



The use of natural resources in the economy

A Global Manual on
Economy-Wide Material Flow
Accounting

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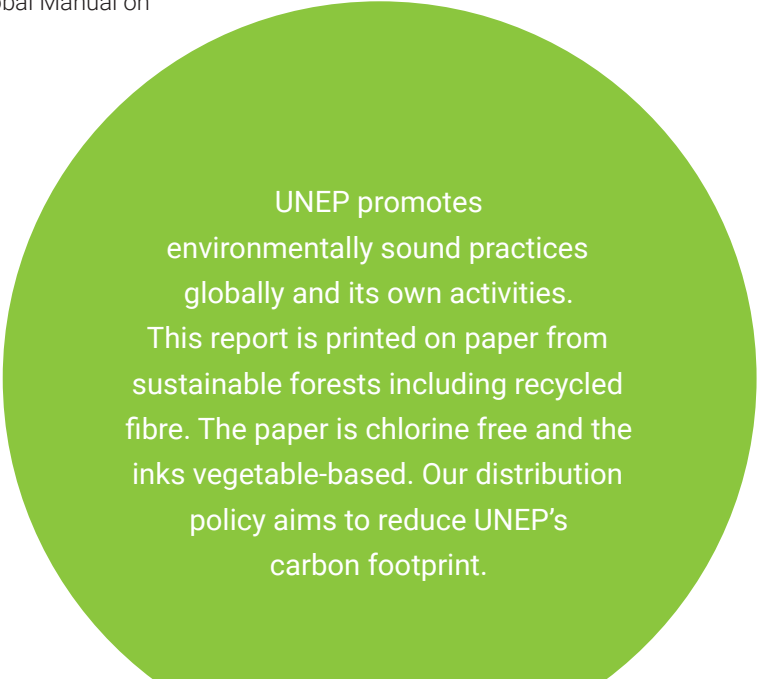
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Foreword



The world has a finite volume of natural resources and a limited ability to produce new resources. Extraction and processing of materials, fuels and food causes 50 per cent of global greenhouse gas emissions and 90 per cent of biodiversity loss and water stress. Our production and consumption are unsustainable, with natural resource use tripling from 1970 and continuing to grow. Therefore, we need to rethink how we exploit resources, how we build our cities and infrastructure, how we grow our food, and how we manage our waste.

In order to sustainably manage these resources, there is a need to identify ways to minimize the use of natural resources while at the same time maximizing the economic growth and social benefit of natural resource use. Developing policy which promotes a circular economy and decoupling economic growth can only be done by tracking how materials are being used and identifying opportunities for improving efficiency, reducing material use and waste, promoting recycling and changing processes.

Material flow accounts provide a statistical framework for measuring natural resource extraction, trade in natural resources, waste disposal and emissions. Domestic material consumption and material footprint, including by extraction type (biomass, fossil fuels, metal ores and non-metallic minerals), are seen as a proxy for overall environmental pressure within a national economy and the impact of a national economy on the environment.

The importance of improving resource productivity and the sustainable use of natural resources underpins the Sustainable Development Goal on Sustainable Consumption and Production (Goal 12) and is specifically recognized in dedicated SDG targets on resource productivity (SDG 8.4) and sustainable use of natural resources (SDG 12.2).

This report builds upon the existing experiences of compiling economy-wide material flow accounts in Europe and provides global guidance on compiling material flow accounts which can be used by national statistical systems around the world. We hope that this will not only be useful for helping countries understand their natural resource use, but that it will also lead to more sustainable economic development, by informing governments so as to design and implement the right policies.

A handwritten signature in black ink, appearing to read 'J. Liu'.

Jian Liu

**Director, Science Division
United Nations Environment Programme**

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Core drafting team

The manual was drafted by a team of technical experts in material flow accounting, including the lead authors, Heinz Schandl (CSIRO), James West (CSIRO), Stephan Lutter (Vienna University of Economics and Business), Nina Eisenmenger (University of Natural Resources and Life Sciences Vienna), Alessio Miatto (Nagoya University) and Myriam Linster (OECD). Jillian Campbell of UNEP led the development of the manual.

The manual was largely based on the existing European Commission compilation guidelines: Eurostat (2018), *Economy-wide material flow accounts handbook*:

<https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-18-006>.

This contribution also builds on the OECD documents: OECD (2008), *Measuring Material Flows and Resource Productivity Volume I. The OECD Guide*:

<https://www.oecd.org/environment/indicators-modelling-outlooks/MFA-Guide.pdf>, and OECD (2008), *Measuring Material Flows and Resource Productivity Volume II. The Accounting Framework*: <https://www.oecd.org/environment/indicators-modelling-outlooks/MFA-Accounting-Framework.pdf>.

