

Accounting for domestic used extraction of minerals always refers to the run-of-mine production. Run-of-mine production means that the total amount of extracted crude mineral that is submitted to the first processing step is accounted for. Material extracted but not used as an input for subsequent processing is termed unused domestic extraction and is not accounted for. Unused extraction may, for example, include overburden removed and deposited or interburden removed and filled. Databases on mineral production often also include production from further metal processing such as production of smelters or refineries. In MFA only the extraction from the natural system, i.e. mine production in gross ore, is considered as domestic extraction.

The run-of-mine concept concerns metals in particular, but principally holds true for all minerals. For most minerals other than metallic ores, the difference between run-of-mine production and reported production is not relevant; an important exception is rock phosphate.

Polymetallic ores: Metals mostly occur as co-products in polymetallic ores, which is an ore body that contains a combination of several metals in different concentrations. In the MFA literature this has also referred to as “coupled production” of metals. This applies to most metals and ores. Exceptions are most iron ores and bauxite which are only mined to produce one specific ore (iron and aluminium, respectively) and do not contain significant amounts of other metals.

The **ore grade** specifies the metal content of a specific gross ore. The ore grade is an important source of information both in economic as well as biophysical terms. Economically, deposits with high ore grades (higher volumes of metal contained) are of higher value and their exploitation is given priority. Biophysically, the ore grade is the relation between metal content and gross ore and thus allows for estimations of gross ore volume from metal content or vice versa. Additionally, cross checks can be performed to evaluate the data quality of reported gross ore. Ore grades are variable across ores, mines, and time; an overview of ore grades of different metals (metal content in % of gross ore) in European countries is provided in Table 13.

Estimation of gross ore volume: MFA accounts require accounting for the gross ore (run of mine). In those cases, where mine output is reported only in metal content, estimations have to be applied to estimate gross ore volumes: First and most preferably, estimations are based on data from single mines and their specific production system with good knowledge of the reported production data and information on the mine-specific ore grade. Data provided by mining companies or experts serve as data sources. Unfortunately, this mine-by-mine approach is quite data intensive and access to the relevant information is often not easy to get. Thus, often a simpler approach has to be applied, which uses aggregate national data on mine production in metal content and ore grades. Respective estimation procedures are described in detail in the section concerned with the specific material group.

Estimations for bulk minerals for construction: Bulk minerals for construction are often under-represented in statistics. In this case it is necessary to estimate the actual amounts of material that has been extracted. This refers mainly to sand and gravel, limestone, and clays for construction. Respective estimation procedures are described in detail in the section concerned with the specific material group.

Moisture content: Minerals have specific moisture content that is usually not subject to high variability. Therefore, data for the extraction of minerals are simply taken as they are reported.

Data compilation A.2 metal ores

Among metal ores, three sub-categories are differentiated: iron ores, aluminium ores (mostly bauxite), and other metals ores. Iron and aluminium are represented in separate categories for several reasons: In terms of total tonnage, the two metals are the ones most extensively extracted and used. Second, iron and aluminium ores mostly do not contain other metals than iron and aluminium, respectively, while all other metals mostly occur in polymetallic ores. Finally, both metals are mostly reported as gross ore mined in mineral statistics and no estimation procedures have to be applied.

A.2.1 Iron ores

The two main iron ores are hematite and limonite. Iron ores are chiefly used to produce steel in integrated steel plants; cast iron is a minor part of production. Data for the extraction of iron ores are provided in good quality by national and international statistical sources and generally report gross ore production. Ore grades range from 25-35% in low grade ores and up to 60% in high grade ores. Global average ore grade is estimated at around 50% (see e.g. Mudd (2013)). Low grade ores gave to be concentrated; concentrates contain around 64% Fe by weight.

A.2.2 Bauxite and other aluminum ores

The only important mineral source of aluminium is bauxite, which contains 30-60% alumina (Aluminumoxide, Al_2O_3) (Ayres et al. 2006). The main applications of aluminum are in packaging, transportation, and construction. Data for the extraction of bauxite are provided in good quality by national and international statistical sources and generally refer to gross ore production.

A.2.3 other non-ferrous metal ores

This group contains many different metals of very different characteristics and ore grades such as nickel, lead, copper, silver, gold, uranium etc. These metals mostly occur in polymetallic ores, i.e. several metals are combined in one ore body. The metal combination differs by ore type and therefore from mine to mine and between and within national economies. In mining surveys, the mine output for these metals is mostly reported in metal content, i.e. the metal contained in the ore mined. In MFA, metal extraction needs to be reported in gross ores (run of mine). In those cases, where only metal content is available in mining statistics, gross ore values need to be estimated.

Run-of-mine estimation from metal content

The occurrence of combined metals in one gross ore body (polymetallic ores) poses several difficulties in compiling the DE of metals. The following information is required: (1) mine output (metal), (2) which metals are mined together as coupled production, (3) the ore grades of the mines in the country.

The **mine output** is reported in mining surveys, provided by mining companies, national statistics, or international mining surveys such as the United States Geological Survey (USGS, ref) or the British Geological Survey (BGS, ref). For the metals in this category, mine output is mostly reported in metal content.

Information on the **combination of metals in a polymetallic ore:** the composition of specific ores may differ between deposits within one national economy. For example, at site A, an ore containing copper, lead, and zinc may be mined, while at site B, lead and zinc are mined together with gold. The information on which metals are mined together in which mine, is available from mining companies, or national statistics, or international mining surveys (USGS, BGS). Ideally, the information would be collected on a mine to mine basis. However, this is very time consuming and requires a lot of detailed data, which is often not easy to access. Therefore, in a simpler approach one determines which form of mining is dominant for each metal, i.e. that type of ore from which the major part of the metal in question is mined. In case this type of information is not available from the national statistical unit responsible for mining, it can be obtained from the USGS country reports. This approach is, of course, a simplification, but often unavoidable due to data constraints.

Ore grades: the ore grade represents the percentage of metal contained in an ore. Also the ore grade differs from mine to mine, and the average ore grade of a certain metal in a country depends on the different ores mined at different sites. Often national averages are available from mining handbooks and other statistical sources; in case no information is available, even information from other countries (in the region) mining similar ores can be used. Additionally, ore grades change over time, in most cases it decrease over time since the best ores have been mined first (see e.g., Mudd (2013)). Data sources for ore grades are the same as for mine production, i.e. mining companies, national statistics, or international surveys (USGS, BGS). For some examples of ore grades, see Table 13.

Calculation of gross ore (i.e. run-of-mine) is based on data on metal extraction (in tonnes) and the mine-specific or national ore grade. If coupled production for a specific metal can be excluded (that is, only a single metal is extracted from the given ore), equation (12) holds true:

$$\text{(12)} \quad \text{gross ore [t]} = \frac{\text{metal content [t]}}{\text{ore grade}}$$

If more than one metal is extracted from the same ore, care must be taken to ensure that the same run-of-mine is not accounted for more than once. In the case that coupled production from polymetallic ores has been identified for two or more metals, the following calculation procedure according to equation (13) can be applied.

(13) gm_{tot} [t] = m_{tot} [t] / og_{tot} [%]

gm_{tot} = mass of total gross ore which contains metals m_1 to m_n

m_{tot} = sum of metals m_1 to m_n contained in the gross ore

The sum of all metal content m_1 to m_n (in tonnes) extracted in coupled production corresponds to the total amount of metal contained in the gross ore in question. The data can be obtained from mining statistics or specific allocation studies.

og_{tot} = sum of ore grades (og_1 to og_n)

The sum of all ore grades (in %) og_1 to og_n contained within the same ore corresponds to the total ore grade og_{tot}. The respective ore grades can be obtained from statistics or literature.

The calculation of gross ore from metal content is performed for all metals or polymetallic ores extracted in a country.

Allocation of waste rock to metal content

In the case of polymetallic ores, the question now arises, how to allocate the calculated gross ore mass to the metals contained, i.e. the different MFA metal categories. Different approaches are used. In the Eurostat manual (Eurostat, 2013), the allocation is done based on the fraction of the total ore grade which the respective metal represents. A global MFA account published by Schaffartzik et al. (2014) did not distribute the gross ore at all, but reported metal content and total waste rock (i.e. gross ore subtracted by metal content). This approach owes the fact that a) no unambiguous allocation can be performed and that b) information on metal content is highly relevant for strategic uses in industrial processes, whereas waste rock is of low economic value an even of different physical characteristics than the metal contained.

Finally, the forthcoming MFA Manual of UNEP uses a third approach, which is also recommended and described in this Manual: total gross ore is not distributed to the single metals contained but reported as total gross ore for iron, bauxite and all other metals. Additionally, also the actual metal content of the individual metals is reported as memorandum items M.2.1, M.2.2, and M.2.3.1 to M.2.3.8 (see Table 9), to provide this important information.

The following **example** illustrates the calculation procedure. Table 12 represents the metal output of a hypothetical economy. Since the data is provided in terms of metal content, it is necessary to calculate the associated gross ore.

Table 12: Coupled production, Metal output of hypothetical economy

Metal	Mine Output, Metal Content [t]	Ore Grade	Coupled Production with:
Copper	10 000	0.01	Tin
Iron	300 000	0.5	no coupled production
Lead	30 000	0.08	Zinc
Zinc	150 000	0.05	Lead
Tin	500	0.0002	Copper

In the example given in Table 12 iron is the only metal which is not mined in coupled production (single metal ore). Copper occurs together in one deposit with tin, and lead occurs together with zinc, so that the procedure for coupled production calculation must be followed.

a) Calculation of iron gross ore

$$\text{iron gross ore [t]} = \frac{300\,000\text{ t}}{0.5} = 600\,000\text{ t}$$

b) Calculation of Coupled Production Ores

$$\text{copper and tin gross ore [t]} = \frac{10\,000\text{ t} + 500\text{ t}}{0.01 + 0.0002} \approx 1\,029\,412\text{ t}$$

$$\text{lead and zinc gross ore [t]} = \frac{30\,000\text{ t} + 150\,000\text{ t}}{0.08 + 0.05} \approx 1384\,615\text{ t}$$

Table 13 provides country-specific ore grades and occurrences of coupled production in Europe as examples. Coupled production is listed for the dominant ore, which accounts for the majority of extraction of a specific metal in a country. This information is based on data from international statistical sources. More precise information both on ore grades and coupled production may be available from national statistical sources and should be given preference over the data provided here.

Table 13: A selection of country-specific ore grades and occurrences of coupled production according to international statistical sources for European countries

	Metal	Ore Grade [%]	Coupled Production
Austria	W – Tungsten	0.27 to 0.31	–
	Fe – Iron	32	with Mn (total gross ore reported under iron ore)
	Mn – Manganese	0.8	with Fe (total gross ore reported under iron ore)
Bulgaria	Cu – Copper	0.45	with Au, Ag
	Ag – Silver	0.001	with Au, Cu
	Au – Gold	0.0004	with Ag, Cu
	Pb – Lead	7	with Zn
	Zn – Zinc	7	with Pb
	Fe – Iron	27 to 33	mining ceased in 2005
	Mn – Manganese	27 to 30	no coupled production
Czech Republic	U – Uranium	0.48 to 0.52	no coupled production
	Fe – Iron	30	mining ceased in 2002
Spain	Ag – Silver	0.01169	with Au, Cu, Ge, Pb, Zn
	Au – Gold	0.000576	with Ag, Cu, Ge, Pb, Zn
	Cu – Copper	1.58	with Ag, Au, Ge, Pb, Zn
	Ge – Germanium	0.005	with Ag, Au, Cu, Pb, Zn
	Hg – Mercury	0.4	no coupled production
	Pb – Lead	1.48	with Ag, Au, Cu, Ge, Zn
	Sn – Tin	0.016	no coupled production
	Sr – Strontium	43.88	no coupled production
	Zn – Zinc	5.71	with Ag, Au, Cu, Ge, Pb
Finland	Cr – Chromium	35 to 36 (Cr_2O_3)	no coupled production
	Cu – Copper	1.17	with Zn and with Ni
	Au – Gold	0.00007	no coupled production
	Ni – Nickel	0.22	with Cu
	Zn – Zinc	0.49	with Cu
France	Al – Aluminium		reprocessed, gross weight
	Au – Gold		mine closed
	Ag – Silver		(probably with gold)
	U – Uranium		mine closed
Germany	Fe – Iron	11 to 14	no coupled production

	Metal	Ore Grade [%]	Coupled Production
Greece	Ni – Nickel	0.8	with Fe
			with Fe, Mn
	Zn – Zinc	9.0	with Pb, Au, Ag
	Pb – Lead	8 to 10	with Zn, Au, Ag
	Au – Gold	0.00036	with Pb, Zn, Ag
	Ag – Silver	0.02	with Pb, Zn, Au (also with barite and bentonite)
	Al – Aluminum	53 (alumina)	no coupled production
	Mn – Manganese	15 to 19	with Fe, Ni
Hungary	Mn – Manganese	26 to 27	no coupled production
Ireland	Pb – Lead	8 to 15	with Zn, Ag
	Zn – Zinc	13.6	with Pb, Ag
	Ag – Silver	0.5	with Pb, Zn
Italy	Au – Gold	0.00025	no coupled production
	Mn – Manganese	35.0	no coupled production
Norway	Co – Cobalt	1.38	no coupled production
	Fe – Iron	32.6	no coupled production
	Ti - Titanium	18.0	no coupled production
	Ni – Nickel	0.5	no coupled production
Poland	Pb – Lead	1.7	with Cu (33%) & Zn
	Cu – Copper	1.8 to 1.9	with Pb, Ag, Au
	Zn – Zinc	4.2	with Pb
	Au – Gold	0.0001	by-product of copper
	Ag – Silver		with Cu (mainly), with Pb, Zn (less)
	Cd – Cadmium		by-product of lead/zinc
Portugal	Cu – Copper	6	with Sn, Zn
	Sn – Tin		with Cu, Zn
	Zn – Zinc	8	with Sn, Cu
	W – Tungsten	0.25 (WO_3)	no coupled production
	U – Uranium		no coupled production

	Metal	Ore Grade [%]	Coupled Production
Romania	Cu – Copper	0.6 to 1	with Pb, Zn (partly)
	Pb – Lead	0.4 to 1	with Zn, Cu (partly)
	Zn – Zinc	0.6 to 1.2	with Pb, Cu (partly)
	Au – Gold		associated with Pb, Zn
	Ag – Silver		associated with Pb, Zn
	Antimony		associated with Pb, Zn
	Bismuth		associated with Pb, Zn
	Cadmium		associated with Pb, Zn
	Mn – Manganese	16 to 25	no coupled production
Slovakia	Au – Gold	0.00014	--
	Cu – Copper	1	no coupled production
	Fe – Iron	26.68	no coupled production
Sweden	Cu – Copper	25 to 28 (concentrate)	-- with Au with Au, Pb, Zn with Pb, Zn
	Pb – Lead	5	with Zn with Cu,Zn with Cu, Au, Zn with Cu, Au
	Zn – Zinc	8	with Pb with Pb, Cu with Pb, Au, Cu
	Au – Gold		-- with Cu with Cu, Pb, Zn
	Ag – Silver		probably with Au
United Kingdom	Pb – Lead	27 (concentrate)	--

Source: according to USGS Minerals Yearbook, Volume III, Area reports: International.

A.2.3.1 Copper ores

There are several copper ores, but they all fall into two main categories: oxide ores and sulphide ores. Azurite, malachite, and chrysocolla are a few examples of oxide ores. Chalcocite, bornite, idaite, covellite, and chalcopyrite are all examples of sulphide ores. Currently, the most common source of copper ore is the mineral chalcopyrite, which accounts for about 50% of global copper production. Copper is used in the electrical, electronics, transportation, and construction industries. Typical copper content in gross ores currently mined typically ranges between 0.5% and 1% in most mines but it can be as high as 2% and 4%, the global averaged Grade has been estimated at 0.62% (Calvo et al. 2016). Copper concentrates commonly contain between 20 and 40% copper by weight.

A.2.3.2 Nickel ores

Two important nickel ores are the iron-nickel sulphides, pentlandite and pyrrhotite; the ore garnierite is also commercially important. The most important use of nickel is in steel alloys, it is further used in plating, both metals and plastics, and combined with copper in cupro-nickel alloys. Nickel ores mine production is usually reported in metal content. Metal content in gross ores typically ranges between 0.5% and 1%. Nickel concentrates typically contain 10% to 15% Ni by weight.

A.2.3.3 Lead ores

The most common lead ore is galena, a sulphide. The other minerals of commercial importance are cerussite, a carbonate and anglesite, a sulphate. Lead also occurs in various uranium and thorium minerals, arising directly from radioactive decay. Commercial lead ores may contain as little as 3% lead, but a lead content of about 10% is most common. The ores are concentrated to 40% by weight or greater lead content before smelting. Lead is mainly used in lead-acid batteries, but also widely in architecture, plumbing, solder, radiation shielding, and insecticides.

A.2.3.4 Zinc ores

Chief sources of zinc are zinc blende, a sulphide ore (called also sphalerite or “Black Jack”), zincite, an oxide, calamine, a silicate, and smithsonite, the zinc carbonate. Zinc ores are widely and abundantly distributed throughout the world. Chief use of zinc is for steel coating (galvanising), but it is also used as zinc die-casting, and alloyed with copper to make brass which is widely used in the electrical, engineering, and construction industries. Metal contents in gross ores can be as high as 10-15% in sedimentary exhalative (SEDEX) Zinc-Lead Silver deposits, but also significantly lower e.g. in Zinc-Lead MVT deposits (2-6%). Zinc concentrates typically contain around 55% Zn by weight.

A.2.3.5 Tin ores

The most important tin-bearing mineral is cassiterite. No high-grade deposits of this mineral are known. The bulk of the world's tin ore is obtained from low-grade alluvial deposits. Ore grades are typically between 0.015% to 1%. The chief use of tin is to coat metals that are more susceptible to corrosion, especially steel. It is also widely used as an alloying agent (e.g. with lead to make pewter) and its use in solders is rapidly growing as it replaces lead. Tin chemicals are used as fungicides and other biocides. Tin concentrate from cassiterite typically contains 70-77% tin by weight.

A.2.3.6 Gold, silver, platinum and other precious metal ores

Gold: Native, or metallic, gold and various telluride minerals are the only forms of gold found on land. Native gold may occur in veins among rocks and ores of other metals, especially quartz or pyrite, or it may be scattered in sands and gravel (alluvial gold). The high grade gold ores are considered ores with a gold content of 8-10 g/t, but ore grade of most ores is much lower around 1-4 g/t. Gold is highly valued as an investment commodity, in jewellery and in specialised electronic appliances.

Silver: The principal silver ores are argentite, cerargyrite or horn silver, and several minerals in which silver sulphide is combined with sulphides of other metals. About three-fourths of the silver produced is a by-product of the extraction of other metals, copper, lead and gold in particular. Ore grades vary greatly and often range between 100 and 1000 g/t. Silver is widely used in electronics although the most important uses are in photography (silver nitrate) and making mirrors.

Platinum: South Africa is the largest producer of platinum in the world. Platinum, often accompanied by small amounts of other platinum family metals, occurs in alluvial placer deposits in the Witwatersrand of South Africa, Colombia, Ontario, the Ural Mountains, and in western USA. Platinum is produced commercially as a by-product of nickel ore processing in the Sudbury deposit. The huge quantities of nickel ore processed makes up for the fact that platinum is present as only 0.5 ppm in the ore.