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Revision

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Design and layout

Estudio Relativo

Acronyms

AEA	Air emissions account
Al₂O₃	Alumina
AOX	Absorbable organic halogen compounds
BGS	British Geological Survey
BOD	Biological oxygen demand
CH₄	Methane
CLRTAP	UNECE Convention on long-range transboundary air pollutants
CO	Carbon monoxide
CO₂	Carbon dioxide
COD	Chemical oxygen demand
CPC	Central Product Classification
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAP	Diammonium Phosphate
DE	Domestic Extraction
DEU	Domestic Extraction Used
DM	Tonnes of dry matter
DMC	Domestic Material Consumption
DMI	Direct Material Input
DPO	Domestic Processed Output
DTA	Domestic Technology Assumption
EIA	US Energy Information Administration
Eurostat	The European Union statistical office
EW-MFA	Economy-wide material flow accounting
EX	Direct physical exports
FAOSTAT	FAO statistics
FISHSTAT	FAO fishery statistics
GCV	Gross calorific value
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GNI	Gross National Income
GSO	General Statistics Office of Viet Nam
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
HFCs	Hydrofluorocarbons
HS	Harmonized system
IEA	International Energy Agency
IM	Direct physical Imports
INEGI	Instituto Nacional de Estadística y Geografía

IO	Input-Output Model
IOA	Input-Output Analysis
IPCC	International Panel on Climate Change
IRES	International Recommendations for Energy Statistics
LCA	Life Cycle Assessment
LCA-IO	Life Cycle Assessment-Input-Output model
LPG	Liquefied Petroleum Gas
MAP	Monoammonium Phosphate
Mc	Moisture content
MF	Material Footprint of consumption
MRIO	Multi-Regional Input-Output models
N	Nitrogen
N₂O	Dinitrogen oxide
NAS	Net Additions to Stocks
NGL	Natural Gas Liquids
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides
NSO	National Statistics Office
OECD	Organization for Economic Co-operation and Development
OQB	Operator Questionnaire-Based
P	Phosphorus
PAHs	Sum of the four indicator polycyclic aromatic hydrocarbons
PBTs	Persistent, bioaccumulative and toxic substances
PFC	Perfluorocarbons
POPs	Persistent organic pollutants
ppm	Parts per million
PSUT	Physical Supply and Use Table
PTB	Physical Trade Balance
RMC	Raw Material Consumption
RME	Raw Material Equivalents
RME_{IM}	Raw Material Equivalents of Imports
RME_{EX}	Raw Material Equivalents of Exports
RMI	Raw Material Input
ROM	Run of Mine
ROW	Rest of the World
RTB	Raw material Trade Balance
scm	Solid cubic metres
SDGs	Sustainable Development Goals
SEEA	System for integrated Environmental and Economic Accounting
SEEA-CF	SEEA Central Framework
SF₆	Sulphur hexafluoride

SIEC	UNSD Standard International Energy Product Classification
SMS	Secondary Mixed Sources
SNA	System of National Accounts
SO₂	Sulphur dioxide
TMC	Total material consumption
TMR	Total Material Requirement
TOC	Total organic carbon
TOMPs	Toxic Organic Micro Pollutants
UDE	Unused Domestic Extraction
UN	United Nations
UNCEEA	UN Committee of Experts on Environmental-Economic Accounting
UN Comtrade	UN Commodity Trade Statistics Database
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division
USGS	United States Geological Survey

1

Introduction



1 Introduction

1.1 Purpose and policy applications of economy-wide material flow accounts established at the national level

Environmental policy is the specific field of public policy focusing on the interrelationship between socioeconomic processes, natural resource use, the disposal of waste and emissions and the related ecosystem functions. Because of these complex interactions between natural and social systems environmental policymakers require data and information that go beyond traditional economic statistics to be able to deliver policies and programmes that comprehensively address economic and environmental dimensions. Physical accounts provide such additional information in a way that is complementary to economic statistics.

EW-MFA represents a framework for describing the interaction of a domestic economy with the natural environment and the economy of the rest of the world in terms of flows of materials, waste and emissions. As much as possible, EW-MFA principles are aligned to the System of National Accounts with regard to definitions, system boundaries and classifications.

Accounting principles and calculation methods for EW-MFA have been standardized for two decades now and have been implemented in national statistics in a number of countries, most notably European Union Member States. The Eurostat has been instrumental in establishing binding conventions for EW-MFA, and its integration into SEEA. The accounting principles have been laid out in a series of compilation guides which Eurostat has published since 2001. The Eurostat compilation

guide (Eurostat 2018) and the accounting methods have become increasingly refined over time.