Other precious metal ores: These include the (other) Platinum Group Metals (PGM), palladium, rhodium, ruthenium, osmium and iridium. There is likewise no mine production in the EU.

Of the PGM family, platinum and palladium are the most commercially significant, having important applications as catalysts and in electronics and jewelry and as investment commodities.

A.2.3.7 Uranium and thorium ores

Minerals that contain uranium or thorium as an essential component of their chemical composition are called radioactive minerals. Examples are uraninite or thorite. Uranium is chiefly used as the fuel source for nuclear power stations and in weapons. Typical metal content in gross ores is around 0.17%. Yellowcake concentrate is produced in all countries where uranium is mined and contains about 80% uranium oxide.

A.2.3.8 Other metal ores

Other non-ferrous metal ores include (according to the BGS commodity list for European mineral statistics): antimony, arsenic, bismuth, cadmium, chromium, cobalt, lithium, magnesium, manganese, mercury, molybdenum, rare earths (yttrium and scandium), selenium, strontium, tantalum (and niobium), titanium (ilmenite), tungsten, vanadium, zirconium. Some important metals in group A.2.2.8. are briefly described below.

Arsenic: Arsenic is found native as the mineral scherbenkobalt, but generally occurs among surface rocks combined with sulphur or metals. Its principal uses are as compounds in wood preservatives and pesticides, and in semi-conductors as gallium arsenide.

Chromium: Chromium is mined from the ore Chromite. It is an essential component of stainless steel and other alloy steels. It is also used in superalloys and metal plating, as pigments and in refractories.

Lithium: Lithium may profitably be extracted from ores containing as little as 1% lithium (measured as lithium oxide). Some commercially important minerals are lepidolite, petalite, spodumene, and amblygonite. Lithium is also produced from brines such as those in Searles Lake, Calif., and in the Great Salt Lake, Utah. Its uses are as fluxes in the ceramics and glass industries, in lubricants, as alloying agent in primary aluminium, and in rechargeable batteries.

Magnesium: is a light metal commonly mined as magnesite. Although magnesium is found in over 60 minerals, only dolomite, magnesite, brucite, carnallite, talc, and olivine are of commercial importance. It is most commonly used in refractory bricks in furnaces, but also in fertilisers.

Manganese: is sometimes reported together with iron ores as iron-maganese ores. Manganese occurs principally as pyrolusite and to a lesser extent as rhodochrosite. Its principal use is in the steel industry as desulphuriser and as an alloy, further as an aluminium alloy, in dry-cell batteries, and in the chemical industry.

Mercury: is mainly used in electrical switches and other control apparatus, and in dental amalgam, but also in chlor-alkali plants and in batteries where the use is being phased out.

Strontium: Its dominant use is in the faceplate glass of cathode ray tubes where it blocks X-ray emissions. Other uses are in pigments, pyrotechnics, and fluorescent tubes.

Tungsten: Ore grades may range from 0.25 to 2.5 % tungsten oxide; for Austria values of 1.8% have been reported. Its largest use is in cemented carbides in cutting tools, but also as an alloying agent with steel for tools and in superalloys. Its most familiar use is in light bulb filaments.

Data compilation A.3 non-metallic minerals

A.3.1.Ornamental or building stone

This category comprises almost any competent rock type that may be used in the form of shaped and/or sized blocks for either structural or decorative purposes. It includes marble and other calcareous ornamental or building stone (e.g. travertine, ecaussine, and alabaster), and granite, sandstone, and other ornamental or building stone (e.g. porphyry, basalt), as well as roofing stone.

Data are often given in cubic meters (m^3) and have to be converted to tonnes (see Table 14 for conversion factors).

Table 14: Specific densities of ornamental and building stone

	kg per cubic meter
Marble, solid	2563
Granite, solid	2691
Sandstone, solid	2323
Porphyry, solid	2547
Basalt, solid	3011
Stone (default value if no other specifications are available)	2500

Source: SIMETRIC

A.3.2 Limestone, gypsum, chalk and dolomite

Limestone: In Europe, limestone is mostly used for cement production, followed by its use as crushed rock aggregate. Limestone requires special attention in the account for non-metallic minerals. Statistics often underreport amounts of limestone extracted for construction purposes, in particular for cement production. This position, however, commonly represents a large mass flow accounting for a considerable share of DE of non-metallic minerals. To check and eventually correct for missing limestone extraction for cement production, the following estimation can be applied:

Estimate of limestone extraction based on (finished) cement production: The German Federal Institute for Geosciences and Natural Resources (BGR) explicitly reports limestone used for the production of Portland cement. Using corresponding production figures for cement from the BGR, a ratio of 1.19 tonnes of limestone for the production of 1 tonne of cement can be identified. The extraction of limestone can be calculated based on data for cement production in tonnes and the ratio of limestone to cement (equation (16)):

(16) Limestone for cement production [t] = cement production [t] * 1.19

Data for cement production are reported for example in USGS statistics. A comprehensive source of global cement data is the European Cement Association (CEMBUREAU) which publishes yearly updates of global cement production, imports, exports and apparent consumption for individual countries. The World Statistical Review of 1998 (CEMBUREAU 1998) includes data for the period 1910-1995; later editions of this annual publication provide data in 10year intervals and yearly updates. For EU countries also production statistics can be used and should include PRODCOM-2007 items 26511210 (White Portland cement); 26511230 (Grey Portland cement including blended cement); 26511250 (Alumina cement) and 26511290 (Other hydraulic cements).

It is recommended to compare the estimated figure for limestone extraction for cement with the figure for limestone reported in statistics. The higher number should be selected as data for the domestic extraction of limestone (with a tolerance of about 10% in favour of using the original statistics figure). If limestone for other use than for cement is clearly indicated in statistics, this figure has to be added to the estimate for limestone for cement.

For minerals of category A.3.2. data are often reported in cubic meters (m^3) and have to be converted to tonnes (see Table 15 for conversion factors).

Table 15: Specific densities of limestone and gypsum

	kg per cubic meter
Gypsum, crushed	1602
Limestone, broken	1554
Limestone (default value if no other specifications are available)	1500

Source: SIMETRIC

Chalk is a soft, white, porous form of limestone composed of the mineral calcite. It is also a sedimentary rock. Uses are widespread and comprise blackboard chalk, to mark boundaries, in sports, applied to the hands or to instruments to prevent slippage, and as tailor's chalk.

Dolomite is the name of both a carbonate rock and a mineral consisting of calcium magnesium carbonate found in crystals. Dolomite rock (also dolostone) is composed predominantly of the mineral dolomite. Limestone, which is partially replaced by dolomite, is referred to as dolomitic limestone. Limestone and dolomite are commonly used as crushed-rock aggregate, for cement production, and for other industrial and agricultural uses. Limestone and dolomite are often combined in statistical reporting.

Please note! In case data for limestone are derived from an estimate described under A.3.2., it should be figured out if this estimate includes use of dolomite (for cement production). Data reported for dolomite under A.3.2 sourced from mineral statistics then eventually have to be corrected for double counts. It is recommended to consult a national expert for clarification of this issue.

For minerals of category A.3.2 data are often reported in cubic meters (m^3) and have to be converted to tonnes (see Table 16 for conversion factors).

Table 16: Specific densities of chalk and dolomite

	kg per cubic meter
Chalk, lumpy	1442
Dolomite, lumpy	1522
Chalk and dolomite (default value if no other specifications are available)	1500

Source: SIMETRIC

A.3.3 Slate

Slate is a fine-grained, homogeneous, metamorphic rock derived from an original shale-type sedimentary rock composed of clay or volcanic ash through low grade regional metamorphism. Slate can be made into roofing slates, also called roofing shingles. Fine slate can also be used as a whetstone to hone knives. Because of its thermal stability and chemical inertness, slate has been used for laboratory bench tops and for billiard table tops. Slate tiles are often used for interior and exterior flooring or wall cladding. Slate for construction purposes may be included in statistics as building or dimension stone (A.3.1) and should, if possible included there. Depending on the predominant characteristics of slate, conversions from m^3 to tonnes may be performed as shown in Table 17.

Table 17: Specific densities of slate

	kg per cubic meter
Slate, solid	2691
Slate, broken	1290-1450
Slate, pulverized	1362
Slate (default value if no other specifications are available)	1400

Source: SIMETRIC

A.3.4 Sand and gravel

There are two major groups of gravel and sand (sometimes also subsumed under the notion natural aggregates) which are distinguished by their principal uses:

Industrial sand: Industrial sands show specific material properties that are required for use in iron production and manufacturing including fire resistant industrial use, in glass and ceramics production, in chemical production, for use as filters, and for other specific uses. Statistical sources (e.g. the USGS) often report the amount of sand in industrial production processes explicitly.

Sand and gravel for construction: Sand and gravel for construction is used in structural engineering (e.g. buildings) and civil engineering (e.g. roads). Use of sand and gravel in structural engineering is mainly for the production of concrete. In civil engineering gravel is mainly used for different kinds of base-course and subbase layers in road and building construction, in concrete elements and for asphalt production.

Note: Sand and gravel can contain considerable amounts of moisture (15-25%). In material flow accounts, sand and gravel is accounted for in dry weight. If necessary, an appropriate correction should be applied.

Statistics for sand and gravel may not report the total amount extracted for both industrial and construction use adequately. Often, only special sand and gravel for industrial use is included (see above). Statistics also may report numbers for sand and gravel for construction but not report total numbers due to e.g., limitations in the census. To find out if sand and gravel is not adequately reported or underestimated in statistical sources, the following checks can be performed:

The amount of sand and gravel per capita of the population in the respective year can be taken as an indicator. DMC of industrial countries averages at around 5t/cap, in least developed countries it can be as low as 1-2 t/cap/yr. As a rule of thumb, if sand and gravel reported in statistical sources is significantly below 1 ton per capita, it can be assumed that sand and gravel for construction purposes is not adequately reported and has to be estimated. Additionally stakeholders and experts concerned with this economic activity should be consulted to clarify the significance of the reported numbers. If no adequate statistical data are available, the total amount of sand and gravel extracted for construction can be estimated.

Estimation of sand and gravel for construction:

The following simple procedure to estimate the amount of sand and gravel used in construction takes into account the two most important uses of sand and gravel. It combines an estimate of sand and gravel required for the production of concrete (step 1) with an estimate of sand and gravel used in asphalt production (step 2). Step 3 describes procedures for a rough estimate of the amount of additional sand and gravel in subbase and base-course layers of buildings and roads. The total amount of sand and gravel is than calculated in step 4 as the sum of the results obtained from step 1 and step 2 and – if performed - also step 3. It is important to note that this is a conservative estimate, which does not consider sand and gravel used as fillings and base material. In industrial countries, this approach typically underestimates the overall extraction of sand, gravel and crushed stone for construction by 20-40% (see estimate of sand and gravel used in subbase and base-course layers of buildings and roads below).

Step 1: Estimation of sand and gravel required for the production of concrete: Concrete is a mixture of 6% air, 11% Portland cement, 41% gravel or crushed stone (coarse aggregate), 26% sand, and 16% water (PCA 2007). Thus, sand and gravel make up about 67% of the produced concrete. Based on these relations two ways for calculating sand and gravel required for concrete production are possible:

Method 1a: Estimation of sand and gravel based on the consumption of cement: The required input of sand and gravel to produce one ton of concrete typically ranges between is 5 and 6.5 kg sand and gravel per kg cement. Here we use a coefficient of 6.1 to extrapolate snad and gravel from cement use (PCA 2007). Accordingly, sand and gravel input into concrete production can be calculated following equation (17):

(17) Sand and gravel input [t] = cement consumption [t] x 6.1

Cement consumption can be derived from data on production of and trade with cement using equation (18):

(18) Apparent cement consumption = cement production + cement imports – cement exports

Data on cement flows can be obtained from statistical sources, e.g. the world statistical review of the European Cement Association (CEMBUREAU 1998, 2013). If industrial production and trade statistics are used, production includes PRODCOM-2007-items 26511210 (White Portland cement); 26511230 (Grey Portland cement including blended cement); 26511250 (Alumina cement) and 26511290 (Other hydraulic cements); Trade flows include HS-CN-items 252321 (White Portland cement); 252329 (Portland cement excl. white); 252330 (Aluminous Cement); 252390 (Cement weather or not coloured excl. Aluminous and Portland cement).

Method 1b: Alternatively, sand and gravel can be estimated on the basis of concrete production data using equation (19):

(19) Sand and gravel input [t] = concrete production [t] x 0.67

Data on concrete production can be obtained from production statistics (PRODCOM-2007-item 26631000 Ready-mixed concrete); in general, method 1b tends to underestimate the amount of sand gravel, because concrete reported in statistics commonly refers to transport concrete and does not include concrete produced directly at the construction site. If method 1b is used, clarification of the quality of concrete production data is required.

Step 2: Estimation of sand and gravel for asphalt production: Asphalt or asphalt concrete is a composite material commonly used in construction projects, above all for road surfaces. Asphalt consists of bitumen, a product of the petrochemical industry, which is mixed with mineral aggregate (gravel, crushed stone, etc.). To encompass at least some of the sand and gravel used in road construction and maintenance sand and gravel demand for asphalt production can be estimates by combining data on bitumen consumption and the ratio of bitumen to sand and gravel in asphalt, which is typically around 1:20. Data on apparent consumption of bitumen are reported for example in IEA's international energy statistics database or the United Nations energy statistics database (UNSD 2008). Sand and gravel input is calculated using equation (20):

(20) Sand and gravel input [t] = bitumen consumption [t] x 20

Step 3: Additional sand and gravel for subbase and base-course layers

Krausmann et al. (2017b) propose a method to estimate the additional sand and gravel used as subbase or base-course layers in building and road construction based on information provided in Miatto et al. (2016). The estimate of aggregate demand for base-course layers of roads is derived from technical construction standards for roadways, where a multiplier is calculated to extrapolate aggregate demand from asphalt use. The value of the multiplier takes into account that with the expansion of road networks in the 20th century an increasing share of asphalt is used in the refurbishment of existing roads, requiring much less aggregate. It was assumed that aggregate requirement per t of asphalt remained constant at 100 t until 1940 and then declined to 50 t in 1980 and then remained at this level. The estimate of aggregates required for sub-base layers of buildings is estimated on the basis of the used amount of concrete and bricks and a sub-base multiplier of 70 kg of aggregate per t of concrete and 45 kg per t of bricks used in construction. To estimate the amount of primary extraction of sand and gravel to meet the calculated demand should take into account, that downcycled construction and demolition waste (C&D) (e.g. sourced from statistics on C&D recyling) can be used to substitute for primary sand and gravel. For more details see Krausmann et al. (2017b) and Miatto et al. (2016).

An alternative approach, which uses information on the length of newly built roads (by type of road and year) to estimate the amount of sand and gravel used in the construction of roads is described in Eurostat (2013). Data on the length and enlargement of the road network are commonly provided by national transport or road statistics. Data for the EU Member States and other countries are e.g. available from the publication "EU energy and transport in figures" (DG TREN 2008). The International Road Federation publishes the world road statistics, which could also be used as a data source; information on road length is also available from the World Development Indicators database (The World Bank Group 2014). Quality of road length data and comparability across countries is, however, quite poor and this method should only be applied when expert knowledge is available.

In addition to information on the length of the road network, data on the amount of sand and gravel required to build one kilometre of a certain road type have to be acquired. The following Table 18 provides examples for Germany but sand and gravel requirements for the construction and maintenance can vary significantly across regions and countries:

Table 18: Requirements of sand and gravel per km of road construction in Germany

	tonnes sand and gravel per km		Reference data	
	for construction	for annual maintenance	Average width in m	Total length in km
	Germany	Germany	Germany	Germany
Highways	28,383	518	24.4	12,531
National roads	9,692	151	8.8	40,711
Federal state roads	8,719	76	7.5	86,597
District roads	6,777	65	6.5	91,520
Local roads	5,729	67	5.5	460,000
All roads	**6,886**	**81**	**6.4**	**691,359**

Sources: Ulbricht 2006; Steger et al. 2009.

Step 4: Finalization and cross check: Estimated figures for sand and gravel for concrete production (step 1) and sand and gravel for asphalt production (step 2) and – if performed - also estimates of additional sand and gravel (step 3) are finally added and compared with the figure for sand and gravel reported in statistics. The higher number should be selected as data for the domestic extraction of sand and gravel for construction (with an eventual tolerance of about 10% in favour of using the original statistics figure). In case sand and gravel for industrial uses is given as a specific position in statistics, this figure has to be added to the estimated figure. In this category of minerals, data may be given in cubic meters (m^3) and have to be converted to tonnes. Reference values are given inTable 19.

Table 19: Specific densities of sand and gravel

	kg per cubic meter
Gravel, loose, dry	1522
Gravel, with sand, natural	1922
Gravel, dry 1,3 to 5,1 cm	1682
Gravel, wet 1,3 to 5,1 cm	2002
Sand, wet	1922
Sand, wet, packed	2082
Sand, dry	1602
Sand, loose	1442
Sand, rammed	1682
Sand, water filled	1922
Sand with Gravel, dry	1650
Sand with Gravel, wet	2020
Sand and gravel (default value if no other specifications are available)	1900

Source: SIMETRIC

A.3.5 Clays and kaolin

Kaolinite is a clay mineral, rocks that are rich in kaolinite are known as china clay or kaolin. Other kaolinic clays are kaolin minerals such as kaolinite, dickite and nacrite, anauxite, and halloysite-endellite.

The largest use is in the production of paper, as it is a key ingredient in creating “glossy” paper (but calcium carbonate, an alternative material, is competing in this function). Other uses are in ceramics, medicine, bricks, as a food additive, in toothpaste, in other cosmetics, and since recently also as a specially formulated spray applied to fruits, vegetables, and other vegetation to repel or deter insect damage.

In statistics, kaolin may be grouped together with other clays under the heading “industrial or special clays”. Other industrial or special clays can be: ball clay, bentonite, sepiolite and attapulgite, ceramic clay, fire clay, flint clay, fuller’s earth, hectorite, illite clay, palygorskite, pottery clay, refractory clay, saponite, sepiolite, shale, special clay, slate clay.

Kaolin and other special clays are commonly well documented in statistics. Data may be given in cubic meters (m^3) and have to be converted to tonnes (see Table 20).

Table 20: Specific densities of clay

	kg per cubic meter
Clay, dry excavated	1089
Clay, wet excavated	1826
Clay, dry lump	1073
Clay, fire	1362
Clay, wet lump	1602
Clay, compacted	1746
Clay (default value if no other specifications are available)	1500

Source: SIMETRIC

Distinct from special or industrial clays are common clays and loams for construction purposes, in particular for bricks and tiles. These are often not or under-represented in statistics. To check for this, the following estimation procedure developed by the Federal Statistical Office Germany may be applied (Klinnert 1993).

(a) For the production of full and lug bricks 2.2 tonnes crude clay are required to produce 1 m^3 of bricks or 3.4 kg clay per piece of brick (1.35 kg clay per kg brick). Full and lug bricks include PRODCOM-2007-items 26401110 (non-refractory clay building bricks); 26401113 (ceramic bricks and blocks for common masonry: formed units, with or without perforation, for walls with rendering or cladding); 26401115 (ceramic facing bricks: formed units, with or without performation, for use without rendering); 26401117 (ceramic paving bricks: formed units for floor and road surfacing).

(b) For the production of roof bricks 1.05 tonnes crude clay are required to produce 1 t of bricks, and 2.73 kg crude clay are required to produce one single roof brick respectively. Roof bricks include PRODCOM-2007-items 26401130 (non-refractory clay flooring blocks); 26401250 (non-refractory clay roofing tiles); 26401270 (non-refractory clay constructional products (including chimneypots, cowls, chimney liners and flue-blocks, architectural ornaments, ventilator grills, clay-lath; excluding pipes, guttering and the like).

(c) For the production of ceiling bricks (in case reported this way): 0.22 tonnes crude clay are required to produce 1 m^2 of bricks, and 2.2 t crude clay are required to produce 1 m^3 of bricks respectively.

Also for the production of cement considerable amounts of clay or shale are used. Based on data for cement production and information on the raw material requirements for cement production (Kapur et al., 2009; Woodward and Duffy, 2011), a coefficient of 20% of clay in produced cement can be derived.

The overall estimation result is compared with the figure for common clays and loams extraction reported in statistics (excluding industrial or special clays). The higher number should be selected as data for the domestic extraction used of common clay and loam (with an eventual tolerance of about 10% for using the original statistics figure).

A.3.6 Chemical and fertiliser minerals

This group of minerals mainly comprises:

Natural calcium or aluminium calcium phosphates, often combined under the heading "phosphate rock". Most of it (over 90%) is used to produce fertiliser; the remainder is used in the production of detergents, animal feedstock, and many other minor applications.

Note: Under phosphate mineral statistics may report gross ore, phosphate rock or produced phosphate. In MFA accounts the mined gross ore should be reported which typically contains about 15-30% phosphate rock, which contains about 30% phosphate (P2O5).

Carnallite, sylvite, and other crude natural potassium salts are often combined under the heading "potash". Potassium is essential in fertilisers and is widely used in the chemicals industry and in explosives. Data for potash are often reported in K_2O contents. In this case, as for metals, the run-of-mine production has to be calculated to obtain the used domestic extraction. Germany is by far the biggest producer of potash in the EU and the third biggest in the world. The K_2O content in run of mine production of potash in Germany is about 55%.

Unroasted iron pyrite which is an iron disulfide. Pyrite is used for the production of sulphur dioxide, e.g. for the paper industry, and in the production of sulphuric acid, though such applications are declining in importance.

Crude or unrefined sulphur is a fundamental feedstock to the chemical industry. **Please note!** Not all domestic sulphur production is accounted for in category A.3.6. For the purpose of MFA three principle types of sulphur can be distinguished: (1) Sulphur from mining: This sulphur should be accounted for in category A.3.6. (2) Sulphur produced in the refinery through desulphurisation of petroleum resources. This sulphur is included in the amounts of extracted petroleum resources and should not be reported under A.3.6. (3) In some cases sulphur can occur as an unused by-product of the extraction of petroleum resources. This sulphur is considered unused extraction and is not accounted for in the MFA tables.

Other chemical minerals are mainly: Baryte, used in a variety of industries for its properties of high specific gravity, witherite, a barium carbonate mineral which is the chief source of barium salts and is mined in considerable amounts in Northumberland. It is used for the preparation of rat poison, in the manufacture of glass and porcelain, and formerly for refining sugar. Borates are chemical products from borate minerals, which are e.g. used as wood preservatives. Borate minerals contain the borate anion, BO_3^{3-}, the most common borate mineral is boron. Fluorspar, i.e. the mineral fluorite mainly a source of fluorine, kieserite, a mineral made of magnesium sulphate and epsomite, a hydrous magnesium sulphate mineral, alunite or alumstone, pozzolana, and other mineral substances n.e.s.

A.3.7 Salt

This material group concerns sodium chloride. Salt may be produced from rock salt, brine or seawater. It is used for human consumption, in the chemical industry, or to 'grit' roads to prevent the formation of ice.

A.3.8 Other mining and quarrying products n.e.c.

This is a diverse group that essentially comprises all minerals not covered by the previous groups. Some of the minerals that are allocated to A 3.8 are listed below.

Bitumen and asphalt, natural asphaltites and asphaltic rock: The largest use of asphalt is for making asphalt concrete for road surfaces, which accounts e.g. for approximately 80% of the asphalt consumed in the United States. Only natural asphalt and bitumen is accounted for in this category. Most of the bitumen, tar and asphalt are products of the petrochemical industry and are not considered domestic extraction.

Precious and semi-precious stones (excluding industrial diamonds): Have no relevance for domestic extraction in the EU.

Industrial diamonds comprise a number of different stones such as pumice stone, emery; natural corundum, natural garnet and other natural abrasives used for various industrial purposes.

Graphite, a stable form of pure carbon, is mainly used in refractories.

Quartz and quartzite are special qualities of silicium used e.g. in the optical industry or in metal manufacturing.

Siliceous fossil meals like Kieselgur, Tripolite, Diatomite and other siliceous earths, used e.g. as absorption agent or material for heat insulation.

Asbestos, a fibrous mineral, is nowadays restricted in its use due to serious hazard to health.

Steatite and talc are magnesium silicate minerals, used for several industrial purposes.

Feldspar, essential component of glass and ceramic manufacture.

A.3.9 Excavated soil, only if used (e.g. for construction work)

Excavated soil that is used in construction as material input conceptually has to be considered as used extraction. However, no standardized estimation procedure for this material flow is available. In its economy-wide MFA for 1980 to 1998, the Italian Statistical Office has reported soil from excavation activities. For further details, please refer to Barbiero et al. (2003).

Specific issues related to DE of minerals

Crushed rock (or crushed or broken stone)

Several statistical sources use the category "crushed rock" or "crushed stone". Crushed rock is commonly produced as broken natural stones for road-, railway-, waterway-, and buildings construction. A range of natural stone types can be used to produce crushed rock. These include the types explicitly addressed in this guide under A.3. 2 (limestone, gypsum, chalk, and dolomite) and under A.3.8 (other mining and quarrying products n.e.c.). In addition, crushed rock may comprise other natural stones like sandstone, volcanic stones, basalt, granite, quartzite, gneiss, and others.

The classification of stone minerals described in this guide, is not fully consistent with a classification that specifies crushed stone (or rock), as is often done in national and international mining statistics. Possible classifications one may find in statistical sources may include:

- statistical data include gravel under crushed rock, or vice versa, without distinction;
- statistics report building stone which may comprise, but not show separately, dimension stone and crushed rock;
- data for limestone are reported as such but also included under crushed rock, so that double counting occurs.

It is therefore difficult at times to judge if the production of crushed stone is complete and without doubles counts. In the first place, we recommend acquiring data for the domestic extraction of non-metallic minerals as described in this guide. Crushed rock should then be mainly covered by limestone, gypsum, chalk, and dolomite, and bitumen and asphalt rock.

The total of these positions may then be compared with the total number for crushed rock in national statistics or alternatively in the BGS European Mineral Statistics. In case the number for total crushed rock is considerably higher than the sum of related minerals accounted for as described in this guide, the difference may be taken as an estimate for additional domestic extraction used of crushed rock, which cannot be further identified.

Please note! If this is the case please add the additional amount of crushed stones to A.3.4 and add a footnote stating what amount of additional crushed stone had been added and by which method it has been estimated.

Fossil energy carriers

Table 21: Domestic extraction of Fossil energy carriers

1 digit	2 digit	3 digit
A.4 Fossil energy carriers		
	A.4.1 Brown coal	
	A.4.2 Hard coal	
	A.4.3 Petroleum (including natural gas liquids)	
	A.4.4 Natural Gas	
	A 4.5 Peat	
	A 4.6 Oil shale and tar sands	

Introduction

Petroleum resources and other fossil energy carriers are materials formed in the geological past from biomass. They comprise solid, liquid, and gaseous materials.

Economic value: Petroleum resources are bulk raw materials of medium economic value (less than 1000 €/t).

Socio-economic use: The largest fraction of petroleum resources is used for the provision of energy, but they may also be employed as raw materials for industrial processes (e.g. for the production of organic chemical compounds and synthetic materials or fibres).

Environment: The extraction of petroleum resources is related to a range of environmental hazards. The combustion of fossil fuels is one of the most prominent socio-economic activities contributing to global warming and to different types of air pollution. The extraction and transportation of petroleum resources is related to the pollution and destruction of terrestrial and marine ecosystems.

The extraction of petroleum resources per capita varies according to geological deposits and their share of total DE ranges from zero to 40% in the 27 EU countries in the year 2000 (Eurostat 2009b). In European countries, extraction averages at 2 t/cap and ranges between zero and 10 t/cap. Coal accounts for roughly half of total DE of fossil energy carriers, followed by natural gas (30%) and oil (20%). The extraction of peat only has regional significance.

Data sources

Different sections of national statistics provide data on the extraction of petroleum resources and other fossil energy carriers: mining statistics, industrial production statistics, and energy statistics. Data quality is usually very high for all subcategories.

International sources: A number of international data sources provide information about DE of petroleum resources and fossil energy carriers. The most prominent are the database of the International Energy Agency (IEA 2014), the United Nations Industrial Commodity Production Statistics, the United Nations Energy Statistics; the data collections of the United States Geological Survey (USGS). All of these databases report the extraction of the various types of coal, crude oil, and natural gas and can be used for the compilation of material flow accounts. The reported values may differ slightly across sources, above all due to differences in definition or unit conversion procedures.

Data on the extraction of all petroleum resources and other fossil energy carriers from national and international statistical sources can usually be integrated into MFA accounts without further processing. In some cases, conversion from values given in volume or energy content into weight may be required. As the technical characteristics of petroleum resources vary from region to region, country specific conversion factors should be applied.

Conventions

Terminology and classification: The terminology and classification of petroleum resources and other fossil energy carriers used in this guide by and large follow the terminology used by the IEA and may differ from the terminology used in national statistics. For further details, refer to the OECD/IEA/Eurostat Energy Statistics Manual (OECD/IEA/Eurostat 2005).

System boundaries: According to the conventions of MFA only extracted petroleum resources without inert matter are considered. Re-injected or flared fractions of crude oil or natural gas are considered unused extraction and not accounted for under domestic extraction. Petroleum resources used within the extraction industries are to be included.

Data compilation

A.4.1 Brown coal

This category includes lignite or brown coal (i.e., non-agglomerating coal with a gross calorific value of less than 17.4 MJ/kg and greater than 31 per cent volatile matter on a dry mineral matter free basis) and sub-bituminous coal (i.e., non-agglomerating coals with a gross calorific value between 17.4 MJ/kg and 23.9 MJ/kg, containing more than 31 per cent volatile matter on a dry mineral matter free basis).

A.4.2 Hard coal

This includes all anthracite coals, bituminous coals and coking coal with a gross calorific value greater than 23.9 MJ/kg on an ash-free but moist basis.

A.4.3 Crude oil and natural gas liquids

Crude oil is a mineral oil consisting of a mixture of hydrocarbons of natural origin. Natural gas liquids are liquid hydrocarbon mixtures, which are gaseous at reservoir temperatures and pressures, but are recoverable by condensation and absorption. Natural gas liquids (NGL) are classified according to their vapour pressure as condensates, natural gasoline or liquid petroleum gas (LPG).

A.4.4 Natural gas

Natural gas comprises gases, occurring in underground deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing only hydrocarbons in gaseous form and "associated" gas produced in association with crude oil as well as methane recovered from coal mines (colliery gas).

Production is measured after purification and extraction of NGL and sulphur and excludes re-injected gas, quantities vented or flared (so called total dry production). Natural gas is often reported in volume or energy content and has to be converted into metric tonnes by applying region specific factors (see Table 22 for average values).

Table 22: Calorific value and density of natural gas of fossil energy carriers

	kg / m³ (standard cubic meter at 15°C)	GCV [MJ/kg]	GCV [MJ/m³]
Natural gas (range)	0.76-0.83	36-55	30-45
Natural gas (default value)	0.8	50	40

Source: derived from OECD/IEA/Eurostat 2005

A.4.5 Peat

Peat is a combustible soft, porous or compressed, fossil sedimentary deposit of plant origin with high water content, which may be used for combustion or agricultural purpose.

A.4.6 Oil shale and tar sands

This category includes oil shale (a sedimentary rock containing kerogen, a solid organic material) and tar sands (naturally occurring bitumen-impregnated sands that yield mixtures of liquid hydrocarbon and that require further processing other than mechanical blending before becoming finished petroleum products) for direct combustion and as inputs into other transformation processes (these are only of regional significance).

Note: Different technologies are applied to extract oil from oil sand (e.g. in situ extraction, surface mining). In the case of surface mining, large amounts of oil sand are extracted and processed. In this case not only the produced oil should be accounted for, but the total extracted mass of oil sand should be reported separately from the produced oil. Typically 2 tons of oil sand are extracted per barrel of oil.

Tables B and C: Imports and exports

Table 23: Classification of trade flows

1 digit	2 digit	3 digit
B.1 Biomass and biomass products		
	B.1.1 Primary crops	
		B.1.1.1 Cereals, primary and processed
		B.1.1.2 Roots, tubers, primary and processed
		B.1.1.3 Sugar crops, primary and processed
		B.1.1.4 Pulses, primary and processed
		B.1.1.5 Nuts, primary and processed
		B.1.1.6 Oil bearing crops, primary and processed
		B.1.1.7 Vegetables, primary and processed
		B.1.1.8 Fruits, primary and processed
		B.1.1.9 Fibres, primary and processed
		B.1.1.10 Other crops, primary and processed
	B.1.2 Crop residues,	
		B.1.2.1 Straw
		B.1.2.2. Other crop residues
	B1.3. Fodder crops and grazed biomass	
		B.1.3.1 Fodder crops (incl. biomass harvested from grassland)
		B.1.3.2. Grazed biomass (not applicable)
	B.1.4 Wood and wood products	
		B.1.4.1 Timber, primary and processed
		B.1.4.2 Wood fuel and other extraction, primary and processed
	B.1.5 Fish capture and other aquatic animals and plants, primary and processed	
		B.1.5.1 Fish capture
		B.1.5.2 All other aquatic animals and plants
	B.1.6 n.a.	
	B. 1.7 Live animals other than in 1.5., meat and meat products	
		B. 1.7.1 Live animals other than in 1.5.
		B. 1.7.2 Meat and meat preparations
		B. 1.7.3 Dairy products, birds eggs, and honey
		B. 1.7.4 Other products from animals (animal fibres, skins, furs, leather etc.)
	B. 1.8 Products mainly from biomass	
B.2 Metal ores and concentrates, primary and processed		
	B.2.1 Iron ores and concentrates, iron and steel	

1 digit	2 digit	3 digit
	B.2.2 Bauxite and other aluminium	
	B.2.3 Other Non-ferrous metal ores and concentrates, primary and processed	
		B.2.3.1 Copper
		B.2.3.2 Nickel
		B.2.3.3 Lead
		B.2.3.4 Zinc
		B.2.3.5 Tin
		B.2.3.6 Gold, silver, platinum and other precious metal
		B.2.3.7 Uranium and thorium
		B.2.3.8 Other metals
	B.2.4 Products mainly from metals	
B.3 Non-metallic minerals, primary and processed		
	B.3.1 Ornamental or building stone	
	B.3.2 Limestone and gypsum, chalk and dolomite	
	B.3.3. Slate	
	B.3.4 Gravel and sand	
	B.3.5 Clays and kaolin	
	B.3.6 Chemical and fertilizer minerals	
	B.3.7 Salt	
	B.3.8 Other mining and quarrying products n.e.s.	
	B.3.9 n.a.	
	B.3.10 Products mainly from non-metallic minerals	
B.4 Petroleum resources, primary and processed		
	B.4.1 Brown coal	
	B.4.2 Hard coal	
	B.4.3 Petroleum (including natural gas liquids)	
	B.4.4 Natural Gas	
	B 4.5 Peat	
	B 4.x Oil shale and tar sands	
	B.4.6 Products mainly from petroleum products	
B.5 Other products		
B.6 Waste imported for final treatment and disposal		

Introduction

The economic boundary between the economy for which the MFA is compiled and other national economies determines the definition of imports and exports. The OECD, following recommendations made by the UN, provides the following definition for foreign trade: “The international merchandise trade statistics record all goods which add to or subtract from the stock of material resources of a country by entering (imports) or leaving (exports) its economic territory. Goods simply being transported through a country (goods in transit) or temporarily admitted or withdrawn (except for goods for inward or outward processing) do not add to or subtract from the stock of material resources of a country and are not included in the international merchandise trade statistics” (OECD 2006).

As opposed to domestically extracted materials, traded goods represent commodities and products at different stages of processing and span from basic commodities such as unmilled cereals or ore concentrates to semi-manufactured goods such as worked wood or steel ingots and finally to finished goods such as computers or furniture.

Please note! Raw materials, as defined in Material Flow Accounting (see chapter “fundamentals”), per definition cannot be traded. Only those materials, which are crossing the border between the environment and the economy are considered as raw materials. Conversely traded goods per definition are crossing the border between national economies, thus they have already achieved a status of a good, i.e. they represent a specific exchange value. In general, traded goods have undergone some kind of processing, be it of purification, concentration or transformation of the raw materials into the goods. We therefore distinguish between basic commodities, semi-manufactured goods and final products to indicate the stage of processing among traded goods.

In MFA, all traded goods are accounted for with the mass they have at the point in time that they cross the administrative borders. This corresponds to the conventions of the foreign trade statistics provided by the UN and the OECD: “Goods should be included in statistics at the time when they enter or leave the economic territory of a country. In the case of customs-based data collection systems, the time of recording should be the date of lodgement of the customs declaration. Lists of goods to be included, and recorded separately, and to be excluded should be provided. Specific goods are to be excluded from detailed international merchandise trade statistics but recorded separately in order to derive totals of international merchandise trade for national accounts and balance of payments purposes” (OECD 2006).

Data structure and sources

Foreign trade statistics is the basic data source for import and export flows in EW-MFA, which are provided by national statistical offices and additionally gathered in databases of international organisations. In general, priority should be given to national data; international data should only be resorted to as a second choice. As the specifics of national foreign trade statistics may not allow for generalisation, we here refer to international databases and their characteristics to explain the main issues regarding the compilation of import and export data within an economy wide MFA.

International nomenclatures and classification of traded commodities

On the international level, two nomenclatures are mainly used: Harmonised System (HS) – Combined Nomenclature (CN) and Standard International Trade Statistics (SITC). Most national data follow one of these nomenclatures. Therefore, this guide and the MFA tables are based on these classifications. National statistics that differ from these classifications cannot be covered in this guide and must be dealt with on an individual basis.

Trade statistics include between 3000 (SITC) to 10.000 (CN) items of traded goods organised by classification schemes. The Harmonized System (HS) classification is promoted by the World Customs Organisation and includes over 5000 commodity groups identified by 6-digit codes (referred to as "sub-headings"), aggregated to the 4-digit level (more than 1200 groups, referred to as "headings"), and to the 2-digit level (almost 100 groups, referred to as "chapters"). HS was first introduced in 1988, revisions were adopted in 1992, 1996, and 2002. The Combined Nomenclature (CN) was developed by the European Community and is based on the HS nomenclature but comprises another subdivision with 8-digit codes.