EW-MFA based accounts and indicators deliver a very comprehensive overview of natural resource extraction, trade in natural resources, waste disposal and emissions. They measure environmental pressures of natural resource use, and EW-MFA based headline indicators have been used as a proxy for overall environmental pressure and impact of a national economy. For this reason, indicators based on EW-MFA data sets have been adopted for monitoring progress of the 2030 sustainable development agenda and the SDG targets for resource productivity (SDG 8.4) and sustainable use of natural resources (SDG 12.2).

MFA data sets and indicators are part of the work programme of a growing number of national statistical offices globally and the global application of EW-MFA in national statistics, beyond Europe, has required the creation of a global guidance manual. This global EW-MFA manual builds on the experience and excellence of the Eurostat accounting guidelines but extends them in several important ways. The global EW-MFA manual:

- presents a modular approach to EW-MFA to allow national statistical offices with different levels of capability in environmental accounting to establish the accounts
- addresses specific issues of resource-extractive economies and subsistence economic activities

- which are more prevalent in developing countries
- favours practicality before detail and focuses on such methods that allow statisticians to capture the important aspects of material throughput in their economy
- also aims to establish a connection between the EW-MFA established, and the environmental and economic policy questions that can be informed by using EW-MFA based data sets and indicators.

This first edition of the global EW-MFA manual represents an important step towards a global accounting standard. Its objective is to provide guidance to environmental statistics experts in national statistical offices across the globe to build capacity for EW-MFA at the national level and to report progress towards SDG targets 8.4 and 12.2.

The global EW-MFA manual is structured into eight chapters.

- Chapter 1 focuses on general accounting principles, and the relationship to other accounting systems; it describes common data

sources for EW-MFA and introduces the main structure of the manual.

- Chapter 2 presents the core of any EW-MFA, namely the domestic extraction of materials – biomass, fossil fuels, metal ores, and non-metallic minerals.
- Chapter 3 describes the accounting principles and specific issues that occur when establishing material accounts for the trade of goods.
- Chapter 4 focuses on material outflows (from the economy to the environment) such as e.g. waste disposal and emissions and builds a bridge to important environmental policy issues of pollution and toxicity.
- Chapter 5 integrates the input and output sides of EW-MFA in a material flow balance.
- Chapter 6 presents headline indicators from EW-MFA accounts which are most commonly used by the policy community.
- Chapters 7 and 8 discuss additional aspects of EW-MFA: material footprint accounts and material stock accounts. The accounting methods for these are, however, not covered in any detail in this edition of the manual.

1.2 Structure and coverage of the global EW-MFA manual

The global EW-MFA manual provides guidance for national statistical offices for the compilation of simple material flow data sets (also referred to as direct material flow accounts in this manual) that focus on primary material extraction, physical trade (i.e. imports and exports), waste and emissions. The direct accounts treat the national economy as a black box and exclude upstream and downstream material flows associated with trade as well as recycling or reuse flows within the economy, and mobilization of materials that do not enter the economic process. They also do not provide

estimates of the amounts of materials embedded in the stock of buildings and infrastructure. Figure 1.1 shows the simplified structure of EW-MFA.

To make the difference between the direct material flow accounts and additional accounts clear, EW-MFA are structured into six accounting modules that cover specific aspects of the interaction between the economy and natural resources.

- The first module is concerned with Domestic Extraction (DE), and Direct Physical Imports (IM)