The SITC is promoted by the UN and structured along 5 hierarchical levels: Level 1 (1-digit codes) includes 10 sections, level 2 (2-digit codes) 67 divisions, level 3 (3-digit codes) 261 groups, level 4 (4-digit codes) 1033 subgroups, and level 5 (5-digit codes) 3121 items. SITC was first introduced in 1961 and underwent revisions in 1981 (revision 2), 1994 (revision 3), and 2006 (revision 4). Correspondence tables exist between the nomenclatures (e.g. from the UN: http://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1).

International databases

On the international level, the UN keeps the database "Comtrade" in which foreign trade data for more than 140 countries are summarized and reported from 1960 onwards depending on national reporting. Data is classified according to HS and SITC nomenclature.

Additionally, FAOSTAT can be used as source for trade with products of agriculture, forestry and fisheries. The energy statistics database of the International Energy Agency (IEA) as well as the United Nations energy statistics database report data on trade with fossil energy carriers and products of the petrochemical industry.

Structure of trade statistics

Units of measurement: Foreign trade data are usually reported in monetary and physical units. The standard physical unit is kilograms or metric tonnes measured at the point in time in which a good crosses an administrative border. For some commodities, data are reported in other physical units such as length (metres), area (square metres), volume (cubic metres, litres), numeric units (pieces, pairs, dozens, packs), or, for electricity, in kilowatt-hours (United Nations 2004).

Due to the use of different physical unit in trade statistics values cannot always be summed up on a higher level. The UN Comtrade database does not return results in physical units if the item for which the query was run includes subordinate categories, which are reported in incommensurable physical units. Using UN Comtrade data therefore requires to use an appropriate level of aggregation of trade classifications at which sufficient physical data is returned (see section on data compilation). Usually physical data appear only at the 3 digit level or lower. Also FAOSTAT, IEA and UN energy statistics database report trade flows of biomass and energy carriers in physical units, mostly in tons, with some exceptions (i.e. certain forestry products are reported in solid cub metres (scm); natural gas in TJ).

Partner countries: Import and export data are reported according to the countries of origin or destination, respectively. In some databases, it is also possible to select country-aggregates as trade partners.

Transit flows: The reported flows of foreign trade statistics are imports and exports. Most commonly, foreign trade statistics also distinguish "transit" flows, i.e. imports that are exported again without any processing occurring within the country and thus to which no value is added before export. In the UN Comtrade database, transit flows are displayed as "re-imports" and "re-exports" in addition to imports and exports.

Conventions, conversions

In this section the most important conventions for the accounting of physical imports and exports are described.

Additional categories compared to DE: Unlike DE, traded goods include basic commodities and manufactured goods but no raw materials. Thus, commodities and goods become relevant that would not be considered in calculating domestic extraction, e.g. pork or milk. In EW-MFA every traded good is considered unless it has no weight (such as electricity). In return, some categories relevant for DE do not apply to trade such as biomass grazed by livestock. Also crop residues are typically not traded internationally.

Packaging materials: According to standard international trade statistics, merchandise trade is reported in net weight units, i.e. excluding packaging materials. However, in some cases, trade statistics might also be reported in gross weight - especially for some finished goods where the commodity may be reported at the weight it has upon being sold. This often includes packaging materials, e.g. for marmalade sold in a glass (Eurostat 2001: 49).

From a purely conceptual point of view, packaging materials should be accounted for in MFA. Practically, though, packaging materials often are of negligible importance. A German study on traded packaging materials revealed that the amount of packaging materials in imported goods was only 0.5% of the imported tonnes (GVM 2005). Considering the minor importance and the huge efforts an estimation of packaging materials in traded goods would take, additional estimation of packaging materials are mostly not performed.

Please note! In any case, though, it should be verified whether trade flows are reported in net or gross weight and any changes in reporting conventions during the covered time period should be identified, in order to avoid flaws in time series of physical trade data.

Transit: In MFA commodities that are simply transported through a country, i.e. transit, are not considered as imports or exports. Note also the discussion on transit flows above.

Confidential trade

Due to reasons of confidentiality, data that would reveal information pertaining to individual firms is suppressed on the respective aggregation level but reported on the next higher level where confidentiality can be adequately ensured.

In the Comtrade database, which does not provide physical values on higher aggregation levels (due to the variance among physical units in the lower levels), the amount of suppressed confidential data cannot be precisely determined. The magnitude of these suppressed amounts can vary significantly over time and also between countries. In compiling an MFA, the difficulty of determining these flows must be taken into consideration. In some cases, it will be necessary to include an estimation of suppressed data based on country specific information, or else request aggregates of the confidential data from the respective unit of the national statistical office.

Conversions

From a conceptual point of view in all cases where units other than standard physical units (see above) are given, reported data have to be converted into tonnes by either using national conversion factors or other conversion factors such as those proposed in Annex 3c which lists unit mass conversion factors for a large number of traded commodities based on CN classification.

Please note! In actual practise it should also be considered that the type and amount of trade data reported in units other than tonnes can substantially vary from country to country. Therefore, no "one size fits all" solution is recommended here. Two aspects should be judged: (1) whether or not the commodities that are reported in supplementary units are representing a significant fraction of total trade, (2) whether or not the effort to actually perform the conversions (including the availability of reliable conversion factors) is high. In this latter respect the decision between regional specific and average conversion factors is particularly important. The treatment of natural gas is a case in point and may serve as an illustration of the problematic.

<u>Natural gas (SITC code 34): conversion to weight</u>

The quantity of natural gas is commonly reported in volume units or calorific values. In principle, country specific data on calorific values and densities would be needed in order to convert reported volumes to metric tonnes. Such country specific coefficients are generally easier to obtain for the focal economy for which the MFA is compiled, than for those countries from which the natural gas is imported. In cases where the quantity of the imported natural gas is of minor relevance among the imported goods, it might be a disproportionately difficult task to investigate into country specific conversion factors for the imported natural gas. Instead, an average conversion coefficient (such as those presented in Table 22) can be used to convert natural gas volumes to mass units. For exported natural gas, national data on calorific values and densities can be applied for the conversion from volume to mass.

Compilation

Allocation of foreign trade data to the MFA classification

For the compilation of EW-MFA data from foreign trade statistics have to be allocated to the material groups listed in the MFA Tables (see Table 23) according to their material composition. As far as possible, trade flows are allocated to material groups on the basis of their primary material component. The MFA classification system is different from any of the standard foreign trade classification systems in terms of groupings of materials and their allocation to a certain digit level. To facilitate an univocal allocation of data structured according to a standard foreign trade classification system to the MFA classification system correspondence tables between the MFA classification system and the most common international trade classification systems (SITC rev.4, CN) are included in MFA tables (see annex 3c to MFA tables). It is assumed that correspondence tables between these classification systems and other national and international trade nomenclatures are easily available.

As can be seen from the correspondence tables in the annex, the level of disaggregation at which the foreign trade data are required depends on the type of products. Foreign trade data can sometimes be integrated into MF accounts on the 2-digit level of trade classifications, but in some cases, data on much higher digit levels are required (see e.g. MFA category 1.3.1. which is an aggregate of five SITC rev.3 commodities at the 5-digit level).

In general, every group of traded goods, which is measurable in tonnes, is allocated to one MFA category. But conversely, not every MFA category has to be filled with trade data. A small number of material categories are not applicable to trade flows (e.g. 1.2.1.1 "straw", 1.2.2.2 "grazed biomass", 1.5 "hunting and gathering"). Additionally, it is possible that in some countries or years no commodities or goods of a specific material group are imported or exported.

In the trade tables some additional categories, which do not apply to DE, are included. This is the case for 1.6 "live animals, meat, and meat products" and for the categories in which products are subsumed such as 1.7, 2.3, 3.3, 4.3, and finally category 5 and 6.

It should be stressed that the allocation of foreign trade categories to the MFA categories is not unambiguous because the trade classifications always distinguish between different goods, whereas the MFA classification distinguishes between different types of materials. As goods are often a mixture of different materials no unequivocal correspondence between these two classification systems is possible.

Despite this conceptual incompatibility between MFA and trade classifications it is possible to determine for most goods the main material component (as e.g. for most biomass goods), or the main raw materials used in the production (as e.g. for steel ingots). For others, it is only possible to classify the good as either of biomass, mineral, or fossil fuel origin. In these latter cases, the commodities are assigned to additional material categories such as "products from biomass origin" (B.1.7). The remaining goods, mostly commodities that are highly processed and consist of a complex mix of materials, for which it is not possible to determine a main material component, are summarized in the category "other products" (B.5).

Data compilation and cross checks

With regard to foreign trade databases, a broad variety of software solutions exist and each requires an individual approach to the process of data acquisition. In the following descriptions, we will use the international databases Comtrade as an example on how to compile physical foreign trade data.

Compilation of physical trade data begins with the definition of the data query, according to the aggregation level specified in the standard tables, followed by the download of the respective data in physical and monetary units. In case of the Comtrade database, in which physical units are not displayed on higher aggregation levels, a medium aggregation level must be chosen on which the share of reported tonnes is sufficient. In the case of Comtrade, the 3-digit level of the SITC classification fulfils this requirement.

Please note! We recommend to carry out the download and the allocation to MFA categories for both physical and monetary data. The reason is that the monetary data represent valuable sources for cross-checks, described subsequently, as well as for additional data analysis.

In industrial economies trade volumes are known to be highly dynamic and characterized by relatively large fluctuations depending on a number of national and international economic factors. Consequently, time series data of physical and also monetary trade flows normally do not reveal smooth trends. Nonetheless, fluctuations in physical trade data compiled in material flow categories can also be the result of changes or flaws in the physical data reported. Reasons for this may be among the following:

- General problems in data reporting,
- Changes in trade classifications,
- Changes in the physical units reported,
- Changes in conventions of trade statistics (such as whether packaging material is included),
- Suppressed data due to reasons of confidentiality.

We therefore recommend carrying out visual assessment of the time series of the data on a medium aggregation level. If this step gives rise to doubt in any of the data, the following methods can be applied to check whether or not the data fluctuation is due to data flaws, which have to be corrected.

Whenever fluctuations are detected that call for further investigation, i.e. fluctuation which are significantly larger as the average, the commodity group(s) responsible in particular should be identified on the next level of dis-aggregation. The monetary trade data and the calculated prices can be used in crosschecking. Where necessary, missing or false physical data in single years can be estimated by use of monetary trade flow data and tonne prices in adjacent years. Another possibility to cross-check or complete missing data is to refer to alternative data sources, e.g. national or international statistics on traded goods, for example the IEA or FAO.

Table D: Domestic processed output (DPO)

The indicator Domestic Processed Output to nature (DPO) comprises releases from the socio-economic system to the natural environment (wastes, emissions, dissipative use). DPO indicates the total weight of materials which are released back to the environment after having been have been used in the domestic economy. Output flows occur at all stages of socio-economic production and consumption, i.e. during extraction, processing, manufacturing, as well as the use phase of products, and at the final disposal stage. These flows include solid wastes and emissions to water and air. Exported materials are not included in DPO because they are yet to be used in other countries.

DPO accounts were developed and applied first by an international team of experts in a joint effort resulting in the publication "The Weight of Nations" (Matthews et al. 2000) where wastes and emissions were calculated for the USA, Japan, Austria, Germany, The Netherlands. Table 24 shows DPO data around the year 2000 for some industrial economies from this study.

Table 24: Selected results for DPO

tonnes per capita	Austria	Japan	Germany	Nether-lands	USA	Finland	Italy
	1996	**1996**	**1996**	**1996**	**1996**	**1997**	**1997**
Emissions to air	10.3	10.4	11.7	15.2	22.0	16.9	8.2
CO2	10.1	10.4	11.5	15.1	20.5	16.8	7.9
Waste landfilled	1.1	0.6	0.9	0.6	1.6	1.9	1.0
Municipal waste		0.10	0.15	0.5		0.4	0.4
Emissions to water	0.01	0.01	0.04	0.04	0.03	1.4	0.2
Dissipative use of products	1.1	0.10	0.6	2.4	0.5	4.2	2.5
Organic fertiliser	0.7	0.09	0.3	2.3	0.3	3.8	2.3
Dissipative losses	0.06		0.01		0.00		0.03
DPO not further defined					1.0	1.0	
DPO	**12.5**	**11.2**	**13.1**	**18.2**	**25.1**	**25.4**	**11.8**

Sources: Matthews et al. 2000: Austria, Japan, Germany, Netherlands, USA; Muukkonen 2000: Finland; Barbiero et al. 2003: Italy.

Note: at the time these studies were performed, also landfilled waste was included in DPO. In this Guide, waste to controlled landfills is excluded from DPO.

In the past years, DPO accounts were also promoted at the EU level, where several EU Member States started reporting DPO flows.

As can be clearly seen from Table 24, emissions to air by far dominate the overall DPO level, and CO_2 emissions dominate the emissions to air. On average (measured as weighted average across all countries shown in Table 24), emissions to air accounted for 85% of DPO and CO_2 accounted for 94% of emissions to air.

The DPO account comprises 5 major categories:

D.1. Emissions to air

D.2. Waste landfilled (uncontrolled)

D.3. Emissions to water

D.4. Dissipative use of products

D.5. Dissipative losses

The first three categories (D.1. to D.3.) refer to the three gateways through which materials are initially released to the environment, i.e. air, land, and water, commonly referred to as emissions and waste in official statistics. The remaining two categories (D.4. and D.5.) are residual categories which are not fully attributable to a specific gateway but are rather attributed to a type of release, dissipative or deliberate, than to an environmental gateway.

Apparently there can be overlaps between a distinction according to gateways and a distinction according to dissipative uses and losses. Mainly these potential overlaps refer to a few emissions to air. Essentially there are two practical rules that help avoiding double counting between emissions to air and other categories of DPO:

1. N_2O emissions from product use and NMVOC emissions by solvents are accounted for in "dissipative use of products" and not in "emissions to air".
2. Emissions to air from fertiliser application, such as N_2O and NH_3 are not accounted for in DPO. The related primary output is fertiliser spread on agricultural soil. The inclusion of these emissions thus would represent double counting.

Bottom-up accounts and full balancing

Common DPO accounts – as described above – follow a "bottom-up" approach, which derives DPO data from waste and emission statistics. Consequently, DPO categories are oriented by gateway and type of release. Accounting methods follow the early approaches in Matthews et al. (2000) which were elaborated in the Eurostat handbook (2001) and amended by the Eurostat compilation guide (first published in 2009 with several later revisions; Eurostat 2013). Methods were discussed intensively in several Eurostat task forces and progress towards standardization was made. However, there are still open issues and challenges to be solved, e.g. inconsistent system boundaries between MFA and waste/emission statistics and incomplete coverage of waste statistics. Empirical studies providing DPO data are available for Italy (Barbiero et al., 2003), the Czech Republic (Ščasný et al., 2003), China (Xu and Zhang, 2008) and Finland (Muukkonen, 2000), Austria (Jacobi et al., 2018) and for the world (Haas et al., 2015).

In recent years, biophysical stock accounts and circular economy initiatives have led to a different approach that has put more emphasis on flows within the socioeconomic system including recycling and reuse, and thus requires consistency between inputs and outputs as well as stocks. These studies require a clear structuring of DPO along material categories in order to consistently close the material balance. Waste statistics, however, do not always allow for the necessary detail and inconsistencies between input data and output data can prevent successfully closing the balance. To avoid these problems, methods are developed that consistently link input and output flows by focusing on corresponding material conversion processes and that take material stocks into account ("top-down modelling"). For further information on methods and empirical data see, for example, Haas et al. (2015).

At the time of publication, it is not possible to provide default procedures in sufficient detail to fit all needs. The following recommendations follow the Eurostat bottom-up approach and highlight open issues with full balancing. The provided guidelines are of a general nature and do not provide standardized step by step procedures. It certainly will require the judgement and creativity of the practitioner to apply these general rules to the specific national situation. It is good practice to clearly specify the assumptions made and the data sources used so the issue of completeness can be evaluated.

Emissions to air

Table 25: Domestic processed output: emissions to air

1 digit	2 digit	3 digit
D.1 Emissions to air		
	D.1.1 Carbon dioxide (CO2)	
		D.1.1.1 Carbon dioxide (CO2) from biomass combustion
		D.1.1.2 Carbon dioxide (CO2) excluding biomass combustion
	D.1.2 Methane (CH4)	
	D.1.3 Dinitrogen oxide (N2O)	
	D.1.4 Nitrous oxides (NOx)	
	D.1.5 Hydroflourcarbons (HFCs)	
	D.1.6 Perflourocarbons (PFCs)	
	D.1.7 Sulfur hexaflouride	
	D.1.8 Carbon monoxide (CO)	
	D.1.9 Non-methane volatile organic compounds (NMVOC)	
	D.1.10 Sulfur dioxide (SO2)	
	D.1.11 Ammonia (NH3)	
	D.1.12 Heavy metals	
	D.1.13 Persistent organic pollutants POPs	
	D.1.14 Particles (e.g PM10, Dust)	

Introduction

Emissions to air are gaseous or particulate materials released to the atmosphere from production or consumption processes in the economy. In MFA emissions to air comprise 14 main material categories on the 2digit level, as shown in the Table 25.

Data sources

Statistical reporting on air emissions has a relatively short history as compared to agricultural, mining or trade statistics. As a consequence data from different sources are less harmonized and gaps in the historical record are likely to occur. As a general rule in MFA it is recommend to use national data sources. The following section briefly describes three important inventories for emissions to air that are based on national data, and subsequently compiled in international data bases.

1. **National greenhouse gas inventories in the common framework of IPCC:** The national inventories cover emissions to air that have a greenhouse gas potential, i.e. contribute directly and indirectly to global warming. Countries which signed the UN Framework Convention on Climate Change (UNFCCC) are requested to compile their national greenhouse gas inventories according to the respective IPCC (International Panel on Climate Change) guidelines, i.e. in the common reporting format (CRF). The latest revision of these guidelines was published in 2006 (IPCC 2006) and covers sources and sinks of the direct greenhouse gases CO_2 (carbon dioxide), CH_4 (methane), N_2O (dinitrogen oxide), HFC (hydrofluorocarbons), PFC (perfluorocarbons) and SF_6 (sulphur hexafluoride) as well as the indirect greenhouse gases NO_x (nitrogen oxides), NMVOC (non-methane volatile organic components), CO (carbon monoxide), and SO_2 (sulphur dioxide). Country specific data are available at UNFCCC (http://unfccc.int/2860.php).
2. **CORINAIR (CORe INventory of AIR emissions):** Air emission data are also complied under the UNECE convention on long range transboundary air pollutants (LRTAP). The focus of this convention is on classical air pollutants. For European countries air emission data for the LRTAP are collected in CORINAIR a project of the European Topic Centre on Air Emissions and the EEA. CORINAIR includes the pollutants CO, NH_3, NMVOC, NO_X, PM10, PM2.5, SO_2 and it provides cross references to the Integrated Pollution Prevention and Control (IPPC) coding formats. Data for European countries can be accessed via EEA (http://www.eea.europa.eu).
3. **Air emission accounts (NAMEA - national accounting matrices including environmental accounts)**: In NAMEA environmental information is compiled consistently with the way activities are represented in the supply and use framework of the national accounts. NAMEA air thus provides air emission data by economic activity. In Europe NAMEA air data are compiled at the national level by statistical offices and collected by EUROSTAT (http://epp.eurostat.ec.europa.eu). As NAMEA is a framework linking emissions to the input-output framework of the national accounts, the data structure and the applied conventions are somewhat different from the traditional emission inventories as e.g. the CORINAIR and the IPCC statistics, to ensure the comparability of NAMEA to the input output framework.