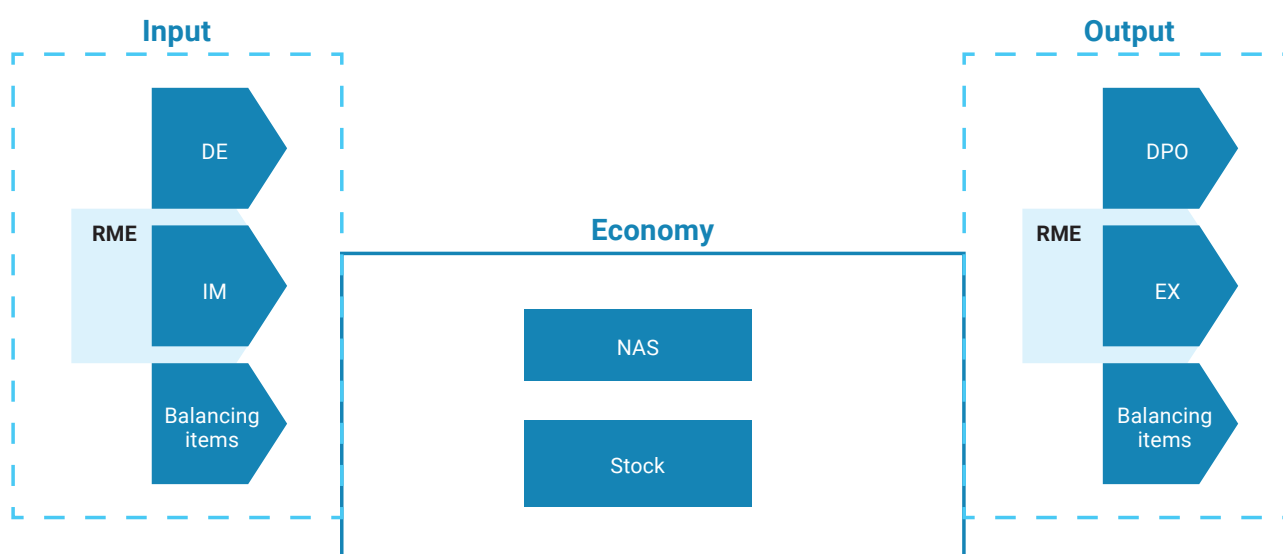
and Exports (EX) of materials (chapters 2 and 3 in this manual).

- The second module focuses on indirect flows associated with imports and exports, i.e. the Raw Material Equivalents of Imports (RME_{IM}) and Exports (RME_{EX}) (chapter 7).
- A third module looks at the output side of the material flow accounts and reports domestic processed output (DPO), i.e. flows of waste and emissions and the gateways through which they leave the economy towards the environment (landfill, soil, water and air) (chapter 4).
- The fourth module measures net additions to stocks (NAS) and may contain a stock account of in-use stock (Stock). It allows for closing

the material flow balance by linking inputs to outputs and introducing a set of balancing items (chapters 5 and 8).

- The fifth module looks at unused extraction that occurs in the context of domestic extraction in a target economy or with regard to raw material extraction related to imports and exports abroad (section 6.3).
- A sixth module would focus on the material flows of different specific industries and would create a true material flow satellite account. It would be related to the full articulation of physical supply and use tables.

Figure 1.1 Simplified structure of EW-MFA.



Each accounting module addresses different policy questions and yields a set of specific headline indicators. These modules are outlined below.

This manual covers module one (in chapter 2 and chapter 3) and module three (in chapter 4) and some limited aspects of module four (in chapter 5). It provides guidance on how to establish data sets for these modules. It discusses module two (in chapter 7) and module four (in chapter 8) but does not provide specific accounting guidelines.

Module 1: Domestic extraction, direct physical imports and exports

Module one is the core of a national material flow data set. It covers DE of materials which are further used in economic processes usually accounted for at the point when the natural resource becomes commoditized and a price is attached¹. This includes biomass, fossil fuels, metal ores, and non-metallic minerals. It also covers IM and EX of goods measured at the volumes at which they cross national boundaries. Imports and exports typically contain products at different stages of processing including unprocessed primary products, processed primary products, simply transformed manufactures and elaborately transformed manufactures. With this information, additional indicators can be derived including a Physical Trade Balance (PTB) and Domestic Material Consumption (DMC) where $PTB = IM - EX$ and $DMC = DE + IM - EX = DE + PTB$. An additional indicator Direct Material Input (DMI) can be calculated where $DMI = DE + IM$.

Module 2: Raw material equivalents of trade and material footprint

Module two focuses on a final demand perspective of material use. It measures the RME_{IM} and RME_{EX} which are the upstream material requirements to produce direct imports and exports. RMEs assume a similar system boundary (point of extraction and commodification) for domestic and traded materials. The Raw material Trade Balance (RTB) is established by subtracting RME_{EX} from RME_{IM} . With this information, the material footprint of consumption (MF) indicator is established. Material footprint attributes global material extraction (wherever it occurs and along the whole lifecycle of natural resources) to final demand in a country where $MF = DE + RME_{IM} - RME_{EX} = DE + RTB$.

Module 3: Material outflows

Module three covers the output side of EW-MFA and records the outflows of materials from the economy to different environmental media. Material outflows include the amounts of waste going to landfills, emissions to air and emissions to water. It allows the establishment of indicators for DPO and for DPO_{land} , DPO_{air} and DPO_{water} where $DPO = DPO_{land} + DPO_{air} + DPO_{water}$.