   Please note! Different to the other sources, NAMEA air emissions data follow the residence principle!

The three accounting systems serve different purposes and therefore reveal differences in coverage and accounting conventions. Often a combination of data source will be necessary to fill in D1 in table D. The most important points to consider when using data from emission inventories for MFA are discussed in the next section.

Conventions

Terminology and classification: The terminology for emissions to air follows international harmonised standards of IPCC, CORINAIR or NAMEA.

System boundaries: In defining the system boundary for emissions to air it is important to ensure that this definition for the output side is consistent with the definition for the input side and with the definition of societal stocks. As a general rule the category **"**emissions to air" indicates the total weight of materials, which are released to the air by national resident units on the national economic territory and abroad. There are some **exceptions** to be taken into account:

- All emissions to air listed under E.2 (**output balancing items**) are not included in DPO.
- **Emissions from fertilizer applications** are not included in DPO, as this would represent double counting with "dissipative uses".
- **N_2O emissions from product use and NMVOC emissions by solvents** are accounted for in "dissipative use of products" and not in "emissions to air".
- Emissions from fuel for use on ships or aircraft engaged in international transport are called **international bunkers**. The quantity of these emissions, predominantly consisting of CO_2 from fossil fuel combustion, may be negligible for some countries and very significant for others. These emissions should be included in DPO. A note containing a clear description of the used data sources and applied assumptions is instrumental here.

Please note! The MFA system boundary is not necessarily identical with the system boundaries applied in the above mentioned emission inventories. There are several points to consider when using emissions inventories.

- IPCC and CORINAIR inventories are based on the territory principle and account for anthropogenic emissions from the economic territory, whereas NAMEA accounts for economic activities of residents, regardless whether they are active on the national economic territory or abroad (i.e. applying the residence principle; NAMEA also includes CO_2 emissions from international bunkers). If IPCC and/or CORINAIR data are used, adjustment to ensure consistency with the residence principle are required. For these adjustments data reported in the "bridge tables" of air emissions accounts (cf. Eurostat's (2009a) *Manual Air Emissions Accounts*) can be used for these adjustments. In general, it is recommended to use NAMEA air emissions accounts as primary data source for all relevant emissions of greenhouse gases and air pollutants.

- IPCC reports usually totals GWP (global warming potential) measured in CO_2 equivalents and not in metric tonnes. In addition, the totals reported in the national greenhouse gas inventories are calculated according to a complex set of rules, specifying the recognition of sinks and the inclusion or exclusion of certain emissions. It is therefore necessary to use the underlying inventories rather than the totals for compiling emissions to air. It is also advisable to refer to the methodological guidelines (IPCC 2006) in order to check what is included or not in the data. IPCC recommends reporting emissions from international bunkers separately and not as part of the totals.

Estimations: Estimations are necessary if data are not available in tonnes or if emissions have to be estimated directly from input data by using coefficients. Estimations might also be necessary for longer time series. In rare cases emission data are reported without oxygen content (e.g. as carbon instead of CO_2); they have to be converted using stoichiometric equations. In this guide we do not describe any estimation procedures for emissions to air. However, some important stoichiometric equations are reported in the chapter on balancing items. Should estimations become necessary, please refer to the Eurostat Manual Air Emissions Accounts (Eurostat 2009a).

Oxygen content: Oxygen is drawn from the atmosphere during fossil fuel combustion and other industrial processes. Overall, the amount of oxygen uptake from the atmosphere during production and consumption is quite substantial and accounts for approximately 20% by weight of material inputs to industrial economies (Matthews et al. 2000). In MFA, this atmospheric oxygen is not included in the totals on the input side (DE, DMC, and DMI) but it is included in the totals on the output side (DPO). The reason is that oxygen is a constituent part of the pollutants and greenhouse gases, and that these emissions are usually reported and analysed with their oxygen content. To arrive at a full mass balance, the missing oxygen on the input side is reported as input balance items (see chapter on table E).

Data compilation

D.1.1 Carbon dioxide (CO_2)

Carbon dioxide is a naturally occurring gas. It is a constituent part of the atmosphere and plays a decisive role for the metabolism of all living species. CO_2 serves as a nutrient for plants and is a metabolic residual for animals. Thus plant and animal metabolisms together constitute a dynamic equilibrium that is able to keep CO_2 concentrations in the atmosphere within a narrow range. The industrial metabolism, mainly by combusting huge amounts of fossil fuels, entails enormous net releases of CO_2 into the atmosphere. This CO_2 is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.

Please note! CO_2 represented 77% of the global warming potential of all greenhouse gas emissions in 2004 (IPCC 2007), and it constituted some 90% of the weight of all emissions to air in industrial economies in the late 1990ies (Matthews et al. 2000). Apparently CO_2 is not only the most important part of DPO in terms of policy relevance. CO_2 also dominates the quantity of overall DPO: It is therefore good practise to concentrate most of the effort on the CO_2 account. Provided careful consideration of the applied system boundaries in each case, inventory data from NAMEA air emissions should be used. To assure correct accounting, it may be advisable to consult a national expert.

D.1.1.1 Carbon dioxide (CO_2) from biomass combustion

This subcategory includes:

- Biofuels like biodiesel and bioethanol,
- biogas (which may be used both as a biofuel and as a fuel for producing electricity and heat),
- biomass for electricity and heat, mainly wood and agricultural harvest residuals,
- biomass used in rural areas of developing countries, especially fire wood and residuals or wastes from agriculture and forestry, also referred to as traditional biomass (REN21 2005).
- **Please note!** This category **does not include**
  - CO_2 emissions form land use and land use changes: These flows cannot be accounted for with an input side equivalent. Instead, they are considered flows within the environment.
  - CO_2 emissions from human or animal respiration, they are considered as output balancing items (see chapter G).

D.1.1.2 Carbon dioxide (CO_2) excluding biomass combustion

This category includes CO_2 emissions from both energetic and non-energetic non-biotic sources.

Please note! CO_2 emissions from **international bunkers** should be included under D.1.1.2 These emissions may be estimated following the guidelines of IPCC (2006). The applied assumptions and data sources used should be described in a footnote.

D.1.2 Methane (CH_4)

Methane, a hydrocarbon, is a greenhouse gas produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production, and incomplete fossil-fuel combustion.

Please note! Make sure that methane emissions from uncontrolled landfills are not included in the “emissions to air” total. They may be reported as a separate memorandum item.

D.1.3 Dinitrogen monoxide (N_2O)

Dinitrogen monoxide (nitrous oxide) is a colourless non-flammable gas, with a pleasant, slightly-sweet odour. It is used in surgery and dentistry for its anaesthetic and analgesic effects, where it is commonly known as laughing gas due to the euphoric effects of inhaling it. It is also used as an oxidizer in internal combustion engines. N_2O acts as a powerful greenhouse gas.

Please note! Make sure **not to include**:

- N_2O emissions from product use which should instead be allocated to "dissipative use of products", and
- N_2O emissions from agriculture and from wastes to uncontrolled landfills.

D.1.4 Mono-nitrogen oxides (NOx)

The two mono-nitrogen oxides are nitrogen dioxide (NO_2) and nitric oxide (NO). NO_2 is an orange/brown gas and has a characteristic sharp, biting odour. NO_2 is one of the most prominent air pollutants and a respiratory poison.

D.1.5. Hydrofluorocarbons (HFCs)

HFCs are commercially produced gases used as a substitute for chlorofluorocarbons. HFCs largely are used in refrigeration and semiconductor manufacturing.

D.1.6. Perfluorocarbons (PFCs)

PFCs are by-products of aluminium smelting and uranium enrichment. They also replace chlorofluorocarbons in manufacturing semiconductors.

D.1.7. Sulfur hexafluoride

Sulfur hexafluoride is largely used in heavy industry to insulate high voltage equipment and to assist in the manufacturing of cable-cooling systems.

D.1.8. Carbon monoxide (CO)

CO is a colourless, odourless, and tasteless toxic gas. It is the product of the incomplete combustion of carbon-containing compounds, notably in internal-combustion engines. It still has significant fuel value, burning in air with a characteristic blue flame, producing carbon dioxide. CO is valuable in modern technology, being a precursor to myriad products.

D.1.9. Non-methane volatile organic compounds (NMVOC)

NMVOC is the abbreviation for non-methane volatile organic compounds. They easily vaporise at room temperature and most of them have no colour or smell. **Please note!** NMVOC emissions of solvents are included in "dissipative use of products" and not in “emissions to air”.

D.1.10. Sulfur dioxide (SO_2)

Sulphur dioxide is a colourless gas with a penetrating, choking odour. It dissolves readily in water to form an acidic solution (sulphurous acid) and is about 2.5 times heavier than air.

D.1.11. Ammonia (NH_3)

In its pure state and under usual environmental conditions, ammonia exists as a colourless, pungent-smelling gas. It is alkaline, caustic and an irritant. Under high pressure, ammonia can be stored as a liquid. It is highly soluble in water. It reacts with acids to form ammonium salts.

Please note! Ammonia emissions from agriculture are not included in “emissions to air”.

D.1.12. Heavy metals

There are several different definitions of which elements fall in this group: According to one definition, heavy metals are a group of elements between copper and bismuth on the periodic table of the elements having specific gravities greater than 4.0. All of the more well-known elements with the exception of bismuth and gold are toxic.

D.1.13. Persistent organic pollutants (POPs)

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. Because of this, they have been observed to persist in the environment, to be capable of long-range transport, bio-accumulate in human and animal tissue, bio-magnify in food chains, and to have potential significant impacts on human health and the environment.

In May 1995, the UNEP Governing Council (GC) decided to begin investigating POPs, initially beginning with a short list of twelve POPs, which has been extended since then. The groups of compounds that make up POPs are also classed as PBTs (Persistent, Bioaccumulative, and Toxic) or TOMPs (Toxic Organic Micro Pollutants).

D.1.14. Particulates (e.g. PM10, Dust)

PM10 are particles that vary in size and shape, have a diameter of up to 10 micrometers and are made up of a complex mixture of many different species including soot (carbon), sulphate particles, metals, and inorganic salts such as sea salt.

Waste landfilled

Introduction

By definition, waste refers to materials that are not prime products (i.e. products produced for the market) and which are of no further use to the generator for purpose of production, transformation or consumption. The generator discards, intends or is required to discard these materials. Wastes may be generated during the extraction of raw materials, during the processing of raw materials to intermediate and final products, during the consumption of final products, and in the context of other activities.

The MFA table distinguishes between municipal and industrial waste and accounts for both of these only if they are discharged to uncontrolled landfills (see Table 26):

Table 26: Domestic processed output: waste landfilled

1 digit	2 digit	3 digit
D.2 Waste land filled (uncontrolled)		
	D.2.1 municipal waste (uncontrolled)	
	D.2.2 industrial waste (uncontrolled)	
M.2 Waste land filled (controlled)		

A landfill is defined as a deposit of waste into or onto land, both in the form of a specially engineered landfill and of temporary storage for over one year on a disposal site. These may be either internal (i.e. the waste is generated and disposed at the same site) or external (Eurostat 2005).

A controlled landfill is one whose operation is subject to a permit system and to technical control procedures in accordance with the national legislation in force. The sites of controlled landfills are specifically modified and maintained for this purpose. For the purposes of MFA, only waste disposed of outside of these controlled sites should be accounted for. This refers to so-called “wild“ dumping (uncontrolled landfills) which should be reported under D.2 if data available.

The following flows are excluded:

- Residuals directly recycled or reused at the place of generation.
- Waste materials that are directly discharged into ambient water or air. They are accounted for in emissions to air or water respectively.
- Waste that was generated by unused extraction. This refers mainly to soil excavation in constructions and to overburden from mining and quarrying.
- Waste incinerated. This flow is already accounted for in emissions to air.

Conventions

System boundaries: There are two important system boundaries to be considered when accounting for waste as part of DPO. In a strict sense only waste deposited in **uncontrolled** landfills (wild dumping) is an output to nature and therefore part of DPO.

In contrast, **controlled landfills** are considered a component of the socio-economic system, since they are managed or maintained. Therefore, wastes deposited in controlled landfills should be accounted for as an addition to stock and only outputs to the environment from waste deposits, i.e. emissions to water or air from controlled landfills, should be considered as DPO. This comprises unintentional flows such as leakages and seeping water (conceptually part of dissipative losses) as well as controlled emissions to air or water.

There are, however, also good reasons to account for all waste flows regardless if they are deposited on controlled or uncontrolled landfills in MFA accounts and additionally record waste to **controlled landfills as a memorandum item**. First, it might be difficult to separate controlled from uncontrolled landfills in national statistics. Second, data on total amount of waste produced provides valuable information for estimations in the DPO data compilation process (e.g. estimations of DPO to air and water from landfills, etc.) as well as in material stock accounts. It might nourish secondary analysis e.g. on recycling and reuse rates, serving as a reference for policies addressing environmental issues related to waste generation and treatment. It is therefore recommended that additions to controlled landfills should be shown as a memorandum item (and excluded from the indicator NAS).

Water content: Wastes are commonly reported in wet weight (including water content). If this waste flow is of substantial quantity, an attempt should be made to additionally provide the dry matter value (EC 2002).

Data compilation

If possible, waste flows should be distinguished according to **municipal and industrial wastes**. But waste statistics often only report the total amounts of waste to uncontrolled landfills. If this is the case, the figures for waste landfilled should be taken as totals for the accounting of D.2 without further distinction between municipal waste and industrial waste.

Waste statistics often report **construction and demolition waste** which includes rubble and other waste material arising from the construction, demolition, renovation or reconstruction of buildings or parts thereof, whether on the surface or underground. It consists mainly of building materials and soil, including excavated soil. It includes waste from all origins and from all economic sectors. For the requirements of EW-MFA, special attention has to be paid to avoid double counting but also to include all relevant flows to arrive at a comprehensive data set. This applies, in particular, to excavated soils: on the input side, excavated soil or earth represents unused domestic extraction, which is not part of the direct material inputs to the economy. Consequently, excavated soil has to be omitted from the domestic processed output of the economy as well. Only used parts of excavated soil need to be included both on the MFA input side as well as the output side.

Emissions to water

Introduction

Emissions to water are substances and materials released to natural waters by human activities after or without passing waste water treatment. This category comprises all outflows from municipal or industrial sewage treatment plants and also “dumping of materials at sea”. Accounting for only 1%, emissions to water represent the smallest category of DPO (Matthews et al. 2000). In the context of a full material balance of a national economy it is therefore sufficient to roughly estimate emissions to water.

Table 27: Domestic processed output: emissions to water

1 digit	2 digit	3 digit
D.3 Emissions to water		
	D.3.1 Nitrogen (N)	
	D.3.2 Phosphorus (P)	
	D.3.3 Heavy metals	
	D.3.4 Other substances and (organic) materials	
	D.3.5 Dumping of materials at sea	

Conventions

Reporting unit: Statistics on water pollution commonly use a specific reporting terminology. Statistics on water pollutants have traditionally focused on the concentration of pollutants in water bodies, measured in quantity per volume. However, in MFA terms data needs to be included as flows of pollutants into water bodies (normally measured in quantity per year).

While the inorganic pollutants nitrogen and phosphorus as well as heavy metals are commonly reported as elements, organic pollutants are reported as compounds by using various indirect aggregate indicators. Due to the minor quantitative importance of emissions to water in the overall material flow accounts, a detailed estimation does not have high priority.

Point and diffuse sources: Emissions to water are commonly reported as flows from point sources (municipal wastewater treatment plants and industrial direct discharge) and from diffuse sources. For category D.3. only emissions from point sources need to be considered, whereas emissions from diffuse sources should be included in the DPO category D.4. "dissipative use".

System boundaries: Emissions to water are materials, which cross the boundary from the economy back into the environment with water as a gateway. Therefore, emissions to water should be accounted for at the state they are in upon discharge to the environment. Where waste water treatment occurs, this refers to the post-treatment state. Otherwise, it refers to the substances or materials directly released to the environment via water.

Data compilation

D.3.1 Nitrogen (N)

Total nitrogen (N) stands for the sum of all nitrogen compounds. Nitrogen from agriculture is not included in the category emissions to water because it is already included in the category "dissipative use of products" as nitrogenous fertilisers. N-emissions to water include emissions by waste water from households and industry.

D.3.2 Phosphorus (P)

As with nitrogen, total phosphorus (P) stands for the sum of all phosphorus compounds. P-emissions to water include emissions by waste water from households and industry and do not include emissions from agriculture, as these are again included in category "dissipative use of products" as phosphorus fertilisers.

D.3.3 Heavy metals

Heavy metals may come from municipal and industrial discharges. For example, for Germany the share of municipal emissions in total discharge of heavy metals is 77 % on average (between 62 % for lead and almost 93 % for mercury). The most important industrial source is the chemical industry with 40 % of the total industrial discharge (Böhm et al. 2000).

Two **accounting approaches** can be applied for all three of these emissions to water:

First, annual flows of pollutants (in quantity per year) can be derived from statistics on emissions to water, if available.

Second, emissions to water can be estimated based on the maximum legal limit value for each pollutant multiplied by the quantity of water treated by wastewater treatment plants. This approach assumes that plants respect legal regulations and that the concentration of pollutant in water emitted is close to the legal maximum.

The estimated value from the second approach can result in over- as well as underestimation. Further analysis of the specific national or local situation is highly recommended.

D.3.4 Other substances and (organic) materials

Organic substances are commonly reported in water emission inventories as indirect summary indicators (compound indicators). The most commonly used are:

BOD (biological oxygen demand),

COD (chemical oxygen demand),

TOC (total organic carbon), or

AOX (adsorbable organic halogen compounds).

Please note! All of these indicators measure organic substances in water by each using a different indirect method. The values reported for these indicators should therefore neither be included directly in MFA nor should they be aggregated. It is necessary to:

(1) Make a decision as to which of the indicators to use. Our recommendation is to take TOC, if available, as it is the most comprehensive and sensitive indicator.

(2) Convert the reported quantity, which indirectly indicates the amount of organic substances into the quantity of the organic substance itself by using a simplified stoichiometric equation.

D.3.5 Dumping of materials at sea

Dumping of materials at sea is not a common reporting format and data are rare. **Please note!** Attention should be paid not to include materials, which are part of the unused domestic extraction, like dredging, in order to be consistent with the material input side.

Material flows comprised as "dumping at sea" can be differentiated into land-based and sea-based litter:

Sea-based litter includes litter from the fishing industry, shipping (e.g. tourism, transport), offshore mining and extraction, illegal dumping at sea, and discarded fishing gear.

Land-based litter comprises litter ending up in the oceans from coastal regions and litter reaching the ocean via rivers. It includes discharge to oceans and seas from landfills, rivers and floodwaters, industrial outfalls, discharge from stormwater drains, untreated municipal sewage, and littering of beaches and coastal areas (tourism). Double counting with other DPO flows may occur!

Dissipative use of products

Introduction

"Some materials are deliberately dissipated into the environment because dispersal is an inherent quality of product use or quality and cannot be avoided" (Matthews et al. 2000, p 27). Examples of dissipative use flows are inorganic and organic fertilizers such as manure, compost, or sewage sludge.

Table 28: Domestic processed output: dissipative use of products

1 digit	2 digit	3 digit
D.4 Dissipative use of products		
	D.4.1 Organic fertiliser (manure)	
	D.4.2 Mineral fertiliser	
	D.4.3 Sewage sludge	
	D.4.4 Compost	
	D.4.5 Pesticides	
	D.4.6 Seeds	
	D.4.7 Salt and other thawing materials spread on roads (incl grit)	
	D.4.8 Solvents, laughing gas and other	

Matthews et al. (2000) were the first to make an attempt to account for these flows as part of an MFA. Their results for 1996 show, for example, that applied mineral fertiliser ranged from 17 kilogram per capita and year in Japan to around 110 kg/cap in Austria and Germany, spread manure from 105 kg/cap in Japan to 2282 kg/cap in the Netherlands, sewage sludge from 4 kg/cap in the Netherlands to 13 kg/cap in Germany, pesticides from 0.4 kg/cap in Germany to 3 kg/cap in Austria, and grit materials from 26 kg/cap in Germany to 134 kg/cap in Austria.

Conventions

Water content: Organic fertiliser (manure) spread on agricultural land should be reported in dry weight. If reported with water content, an attempt should be made to convert the data to dry matter. The same holds true for sewage sludge and compost.

Data compilation

D.4.1 Organic fertiliser (manure)

Manure is organic matter, excreted by animals, which is used as a soil amendment and fertilizer.

Manure spread on agricultural land is usually not or not sufficiently reported in agricultural statistics and has to be estimated (see e.g. Matthews et al. 2000). An estimate could be based on the number of livestock by type multiplied with the manure production per animal per year and a coefficient to correct for dry matter. Examples for required coefficients are given in Table 29.

Table 29: Coefficients of daily manure production

	Manure production per animal per day in kg	Dry matter of manure 1= Wet weight
Dairy cows	70	0.085
Calves	17	0.05
Other bovine	28	0.085
Pigs for slaughtering	7	0.071
Pigs for breeding	26	0.028
Other pigs	8	0.071
Sheep	7	0.07
Horses	7	0.07
Poultry	0.2	0.15

Source: Meissner 1994

During stockpiling of manure further losses occur as emissions to air, which should be included in D.1. However, there are no standardized estimation procedures of these losses available so far. In addition, organic fertilizer contains not only the manure of animals, but also other substances, e.g. straw used as bedding material in livestock farming. This additional material (which is also considered as domestic extraction on the input side) needs to be estimated (e.g. based on information on crop residues used as bedding material).

D.4.2 Mineral fertiliser

The fertiliser industry is essentially concerned with the provision of three major plant nutrients – nitrogen, phosphorus and potassium – in plant-available forms. Nitrogen is expressed in the elemental form, N, but phosphorus and potassium may be expressed either as the oxide (P_2O_5, K_2O) or as the element (P, K). Sulphur is also supplied in large amounts, partly through the sulphates present in such products as superphosphate and ammonium sulphate.

Accordingly, agricultural statistics commonly report domestic consumption in agriculture of specified nitrogenous fertilizers, phosphate fertilizers, and potash fertilizers, and multi-nutrient fertilizers (NP/NPK/NK/PK). FAOSTAT e.g. reports nitrogenous fertilizers, phosphate fertilizers, and potash fertilizers for the EU. Data mostly refer to nutrient content of fertilisers. A fertiliser often not reported is lime (e.g. in forestry) for which specific sources should be checked.

MFA accounts for fertilisers and pesticides in terms of the total mass of the applied material. Statistics, however, commonly report fertilisers in nutrient contents (e.g. N, P, K) and pesticides in active ingredients contents. In case multipliers to total weight are known, the account should be based on total weights.

D.4.3 Sewage sludge

Sewage sludge refers to any solid, semi-solid, or liquid residue removed during the treatment of municipal waste water or domestic sewage. Although it is useful as a fertiliser and soil conditioner, sewage sludge, if applied inappropriately can also be potentially harmful to the water and soil environment and human and animal health. The application of sludge on agricultural land is therefore subject to strict regulations in many countries.

Per convention, category D.4.3. should only include sewage sludge spread on agricultural land and used for landscape management. Other applications of sewage sludge are covered in other DPO categories or are not an output according to MFA system boundaries. For example, composting of sewage sludge should be included in D.4.4. (compost), landfill in D.2., dumping at sea in D.3.5. and incineration in D.1.

Sewage sludge should be reported in dry weight. If reported in wet weight, a water content of 85% may be assumed for conversion to dry weight.

D.4.4 Compost

Composting refers to a solid waste management technique that uses natural processes to convert organic materials to humus through the action of microorganisms. Compost is a mixture that consists largely of decayed organic matter and is used for fertilizing and conditioning land.

Compost may be reported in agricultural statistics, in environmental statistics, or in specific studies such as UNFCCC inventories within sectoral background data for waste. Care has to be taken to avoid double counting, for example if emissions from the incineration of biogas are included in F.1., compost incinerated for energy recovery needs to be excluded from D.4.4. “compost”.

Compost should be reported in dry weight. If reported in wet weight, a water content of 50% may be assumed for conversion to dry weight.

Note: Compost may also be derived from waste from management of parks, infrastructure areas, gardens, that is from material which has not been recorded on the input side.

D.4.5 Pesticides

A pesticide is commonly defined as "any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest". A pesticide may be a chemical substance or biological agent (such as a virus or bacteria) used against pests including insects, plant pathogens, weeds, molluscs, birds, mammals, fish, nematodes (roundworms), and microbes. Pesticides are usually, but not always, poisonous to humans. An extensive list and data of pesticides is provided in the PAN Pesticides Database (http://www.pesticideinfo.org/List_ChemicalsAlpha.jsp).

Agricultural statistics commonly report quantities of pesticides used in (or sold to) the agricultural sector. Figures are generally expressed in terms of active ingredients. If multipliers are available, these figure should be converted to total mass.

D.4.6 Seeds

Seeds are the encapsulated embryos of flowering plants. Seeds for agricultural production are a common position in agricultural statistics (e.g. from FAO food commodity balance sheets).

D.4.7 Salt and other thawing materials spread on roads (incl. grit)

Salt is a significant material in this category; other thawing materials include grit or waste products from the iron and steel industry. This category can play a major role in F.4. in countries experiencing rigorous winters. So far, only a few attempts have been made to estimate thawing materials spread on roads (e.g. Matthews et al. 2000). Greenpeace (2011) estimated that 200000 to 300000 tonnes of salt are spread on Austrian roads each year.

D.4.8 Solvents, laughing gas and others

This category includes emissions from use of solvents (in particular NMVOC) and N_2O as a product (for anaesthesia). Data for NMVOC solvents emissions can e.g. be taken from national inventory reports to UNFCCC from the CRF reporting categories:

3.A Paint application

3.B Degreasing & dry cleaning

3.C Chemical products manufacture & processing

3.D Other

N_2O (laughing gas) for anaesthesia is included in 3.D and its specific values may be extracted from detailed countries' air emissions databases.

Specific issues related to dissipative use of products

Manure produced versus manure spread on fields: Not all manure produced is actually spread on agricultural land. A part is lost from the economic system as emissions to water. The Italian Statistical Office estimated this loss at 5% (Barbiero et al. 2003) and reported it under emissions to water in its MFA account. Furthermore, manure loses some of its weight during stockpiling due to emissions to air (nitrogen compounds, methane and NMVOC, partly by combination with atmospheric gases, water vapour). The DPO account may be corrected for these air emission losses from manure if information is available or a feasible estimation procedure has become available.

Dissipative losses

Introduction

Dissipative losses are unintentional outputs of materials to the environment resulting from abrasion, corrosion, and erosion at mobile and stationary sources, and from leakages or from accidents during the transport of goods. This includes abrasion from tyres, friction products, buildings and infrastructure, leakages (e.g. of gas pipelines), or from accidents during the transport of goods.

There are only very few data available internationally. Matthew et al. (2000) report estimated data for the abrasion from tires for Austria, Germany and USA.

Table 30: Domestic processed output: dissipative losses

1 digit	2 digit	3 digit
D.5. Dissipative losses (e.g abrasion from tires, friction products, buildings and infrastructure)		

Data compilation

This category includes various types of dissipative flows. Losses of materials due to corrosion, abrasion and erosion of buildings and infrastructure are assumed to be of significant size and of environmental relevance. Another significant unknown flow is the loss of lubricants, which is estimated at about 50% of total lubricant use.

Many of these flows have never been quantified. The air emission submissions to the UNECE Convention on Long Range Transboundary Air Pollutants (CLRTAP) are the most significant data source for this item. The database includes information on emissions in road transport from automobile tyre and brake wear (NFR code: 1A3bvi) and from automobile road abrasion (NFR code: 1A3bvii).

Some notes on the categories included:

- Abrasion from tires is rubber worn away from car tires. The procedure applied in the Austrian case study in Matthews et al. (2000) used data from transport statistics together with a coefficient of 0.03 g/km for the average abrasion per tire, taken from a special study on ecology and road traffic in Austria.
- Particles worn from friction products, such as brakes and clutches, so far have never been addressed in MFA.
- Losses of materials due to corrosion, abrasion, and erosion of buildings and infrastructure are probably a quantitatively relevant position, and they appear to be relevant under environmental aspects as well. So far, there is no comprehensive approach to account of these flows. Single aspects like losses due to leachate of copper from roofing or paints from construction have been studied, though. Such studies may serve as a starting point towards more comprehensive accounts of material losses of this kind.

- Dissipative losses may also result from the transport of goods. In German statistics, for example, the amount of chemicals irreversibly lost due to accidents during transport is reported.
- Another position may be leakages during (natural) gas pipeline transport (if not reported as emissions to air). Data may be reported in specific studies.

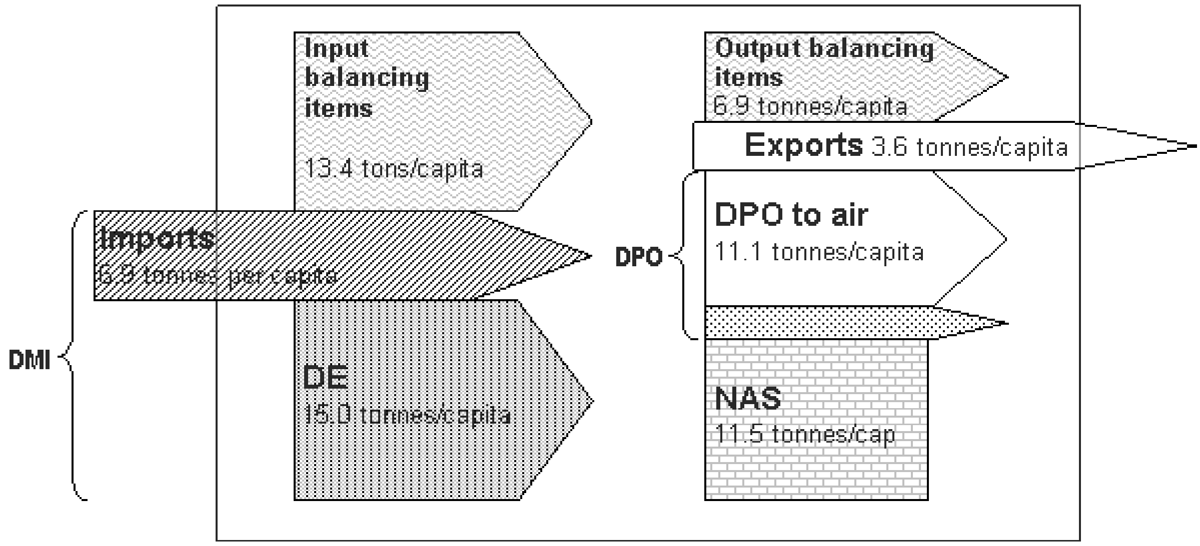
Table E: Balancing items and net additions to stock

Introduction

Some material inputs and material outputs which are part of DMI and DPO are not sufficiently counterbalanced on the respective opposite side of the material balance. For example, carbon contained in an energy carrier is combusted and the CO_2 is counted on the output side. This requires adding the O_2 on the input side to arrive at a correct balance. Or, energy carriers on the material input side contain water which is released through combustion as water vapour on the output side and needs to be added there as a balancing item.

These additional inputs and outputs that are needed to compile a full mass balance are significant mass flows, as can be seen from Figure 3. In MFA they are called balancing items. They are reported in specific tables and are not included in the aggregate indicators. A comprehensive and accurate estimation of balancing items is instrumental when the indicator NAS (net additions to stock) is calculated as the difference between total inputs and total outputs.

Figure 3: Balancing inputs with outputs: Austria 1996



Source: Institute for Social Ecology database

Balancing items: Input side (gases and water)

Introduction

Balancing items on the input side account for those flows of water and air that are accounted for in DPO but not in DE or imports. The main processes concerned are combustion of fuels, respiration of humans and livestock, and the production of ammonia via the Haber-Bosch process. **Please note:** Also water requirements for the domestic production of exported beverages may be a relevant balancing item for the input side in some countries. The amount of water withdrawn from the domestic territory may be estimated based on export data. However, so far no reliable method has been reported for this item. Compilers are encouraged to contribute their experience with this issue to the further development of adequate methods.

Data compilation

E.1.1 Oxygen for combustion processes

Step 1: Oxygen for combustion processes can be calculated stoichiometrically from respective data for emissions of CO_2, CO, SO_2, N_2O and NO_2 from combustion:

$C + O_2 \rightarrow CO_2$, i.e. 12 + 32 = 44, and ≈0.727 oxygen per CO2

$C + O \rightarrow CO$, i.e. 12 + 16 = 28, and ≈0.571 oxygen per CO

$S + O_2 \rightarrow SO_2$, i.e. 32 + 32 = 64, and ≈0.5 oxygen per SO_2

$2N + O \rightarrow N_2O$, i.e. 28 + 16 = 44, and ≈0.364 oxygen per N_2O

$N + O_2 \rightarrow NO_2$, i.e. 14 + 32 = 46, and ≈0.696 oxygen per NO_2

The required data for emissions from combustion should be taken from the DPO account. They are multiplied with the above factors for oxygen per substance emitted to obtain oxygen for combustion processes.

Step 2: In addition, oxygen is required for combustion of the hydrogen (H) contents of energy carriers, with the resulting emission being water vapour (H_2O):

$2H + O \rightarrow H_2O$, i.e. 2 + 16 = 18, and ≈0.889 oxygen per H_2O from H.

For this, hydrogen contents of energy carriers combusted and the resulting emissions of water vapour have to be determined. Table 31 provides exemplary values from German emission inventories for the respective oxygen demand.

Step 3: Total oxygen for combustion is finally calculated as the sum of the amount calculated in step 1 (related to emissions of CO_2, CO, SO_2, N_2O and NO_2) and step 2 (H_2O from H).

Table 31: Oxygen demand for oxidation of H compound of energy carriers to H_2O

Energy carrier	Oxygen in t per t energy carrier
Sewage gas/ Biogas/ Landfill gas	1.57
Hard coal	0.37
Coke (hard coal)	0.06
Hard coal briquettes	0.33
Brown coal, crude	0.15
Dust- and dry coal	0.33
Hard brown coal	0.32
Brown coal briquettes and –coke	0.33
Mine gas	1.57
Coke oven gas	1.57
Natural gas, Crude oil gas	1.83
Gasoline	1.14
Diesel	1.06
Aviation gasoline	1.19
Fuel oil, light	1.07
Fuel oil, medium and heavy	0.93
Liquid gas	1.41
Refinery gas	1.71
Other solid fuels	0.40
Blast furnace gas	0.02

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989.

E.1.2 Oxygen for respiration (of humans and livestock)

Oxygen for respiration can be calculated using standard coefficients based on population numbers and livestock numbers (see Table 32).

Table 32: Metabolic oxygen demand of humans and livestock

Oxygen demand for respiration	t O_2 per capita resp. head and per year
Humans	0.25
Cattle	2.45
Sheep	0.20
Horses	1.84
Pigs	0.25
Poultry	0.01

Source: Wuppertal Institute data base, based on Matthews et al. 2000.

E.1.3 Nitrogen for Haber-Bosch process

The Haber-Bosch process designates the reaction of nitrogen and hydrogen to produce ammonia. Nitrogen is obtained from the air, and hydrogen is obtained from water and natural gas in steam reforming. Via this process around 500 million tonnes of artificial fertilizer are produced every year, mostly in the form of anhydrous ammonia, ammonium nitrate, and urea. Fertilizer produced in the Haber-Bosch process is responsible for sustaining 40% of the Earth's population. Roughly 1% of the world's energy supply is consumed in the manufacturing of this fertilizer (Smith 2002).

The nitrogen (N) and hydrogen (H) are reacted over an iron catalyst (Fe) under conditions of 250 atmospheres (atm) and 450-500°C:

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) + \Delta H$ ...(1)

(Where ΔH is the heat of reaction or enthalpy. For the Haber process, this is -92.4 kJ/mol at 25°C).

Nitrogen required as balancing item to account for the production of ammonia is derived from:

1. data for the production of nitrogen(fixed)-ammonia (e.g. from USGS 2006);
2. the amount of nitrogen required to produce one tonne of ammonia, which is about 0.83 tonnes N for 1 tonne NH_3 (assuming conventional reforming in modern ammonia plants – UNEP/UNIDO 1998);

by multiplying ammonia production in t (1) with nitrogen requirements per ton (2).

Specific issues related to balancing items input side (and in total)

Combustion of energy carriers in the context of emission-relevant consumption: The emission-relevant consumption of energy carriers includes both energetic (combustion) and non-energetic processes. Emissions from combustion of energy carriers are usually by far dominating. Significant non-energetic emissions may, however, come from the production of blast furnace steel where the carbon stemming from coke in pig iron production is blown out as CO_2 through injection of technical oxygen. For a more comprehensive economy-wide MFA, this amount of oxygen for the process related emissions of CO_2 from coke should also be accounted for.

Advanced compilers of MFA may set up at first an account for the emission relevant consumption of energy carriers by type, and then account for oxygen as balancing item on the material input side. Respective energy consumption data are found in common energy statistics or energy balances.

Table 33: Oxygen content of energy carriers (in % of weight)

	Oxygen content in % (wt/wt)
Sewage gas/ Biogas/ Landfill gas	14.93
Hard coal	4.94
Coke (hard coal)	1.70
Hard coal briquettes	2.78
Brown coal, crude	6.00
Dust- and dry coal	16.78
Hard brown coal	12.73
Brown coal briquettes and –coke	16.78
Mine gas	14.93
Coke oven gas	14.93
Natural gas, Crude oil gas	0.19
Other solid fuels	35.97
Blast furnace gas	34.35

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989.

Intrinsic CO_2 in materials: Process-related CO_2 emissions from intrinsic CO_2-contents of materials refer to cement and lime production: $CaCO_3$ + heat → $CaO + CO_2$. These emissions are reported in NAMEAs and in the CRF. It has to be assured that the resulting CO_2 is definitely excluded from the CO_2 value used for O_2 calculation.

Intrinsic oxygen content of energy carriers: Some energy carriers contain oxygen. For an advanced balancing approach this intrinsic oxygen content of energy carriers has to be determined and subtracted from the oxygen calculated as balancing item for combustion, in order to derive the (real) net demand for O_2 for combustion. Exemplary values for oxygen in energy carriers are shown in Table 33.

Nitrogen for combustion as balancing item - input side: Emissions of nitrogen oxides (NO, NO_2) from fuel combustion in motors result at least partly from inputs of nitrogen in ambient air. This nitrogen input can in principle be calculated using standard coefficients based on emissions of NO_2.

Balancing items: Output side (gases)

Introduction

Balancing items on the output side of the account are meant to equalise discrepancies resulting from data for material inputs. The main processes concerned are combustion of fuels and respiration of humans and livestock.

Data sources

Data sources underlying the derivation of balancing items are:

for combustion: (1) data for the combustion of energy carriers to account for hydrogen contents of energy carriers resp. resulting emissions of water vapour, taken e.g. from energy balances (see also balancing items – input side) (2) similarly, data for the water contents of fuels for combustion.

auxiliary data needed to account for CO_2 and water vapour from respiration are population numbers and livestock numbers commonly found in general statistical sources and agricultural statistics (e.g. FAOSTAT), respectively.

Data compilation

E.2.1.1 Water vapour from moisture content of fuels

In the combustion process the moisture contained in fuels is emitted as water vapour (H_2O). Resulting emissions can be estimated based on average values for water emitted per tonne energy carrier combusted:

Table 34: Water vapour from moisture content of fuels

energy carrier	water vapour in t per t energy carrier
Hard coal	0.02
Coke (hard coal)	0.02
Hard coal briquettes	0.02
Brown coal, crude	0.59
Dust- and dry coal	0.11
Hard brown coal	0.18
Brown coal briquettes and –coke	0.12
Fuel oil, light	0.001
Fuel oil, medium and heavy	0.005
Other solid fuels	0.16

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989

E.2.1.2 Water vapour from the oxidised hydrogen components of fuels

As with the carbon component also the hydrogen component of fossil energy carriers is oxidised during combustion. The resulting water is released to the air as water vapour.

Table 35: Water vapour from oxidised hydrogen component of fossil energy carriers

energy carrier	water vapour in t per t energy carrier
Sewage gas/ Biogas/ Landfill gas	1.77
Hard coal	0.42
Coke (hard coal)	0.07
Hard coal briquettes	0.37
Brown coal, crude	0.17
Dust- and dry coal	0.37
Hard brown coal	0.36
Brown coal briquettes and –coke	0.37
Mine gas	1.77
Coke oven gas	1.77
Natural gas, Crude oil gas	2.05
Gasoline	1.28
Diesel	1.19
Aviation gasoline	1.34
Fuel oil, light	1.21
Fuel oil, medium and heavy	1.05
Liquid gas	1.59
Refinery gas	1.92
Other solid fuels	0.45
Blast furnace gas	0.02

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989

E.2.2 Gases from respiration of humans and livestock

CO_2 and water vapour (H_2O) from respiration can be calculated using standard coefficients based on population numbers and livestock numbers (see Table 36).

Table 36: Metabolic CO_2 and H_2O production of humans and livestock

	t CO_2 per capita resp. head and per year	t H_2O per capita resp. head and per year
Humans	0.30	0.35
Cattle	2.92	3.38
Sheep	0.24	0.27
Horses	2.19	2.53
Pigs	0.30	0.35
Poultry	0.01	0.01

Source: Wuppertal Institute data base, based on Matthews et al. 2000.

Material flow indicators

Similar to national accounts, also in material flow accounting highly aggregated indicators can be derived from the detailed data sets normally comprising several hundred material categories. We distinguish between extensive and intensive indicators.

Extensive indicators

Definition: In general a property, which varies directly with the size of the system is called an **extensive** property (e.g. volume, mass, or energy).

Direct Material Input (DMI) measures the direct input of materials for use into the economy, i.e. all materials which are of economic value and are used in production and consumption activities, except balancing items. DMI equals domestic extraction (used) plus imports. DMI is not additive across countries. For example, for EU totals of DMI the intra-EU foreign trade flows must be subtracted from the DMIs of Member States

Domestic material consumption (DMC) equals domestic extraction plus imports minus exports. DMC measures the annual amount of raw materials extracted in a national economy, plus all physical imports minus all physical exports. It is important to note that the term "consumption" as used in DMC denotes "apparent consumption" and not "final consumption". DMC is defined in the same way as other key physical indictors such as e.g. "total primary energy supply" - TPES. DMC represents the part of all material inputs into an economic system that remains there until released to the environment. DMC therefore signifies the "domestic waste potential" of an economy (Weisz et al. 2006).

Physical trade balance (PTB) equals physical imports minus physical exports. The physical trade balance, thus, is defined reverse to the monetary trade balance (which is exports minus imports), taking account of the fact that in economies money and goods move in opposite direction. A physical trade surplus indicates a net import of materials, whereas a physical trade deficit indicates a net export.

Net Additions to Stock (NAS) measures the 'physical growth of the economy' (assuming that the balance is in most cases positive), i.e. the quantity (weight) of new construction materials used in buildings and other infrastructure, and materials incorporated into new durable goods such as cars, industrial machinery, and household appliances. Materials are added to the economy's stock each year (gross additions), and old materials are removed from stock as buildings are demolished, and durable goods disposed of (removals). These decommissioned materials, if not recycled, are accounted for in DPO. The difference between gross additions and removals represents the net-additions to stock.

Domestic processed output (DPO) measures the total weight of materials which are released back to the environment after having been used in the domestic economy. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included in DPO are emissions to air, industrial and household wastes deposited in controlled and uncontrolled landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Recycled material flows in the economy (e.g. of metals, paper, glass) are considered flows within the socio-economic system not crossing the relevant system boundaries and thus not included in DPO.

Intensive indicators

Definition: As distinguished from an extensive property an **intensive** property is one that is independent of the size of the system being considered (e.g. temperature, pressure or density). For cross-country comparisons, intensive material flow indicators are used to compensate for the differences in size. As is common in environmental accounting, we here use population as denominator to compare the levels of economy-wide material use between nation states. In addition we propose the following intensive indicators:

To indicate overall material efficiency of an economy, we relate DMC to GDP. There are two types of efficiency indicators.

Material intensity is defined as the DMC to GDP ratio.

Material productivity is the inverse of material intensity, thus the GDP to DMC ratio.

Area Intensity: DE or DMC to total land area ratio: The ratio between material flows and total land area indicates the scale of the physical economy vis a vis its natural environment. We denote this indicator as area intensity.

DE/DMC: The ratio of domestic extraction to domestic material consumption indicates the dependence of the physical economy on domestic raw material supply. We therefore denote the DE to DMC ratio as “domestic resource dependency” (see Weisz et al. 2006).

Import to DMI ratio and export to DMI ratio: The ratios between imports and exports, respectively, to DMI indicate the import or export intensities of the physical economies. Together they can be addressed as “trade intensity” indicators. Sometimes also expressed as import or export per DMC

The use of different denominators is important for the analysis as different aspects of the physical economies become visible and comparable.

References

Literature

Adriaanse, A., S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich, and H. Schütz. (1997): *Resource Flows: The Material Basis of Industrial Economies*. World Resources Institute, Washington, D.C.

Ayres, R. U. and Ayres, L. W., and Masini, A. (2006): An application of exergy accounting to five basic metal industries. In: von Gleich, Arnim et al. (Eds.): *Sustainable metals management. Securing our future-steps towards a closed loop economy.* Dordrecht: Springer, Eco-Efficiency in Industry and Science Bd. 6, pp. 141-194.

Ayres, R. U. and U. E. Simonis. (1994): *Industrial Metabolism: Restructuring for Sustainable Development*. United Nations University Press, Tokyo, New York, Paris.

Barbiero, G., S, Camponeschi, A. Femia, G. Greca, A. Macrì, A. Tudini, and M. Vannozzi. (2003): *1980-1998 Material-Input-Based Indicators Time Series and 1997 Material Balance of the Italian Economy*. ISTAT, Rome.

Biology-Online.Org. (2005): *Seeds*. Available at http://www.biology-online.org/dictionary/Seeds. Retrieved 03/07/07.

BMVEL. (2001): *Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland*. Landwirtschaftsverlag, Münster-Hiltrup.

Böhm, E., T. Hillenbrand, F. Marscheider-Weidemann, C. Schempp, S. Fuchs, and U. Scherer (2000): *Bilanzierung des Eintrags prioritärer Schwermetalle in Gewässer*. UBA-FB 000181, Federal Environmental Agency, Berlin.

Bringezu, S. and H. Schütz (2001): *Material use indicators for the European Union, 1980-1997: Economy-wide material flow accounts and balances and derived indicators of resource use*. Eurostat Working Paper 2/2001/B/2, 29 June 2001.

Buchberger, A., 2017. Erntenebenprodukte als Ressource. Produktionsmengen, Verwendung und Nutzungspotentiale von Erntenebenprodukten des Zuckerrohrs., Social Ecology Working Paper 172. Institute of Social Ecology, Wien.

Buchgraber, K., A. Deutsch, and G. Gindl. 1994. *Zeitgemässe Grünland-Bewirtschaftung*. Stocker Verlag, Graz, Stuttgart.

Calvo, G., Mudd, G., Valero, Alicia, Valero, Antonio, 2016. Decreasing ore grades in global metallic mining: A theoretical issue or a global reality? Resources 5, 36.

Cembureau, 1998. World Statistical Review. World Cement Market in Figures 1913/1995. The European Cement Association, Brussels.

Cembureau, 2013. World Statistical Review. World Cement Market in Figures. The European Cement Association, Brussels.

Commission of the European Communities (2005): Thematic strategy on the sustainable use of natural resources (TSURE). Brussels: Commission of the European Communities (CEC), COM (2005) 670 final http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52005DC0670:EN:NOT

Cordova, F.J., Wallace, J.D., Pieper, R.D., 1978. Forage intake by grazing livestock: a review. J. Range Manag. 430–438.

Council of the European Union (2006): Review of the EU Sustainable Development Strategy (EU SDS) - Renewed Strategy. Brussels: Council of the European Union, DG I, 10117/06.

CSIRO (2010). CSIRO and UNEP Asia-Pacific Material Flows online database: http://www.cse.csiro.au/forms/form-mf-start.aspx. See also Schandl, H. and J. West. 2010. Resource use and resource efficiency in the Asia-Pacific region. *Global Environmental Change* 20(4): 636–647.

EC (2002): Regulation (EC) No 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics (Text with EEA relevance). *Official Journal of the European Communities* L 332, 1-36. Available at

EEA (2005): *Annual European Community CLRTAP emission inventory 1990–2003: Submission to the Executive Body of the UNECE CLRTAP*. EEA Technical Report No 6/2005.

EEA (2006): *European Community greenhouse gas inventory 1990–2004 and inventory report 2006: Submission to the UNFCCC Secretariat*. EEA Technical Report No 6/2006.

Eisenmenger, N., Wiedenhofer, D., Schaffartzik, A., Giljum, S., Bruckner, M., Schandl, H., Wiedmann, T.O., Lenzen, M., Tukker, A., Koning, A., 2016. Consumption-based material flow indicators—Comparing six ways of calculating the Austrian raw material consumption providing six results. Ecol. Econ. 128, 177–186.

ESA (1995): European System of National and Regional Accounts (ESA 95). Commission of the European Communities (Council Regulation of 25 June 1996), http://circa.europa.eu/irc/dsis/nfaccount/info/data/ESA95/en/titelen.htm

European Parliament and Council (2002): Sixth Community Environment Action Programme, Decision 1600/2002/EC. Brussels: Official Journal of the European Communities, L242/1-15.

European Statistical Office, Luxembourg.Eurostat (2009a): *Manual for Air Emissions Accounts* (draft v2.2, 23 February 2009, revisions included after TF discussions), Luxembourg.

Eurostat (2001): *Economy-wide Material Flow Accounts and Derived Indicators: A methodological guide*. Office for Official Publications of the European Communities, Luxembourg.

Eurostat (2002): Material use in the European Union 1980-2000. Indicators and Analysis. Luxembourg: Eurostat, Office for Official Publications of the European Communities, prepared by Weisz, H., Fischer-Kowalski, M., Amann, C., Eisenmenger, N., Hubacek, K., and Krausmann, F.

Eurostat (2005): *Waste generated and treated in Europe – Data 1995-2003*. Office for Official Publications of the European Communities, Luxembourg.

Eurostat (2006): *Statistics on the trading of goods - User guide*. Office for Official Publications of the European Communities, Luxembourg.

Eurostat (2007). Economy-wide Material Flow Accounting. A Compilation Guide. European Statistical Office, Luxembourg.

Eurostat (2009b): Sustainable Development Indicators. Sustainable Production and Consumption. http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators/theme2.

Eurostat, (2009c). Economy wide Material Flow Accounts. Compilation Guidelines for reporting to the 2009 Eurostat questionnaire (Version 01 - June 2009).

Eurostat, (2012). Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2012, Luxembourg.

Eurostat, (2013). Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2013, Luxembourg: http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/2013_EW-MFA_Guide_10Sep2013.pdf

Eurostat, 2013. Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2013. European Statistical Office, Luxembourg.

Fischer-Kowalski, M. (1998): Society's Metabolism: The Intellectual History of Material Flow Analysis, Part I, 1860 – 1970. In *Journal of Industrial Ecology* 2, 61-78.

Fischer-Kowalski, M. and H. Weisz (2005): Society as Hybrid Between Material and Symbolic Realms: Toward a Theoretical Framework of Society-Nature Interrelation. In: Redclift, M. R. and G. Woodgate (eds.). *New Developments in Environmental Sociology*. Edward Elgar, Cheltenhem and Northampton, 113–149.

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., Weisz, H., 2011. Methodology and indicators of economy wide material flow accounting. State of the art and reliablity across sources. Journal of Industrial Ecology, 15 (6), 855-876.

Frischknecht, R., Hofstetter, P., Knoepfel, I. (1994): Environmental life-cycle inventories of energy systems: methods and selected results. Swiss Federal Institute of Technology (ETH), Zürich. Switzerland.

Gonzales de Molina and Victor Toledo. 2014. *The Social Metabolism - A Socio-Ecological Theory of Historical Change*. Vol. 3. Environmental History. New York, Heidelberg: Springer.

GVM - Gesellschaft für Verpackungsmarktforschung mbH (2005): Importe und Exporte von gefüllten Verpackungen. Wiesbaden, unpublished: Studie im Auftrag des Statistischen Bundesamtes

Herrero, M., P. Havlík, H. Valin, A. Notenbaert, M.C. Rufino, P.K. Thornton, M. Blümmel, F. Weiss, D. Grace, and M. Obersteiner. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*: 201308149.

Hohenecker, J. (1981): Entwicklungstendenzen bei der Futterversorgung Österreichs, dargestellt am Beispiel ausgewählter Jahre. *Die Bodenkultur. Austrian Journal of Agricultural Research* 32, 163-187.

IEA (2014): Energy Statistics and balances of OECD and Non-OECD Countries. International Energy Agency. URL: http://www.iea.org/

IPCC (2000): *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Available at http://www.ipcc-nggip.iges.or.jp/public/gp/english/. Retrieved 03/06/07.

IPCC (2006): *2006 IPCC Guidlines for National Greenhouse Gas Inventories*. Japan: IGES

IPCC (2007): *Climate Change 2007. Mitigation. Contribution of working group III to the Fourth Assessment report of the IPCC*. Cambridge UK and New York, USA: Cambridge University Press

Jacobi, N., Haas, W., Wiedenhofer, D., Mayer, A. 2018. Economy-wide monitoring of the circular economy in Austria: State, challenges and the resource-climate nexus. In: Resources, Conservation & Recycling (in print).

Kapur, A., Oss, H., Keoleian, G., Kesler, S., Kendall, A., 2009. The contemporary cement cycle of the United States. J Mater Cycles Waste Manag 11, 155–165.

Klinnert (1993): *Erfassung von statistischem Datenmaterial über mineralische Rohstoffe*. Report to the Material Flows and Structural Change Division of the Wuppertal Institute. Unpublished.

Krausmann, F., Erb, K.-H., Gingrich, S., Haberl, H., Bondeau, A., Gaube, V., Lauk, C., Plutzar, C., Searchinger, T., (2013). Global human appropriation of net primary production doubled in the 20th century. Proceedings of the National Academy of Sciences of the United States of America, 110, 10324-10329.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., (2009). Growth in global materials use, GDP and population during the 20th century. Ecological Economics, 68 (10), 2696-2705.

Krausmann, F., K.-H. Erb, S. Gingrich, C. Lauk, and H. Haberl. 2008. Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. *Ecological Economics* 65(3): 471–487

Krausmann, F., Schandl, H., Eisenmenger, N., Giljum, S., Jackson, T., 2017. Material Flow Accounting: Measuring Global Material Use for Sustainable Development. Annu. Rev. Environ. Resour. 42, null. https://doi.org/10.1146/annurev-environ-102016-060726

Kugeler, K., Phlippen, P.-W. (1990): Energietechnik - Technische, ökonomische und ökologische Grundlagen, Springer-Verlag Berlin, Heidelberg, New York.

Leffland, K. and H. Kærsgaard (1997): *Comparing Environmental Impact Data on Cleaner Technologies (CEIDOCT)*. EEA, COWI, Copenhagen. Available at http://reports.eea.europa.eu/TEC01/en/tech01.pdf. Retrieved 03/06/07.

Matthews, E., C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. van der Voet, and H. Weisz (2000): *The weight of nations: Material outflows from industrial economies*. World Resources Institute, Washington, D. C.

Meissner, R. (1994): Wohin mit der Gülle?. In: GSF (ed.), Mensch und Umwelt: Wasser, Vol. 9, pp. 55-60.

Miatto, A., Fishman, T., Tanikawa, H., Schandl, H., 2016. Global Patterns and Trends for Non-Metallic Minerals Used for Construction. J. Ind. Ecol. 21, 924–937. https://doi.org/10.1111/jiec.12471

Ministry of the Environment, Government of Japan (1992): *Quality of the Environment in Japan 1992*. Available at http://www.env.go.jp/en/wpaper/1992/index.html. Retrieved 03/06/07.

Mudd, G.M., 2013. The limits to growth and 'finite'mineral resources: re-visiting the assumptions and drinking from that half-capacity glass. Int. J. Sustain. Dev. 16, 204–220.

Muukkonen, J (2000): *TMR, DMI and Material Balances, Finland 1980-1997*. Statistics Finland, Eurostat Working Papers 2/2000/B/1. Office for Official Publications of the European Communities, Luxembourg.

OECD (2006): *International Trade by Commodity Statistics - Standard Definitions*. Available at http://www.oecd.org/dataoecd/60/63/1947767.htm. Retrieved 03/06/07.

OECD/IEA/Eurostat (2005): *Energy statistics manual*. IEA, Paris.

Osteroth, D. (1989): Von der Kohle zur Biomasse. Chemierohstoffe und Energieträger im Wandel der Zeit. Springer-Verlag Berlin, Heidelberg, New York.

Pauliuk, S., Hertwich, E.G., 2015. Socioeconomic metabolism as paradigm for studying the biophysical basis of human societies. Ecol. Econ. 119, 83–93.

PCA (2007): Cement and Concrete Basics. Available at http://www.cement.org/basics/concretebasics_concretebasics.asp. Retrieved 03/07/07.

Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner (2003): *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. IPCC National Greenhouse Gas Inventories Programme, IGES-IPCC, Hayama.

REN21 (2005): *Renewables 2005 Global Status Report*. Worldwatch Institute, Washington, D.C.

Scasny, M., J. Kovanda, and T. Hak (2003): Material flow account, balances and derived indicators for the Czech Republic during the 1990s: results and recommendations for methodological improvements. In *Ecological Economics* 45, 41– 57.

Schaffartzik, A., Eisenmenger, N., Krausmann, F., Weisz, H., 2014a. Consumption-based Material Flow Accounting. Journal of Industrial Ecology 18, 102–112.

Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N., Loy, C., Krausmann, F., 2014. The global metabolic transition: Regional patterns and trends of global material flows, 1950–2010. Global Environmental Change 26, 87–97.

Schandl, H., Fischer-Kowalski, M., West, J., Giljum, S., Dittrich, M., Eisenmenger, N., Geschke, A., Lieber, M., Wieland, H., Schaffartzik, A., others, 2017. Global Material Flows and Resource Productivity: Forty Years of Evidence. J. Ind. Ecol. DOI: 10.1111/jiec.12626.

Schandl, H., West, J., 2010. Resource use and resource efficiency in the Asia-Pacific region. Global Environmental Change 20, 636–647.

Schütz, H. and S. Bringezu (1993): Major Material Flows in Germany. In *Fresenius Environmental Bulletin* 2, 443-448.

Smith, B.E. (2002): Nitrogenase Reveals Its Inner Secrets. In *Science* 297, 1654-1655.

Steger, S., Fekkak, M., Erren, M., Lischka, S., Bringezu, S., Scharp, M. (2009): MaRess AP 2.3. Öffentliche Infrastrukturen. Arbeitsbericht zu Phase II „Bestimmung der aktuellen Bestandsgrößen und des Materialspeichers der Referenzsysteme“. Wuppertal.

Steurer, A. (1992): *Stoffstrombilanz Österreich 1988*. Social Ecology Working Paper,, IFF Social Ecology, Vienna.

Stiller, H. (1996): Materialintensitätsanalysen von Transporten – Neue Prioritäten für Instrumente? (in German with an English Summary). In J. Köhn and M.J. Welfens (eds.). *Neue Ansätze in der Umweltökonomie*. Metropolis-Verlag, Marburg, 253-284.

Takiguchi, H., Takemoto, K., 2008. Japanese 3R Policies Based on Material Flow Analysis. Journal of Industrial Ecology 12, 792–798.

Ulbricht, M. (2006): Stoffströme im Tiefbau. Quantifizierung des Ressourcenverbauches der deutschen Straßeninfrastruktur. Studienarbeit in der Abteilung Sicherheitstechnik der Bergischen Universität Wuppertal, durchgeführt am Wuppertal Institut. Unveröffentlicht.

UNEP, 2011. Decoupling natural resource use and environmental impacts from economic growth. United Nations Environmment Programme, Nairobi.

UNEP, 2016. Global Material Flows and Resource Productivity. Assessment Report for the UNEP International Resource Panel. United Nations Environment Programme, Paris.

UNEP-UNIDO (1998): Mineral Fertiliser Production and the Environment, Part 1: The Fertilizer Industry's Manufacturing Processes and Environmental Issues. Technical Report No. 26.

United Nations (2004): International Merchandise Trade Statistics. Compilers Manual. Department of Economic and Social Affairs, Statistics Division, United Nations, New York.

UNSD 2008. United Nations Energy Statistics Database. United Nations Statistics Division, New York.

USGS (2006): Nitrogen (Fixed) – Ammonia Statistics. Available at http://minerals.usgs.gov/ds/2005/140/nitrogen.pdf. Retrieved 03/07/07.

WCO. 2006. Harmonised System News. Available at http://www.wcoomd.org/ie/En/Topics_Issues/topics_issues.html. Retrieved 03/06/07.

Weisz, H., F. Krausmann, C. Amann, N. Eisenmenger, K. Erb, K. Hubacek, and M. Fischer-Kowalski. (2006): The physical economy of the European Union: Cross-country comparison and determinants of material consumption. In *Ecological Economics* 58 (4), 676-698.

Weisz, Helga, Amann, Christof, Eisenmenger, Nina, Krausmann, Fridolin, and Hubacek, Klaus (2004): Economy-wide Material Flow Accounts and Indicators of Resource Use for the EU: 1970-2001. Final report to Eurostat, contract no. Estat/B1/Contract Nr. 200241200002. Wien: IFF Social Ecology

Wheeler, R.O., G.L. Cramer, K.B. Young, and E. Ospina (1981): *The World Livestock Product, Feedstuff, and Food Grain System: An Analysis and Evaluation of System Interactions Throughout the World, With Projections to 1985*. Winrock International, Morrilton.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2013. The material footprint of nations. PNAS 201220362. doi:10.1073/pnas.1220362110

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proc. Natl. Acad. Sci. 112, 6271–6276.

Wirsenius, S. (2000): Human Use of Land and Organic Materials. Modeling the Turnover of Biomass in the Global Food System*. Doktorsavhandlingar vid Chalmers Tekniska Högskola* 1574, 1-255.

Wirsenius, S. (2003). Efficiencies and biomass appropriation of food commodities on global and regional levels. *Agricultural Systems* 77(3): 219–255.

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J.H., Merciai, S., Tukker, A., 2014. Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. Sustainability 7, 138–163.

Woodward, R., Duffy, N., 2011. Cement and concrete flow analysis in a rapidly expanding economy: Ireland as a case study. Resour. Conserv. Recycl. 55, 448–455.

Databases and Statistical Sources

BGR – Federal Institute for Geosciences and Natural Resources. Bundesrepublik Deutschland: Rohstoffsituation (Annual Report in German). Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

BGS - British Geological Survey. European Mineral Statistics / World Mineral Statistics (Published Annually). Available at http://www.bgs.ac.uk/mineralsuk/free_downloads/home.html#EMS

CLRTAP - Convention on Long-Range Transboundary Air Pollution. For inventories compiled under this convention, please refer to EEA 2005.

Comext – Eurostat's Statistics on the Foreign Trade of the EU Member States. Available at http://comext.eurostat.cec.eu.int

Comtrade – UN Commodity Trade Statistics Database. Available at http://comtrade.un.org/

DG TREN (2008): EU energy and transport in figures. Statistical Pocketbook 2007/2008. Luxembourg: Office for Official Publications of the European Communities, 2008

ETC - European Topic Centre on Resource and Waste Management.

International Databases available at http://waste.eionet.europa.eu/wastebase/international_databases

National Databases available at http://waste.eionet.europa.eu/wastebase/national_databases

FAOSTAT – Statistical Databases of the Food and Agriculture Organisation of the United Nations. Available at http://faostat.fao.org/

FISHSTAT – FAO Fishery Statistics Programme. Available at http://www.fao.org/figis/servlet/static?xml=FIDI_STAT_org.xml&dom=org&xp_nav=3,1,1

IEA - Energy Statistics of the International Energy Agency. Available at http://www.iea.org/Textbase/stats/index.asp

Energy Statistics of OECD Countries (CD-ROM, 2006 Edition), see http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1075

PAN – Pesticide Action Network Pesticides Database. Available at http://www.pesticideinfo.org/List_ChemicalsAlpha.jsp

PRODCOM – Eurostat's Statistics on the Production of Manufactured Goods. Available at http://epp.eurostat.ec.europa.eu/portal/page?_pageid=2594,58778937&_dad=portal&_schema=PORTAL

SIMETRIC - Standard to Metric Conversion Factor Tables: Mass and Density of Materials. Available at http://www.simetric.co.uk/si_materials.htm

USGS - U.S. Geological Survey International Mineral Statistics and Information. Available at http://minerals.usgs.gov/minerals/pubs/country/

United Nations Industrial Commodity Production Statistics Dataset. Available at http://unstats.un.org/unsd/industry/default.

List of abbreviations

Acronyms

AOX Adsorbable Organic Halogens
BGR Federal Institute for Geosciences and Natural Resources, Germany
BGS British Geological Survey
BMVEL Federal Ministry of Consumer Protection, Food and Agriculture, Germany
BOD Biological (Biochemical) Oxygen Demand, *cf. Glossary*
CEIDOCT Comparing Environmental Impact Data on Cleaner Technologies
CLRTAP Convention on Long-Range Transboundary Air Pollution (UNECE)
CN Combined Nomenclature
COD Chemical Oxygen Demand, *cf. Glossary*
COWI International Consultancy within Engineering, Environmental Science & Economics
CPA Classification of Products by Activity
COMEXT Eurostat (↓) Foreign Trade Database
COMTRADE UN Commodity Trade Statistics Database
CRF Common Reporting Format (for UNFCCC (↓) - related reporting), *cf. Glossary*
DDT Dichloro-Diphenyl-Trichloroethane, a pesticide and POP (↓)
DE Domestic Extraction, *cf. Glossary*
DPO Domestic Processed Output, *cf. Glossary*
DM Dry Matter
DMC Domestic Material Consumption, *cf. Glossary*
DMI Direct Material Input, *cf. Glossary*
EC European Community
EEA European Environmental Agency
ESA European Systems of Accounts 1995 (ESA 95)
ETC-WMF European Topic Centre on Waste and Material Flows
EU European Union
Eurostat Statistical Office of the European Communities
FAO Food and Agriculture Organization of the United Nations
FAOSTAT FAO Statistical Database
FISHSTAT FAO Fishery Statistics
FW Fresh Weight
GCV Gross Calorific Value
GDP Gross Domestic Product
GHG Greenhouse Gas, *cf. Glossary*
GNP Gross National Product
GVA Gross Value Added
GWP Global Warming Potential, *cf. Glossary*
HFCs Hydrofluorocarbons (group of greenhouse gases)
HM Heavy Metals
HS Harmonised Commodity Description and Coding System
IEA International Energy Agency
IGES Institute for Global Environmental Strategies
IPCC Intergovernmental Panel on Climate Change
ISIC International Standard Industrial Classification of all Economic Activities
ISTAT National Institute of Statistics, Italy
LPG Liquid Petroleum Gas
LULUCF Land Use, Land Use Change, and Forestry
mc moisture content
MFA Material Flow Analysis, *cf. Glossary*
MFAcc Material Flow Account, *cf. Glossary*
MI Material Intensity, *cf. Glossary*
NAMEA National Accounting Matrices Including Environmental Accounts, *cf. Glossary*
NMVOC Non-Methane Volatile Organic Compound
NACE Classification of Economic Activities Within the European Communities
NAS Net Additions to Stock, *cf. Glossary*

NGL Natural Gas Liquids
NIR National Inventory Report (to the UNFCCC (↓)),*cf. Glossary*
NMS (EU) New Member States, *cf. Glossary*
OECD Organisation for Economic Co-operation and Development
PAH Polycyclic Aromatic Hydrocarbons
PAN Pesticide Action Network
PBT Persistent, Bioaccumulative, and Toxic Pollutant
PCA Portland Cement Association
PFCs Perfluorocarbons (group of greenhouse gases)
PM Particulate Matter
PM10 Particulate Matter with a diameter less or equal to 10 micrometers
POP Persistent Organic Pollutant
PRODCOM Products of the European Community (database)
PTB Physical Trade Balance, *cf. Glossary*
REN21 Renewable Energy Policy Network for the 21st Century
RME Raw Material Equivalent, *cf. Glossary*
ROM Run-Of-Mine, *cf. Glossary*
SEEA System of Integrated Environmental and Economic Accounting 2003 (United Nations)
SITC Standard International Trade Classification
SNA System of National Accounts, *cf. Glossary*

TBT Tributyltin, a toxic additive found in paints
TOMP Toxic Organic Micro-Pollutant
TPES Total Primary Energy Supply, *cf. Glossary*
UN United Nations
UNECE UN Economic Commission for Europe
UNEP UN Nations Environment Programme
UNEP GC UNEP Governing Council
UNFCCC UN Framework Convention on Climate Change
UNIDO UN Industrial Development Organisation
USGS United States Geological Survey
WCO (OMD) World Customs Organisation

Units

cap capita
J joule(s)
scm solid cubic meter
t, mt tonne(s), metric tonnes (1 t = 1000 kg)
toe tonnes of oil equivalent
MJ Megajoule

Band 1
Umweltbelastungen in Österreich als Folge menschlichen Handelns. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut.
Fischer-Kowalski, M., Hg.; Wien (1987)

Band 2
Environmental Policy as an Interplay of Professionals and Movements - the Case of Austria. Paper to the ISA Conference on Environmental Constraints and Opportunities in the Social Organisation of Space, Udine 1989.
Fischer-Kowalski, M.; Wien (1989)

Band 3
Umwelt & Öffentlichkeit. Dokumentation der gleichnamigen Tagung, veranstaltet vom IFF und dem Österreichischen Ökologie-Institut in Wien, (1990)

Band 4
Umweltpolitik auf Gemeindeebene. Politikbezogene Weiterbildung für Umweltgemeinderäte.
Lackner, C.; Wien (1990)

Band 5
Verursacher von Umweltbelastungen. Grundsätzliche Überlegungen zu einem mit der VGR verknüpfbaren Emittenteninformationssystem.
Fischer-Kowalski, M., Kisser, M., Payer, H., Steurer A.; Wien (1990)

Band 6
Umweltbildung in Österreich, Teil I: Volkshochschulen.
Fischer-Kowalski, M., Fröhlich, U.; Harauer, R., Vymazal R.; Wien (1990)

Band 7
Amtliche Umweltberichterstattung in Österreich.
Fischer-Kowalski, M., Lackner, C., Steurer, A.; Wien (1990)

Band 8
Verursacherbezogene Umweltinformationen. Bausteine für ein Satellitensystem zur österr. VGR. Dokumentation des gleichnamigen Workshop, veranstaltet vom IFF und dem Österreichischen Ökologie-Institut, Wien (1991)

Band 9
A Model for the Linkage between Economy and Environment. Paper to the Special IARIW Conference on Environmental Accounting, Baden 1991.
Dell'Mour, R., Fleissner, P. , Hofkirchner, W.,; Steurer A.; Wien (1991)

Band 10
Verursacherbezogene Umweltindikatoren - Kurzfassung. Forschungsbericht gem. mit dem Österreichischen Ökologie-Institut.
Fischer-Kowalski, M., Haberl, H., Payer, H.; Steurer, A., Zangerl-Weisz, H.; Wien (1991)

Band 11
Gezielte Eingriffe in Lebensprozesse. Vorschlag für verursacherbezogene Umweltindikatoren. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut.
Haberl, H.; Wien (1991)

Band 12
Gentechnik als gezielter Eingriff in Lebensprozesse. Vorüberlegungen für verursacherbezogene Umweltindikatoren. Forschungsbericht gem. m. dem Österr. Ökologie-Institut.
Wenzl, P.; Zangerl-Weisz, H.; Wien (1991)

Band 13+
Transportintensität und Emissionen. Beschreibung österr. Wirtschaftssektoren mittels Input-Output-Modellierung. Forschungsbericht gem. m. dem Österr. Ökologie-Institut.
Dell'Mour, R.; Fleissner, P.; Hofkirchner, W.; Steurer, A.; Wien (1991)

Band 14
Indikatoren für die Materialintensität der österreichischen Wirtschaft. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut.
Payer, H. unter Mitarbeit von K. Turetschek; Wien (1991)

Band 15
Die Emissionen der österreichischen Wirtschaft. Systematik und Ermittelbarkeit. Forschungsbericht gem. m. dem Österr. Ökologie-Institut.
Payer, H.; Zangerl-Weisz, H. unter Mitarbeit von R.Fellinger; Wien (1991)

Band 16
Umwelt als Thema der allgemeinen und politischen Erwachsenenbildung in Österreich.
Fischer-Kowalski M., Fröhlich, U.; Harauer, R.; Vymazal, R.; Wien (1991)

Band 17
Causer related environmental indicators - A contribution to the environmental satellite-system of the Austrian SNA. Paper for the Special IARIW Conference on Environmental Accounting, Baden 1991.
Fischer-Kowalski, M., Haberl, H., Payer, H., Steurer, A.; Wien (1991)

Band 18
Emissions and Purposive Interventions into Life Processes - Indicators for the Austrian Environmental Accounting System. Paper to the ÖGBPT Workshop on Ecologic Bioprocessing, Graz 1991.
Fischer-Kowalski M., Haberl, H., Wenzl, P., Zangerl-Weisz, H.; Wien (1991)

Band 19
Defensivkosten zugunsten des Waldes in Österreich. Forschungsbericht gem. m. dem Österreichischen Institut für Wirtschaftsforschung.
Fischer-Kowalski et al.; Wien (1991)

Band 20*
Basisdaten für ein Input/Output-Modell zur Kopplung ökonomischer Daten mit Emissionsdaten für den Bereich des Straßenverkehrs.
Steurer, A.; Wien (1991)

Band 22
A Paradise for Paradigms - Outlining an Information System on Physical Exchanges between the Economy and Nature.
Fischer-Kowalski, M., Haberl, H., Payer, H.; Wien (1992)

Band 23
Purposive Interventions into Life-Processes - An Attempt to Describe the Structural Dimensions of the Man-Animal-Relationship. Paper to the Internat. Conference on "Science and the Human-Animal-Relationship", Amsterdam 1992.
Fischer-Kowalski, M., Haberl, H.; Wien (1992)

Band 24
Purposive Interventions into Life Processes: A Neglected "Environmental" Dimension of the Society-Nature Relationship. Paper to the 1. Europ. Conference of Sociology, Vienna 1992.
Fischer-Kowalski, M., Haberl, H.; Wien (1992)

Band 25
Informationsgrundlagen struktureller Ökologisierung. Beitrag zur Tagung "Strategien der Kreislaufwirtschaft: Ganzheitl. Umweltschutz/Integrated Environmental Protection", Graz 1992.
Steurer, A., Fischer-Kowalski, M.; Wien (1992)

Band 26
Stoffstrombilanz Österreich 1988.
Steurer, A.; Wien (1992)

Band 28+
Naturschutzaufwendungen in Österreich.
Gutachten für den WWF Österreich. Payer, H.; Wien (1992)

Band 29+
Indikatoren der Nachhaltigkeit für die Volkswirtschaftliche Gesamtrechnung - angewandt auf die Region.
Payer, H. (1992). In: KudlMudl SonderNr. 1992:Tagungsbericht über das Dorfsymposium "Zukunft der Region - Region der Zukunft?"

Band 31+
***Leerzeichen.* Neuere Texte zur Anthropologie**.
Macho, T.; Wien (1993)

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Metabolism and Colonisation. Modes of Production and the Physical Exchange between Societies and Nature.
Fischer-Kowalski, M., Haberl, H.; Wien (1993)

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Theoretische Überlegungen zur ökologischen Bedeutung der menschlichen Aneignung von Nettoprimärproduktion.
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Steurer, A.; Wien (1994)

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Fischer-Kowalski, M.; Wien (1994)

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Payer, H., unter Mitarbeit von Zangerl-Weisz, H. und Fellinger, R.; Wien (1994)

Band 38
Wasser und Wirtschaftswachstum. Untersuchung von Abhängigkeiten und Entkoppelungen, Wasserbilanz Österreich 1991.
Hüttler, W., Payer, H. unter Mitarbeit von Schandl, H.; Wien (1994)

Band 39
Politische Jahreszeiten. 12 Beiträge zur politischen Wende 1989 in Ostmitteleuropa.
Macho, T.; Wien (1994)

Band 40
On the Cultural Evolution of Social Metabolism with Nature. Sustainability Problems Quantified.
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