Module 4: Material balance and stock accounts

Module four is about the amount of materials that are stockpiled in buildings and infrastructure in the national economy. This information is a first step towards physical stock accounts by calculating additions to and outflows from stocks and is a proxy for potential future material flows

¹ While commoditization always indicates that a material is used in the economy, the definition of used in EW-MFA is somewhat broader, as it encompasses, for example, things like crop residues which are removed from the field and used on-farm for things like animal bedding or low/zero market value feeds.

that may become secondary raw materials or waste. Full physical stock accounts require the quantification of accumulated stock in addition to NAS. Physical stock accounts enable comparing materials embedded in man-made capital to natural capital. Stocks are reported by material and asset characteristics, including life tables for major assets.

The calculation of NAS where $NAS = DMC - DPO +$ balancing items on the input and output sides can be done with information from modules one and three. There are different additional ways to account for NAS based on stock and flow modelling.

Module 5: Unused extraction

Module five focuses on unused extraction of materials, i.e. materials that are mobilized but do not enter the economy (see footnote to module 1 above). Unused extraction in volume is often the same size as used extraction but data for unused extraction, if they exist, have a higher range of uncertainty. Unused extraction is mostly not reported in official statistics and requires

estimation techniques and modelling that are not yet internationally standardized.

Module 6: Material flow accounts by industry

Module six is about an industry-by-industry perspective on material flows and opens up the black box of the economy by reporting flows between industries. Module six allows production of full satellite accounts for material flows, an important step which has not been undertaken very often mainly because of the additional data needs. The physical data that underpins the material use of specific industries are often not directly available in official statistics. It would require the formation of a physical supply and use table of the economy (PSUT) to support the establishment of industry-specific accounts for material flows.

In the context of the System of Environmental-Economic Accounting (SEEA) material flow and stock accounts could be related to natural resource accounts which may include forest and fish stocks, fossil fuel and minerals reserves.

1.3 Main accounting principles and relationship to other accounting systems

1.3.1 The SEEA Central Framework and EW-MFA

Environmental accounts describe the total scale of socioeconomic activities in physical quantities but are fully compatible with economic national accounts. Environmental accounts are to be seen as a satellite system to the system of national accounts. Different international statistical frameworks exist to provide conceptual and practical guidance. These include the European Environmental Accounts (Eurostat 2015)

and the UN System of Environmental-Economic Accounting (SEEA; UN 2014), which “is a framework that integrates economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets, as they bring benefits to humanity” (UN 2017).

EW-MFA are a module of the European Environmental Accounts and are conceptually embedded into

the framework of the System of Environmental-Economic Accounting (SEEA; UN 2014) which extends the monetary national accounts by a physical and environmental dimension. The SEEA framework creates a focus on physical interactions between environment and economy including stocks (environmental assets) and flows (physical flows) approach. This allows for a close conceptual relationship between environmental accounts to the System of National Accounts (SNA).

The SEEA Central Framework of 2012 (UN 2014) describes the internationally agreed standard concepts, definitions and accounting principles for internationally comparable statistics of the environment and its relationship with the economy. The SEEA Central Framework builds on the concepts, classifications and definitions of national accounts (UN 2014). The integration of material flow accounts into the SEEA central framework achieves complementarity with national accounting principles to the extent possible. EW-MFA is part of the physical flow accounts (chapter 3) of the SEEA Central Framework and captured under section 3.6.6 'Economy-wide material flow accounts' of the SEEA Central Framework.

The SEEA Central Framework establishes PSUT (in parallel to monetary supply and use tables) as the accounting framework for physical flows. It introduces a set of accounting principles and boundaries that enable internally consistent recording of all types of physical flows that go hand in hand with economic activity. Physical flows covered include energy, water, materials, waste and emissions. The physical flow accounts have two important features that are relevant for material flow

accounting: The accounting framework of physical supply and use tables, and the delineation of three types of physical flows which are natural inputs, products and residuals.

EW-MFA is specifically mentioned in a subsection of the physical flows chapter of the SEEA Central Framework, and many aspects of the physical flow accounts relate quite directly and/or overlap with EW-MFA principles.

The division into natural inputs (domestic extraction of materials), products (traded materials or internal flows) and the division of residuals into waste and emissions according to environmental gateways (water, air and soil) all resonate with EW-MFA terminology and accounting principles.

MFA accounts are not fully articulated PSUT as introduced in the SEEA Central Framework (SEEA-CF). Establishing a full PSUT system would be an extremely time-consuming activity and require levels of reporting on physical flows by specific industries which are either not currently in existence, or not made available, and thus are not made part of EW-MFA.

There are some important differences between the SEEA-CF and the system boundaries of EW-MFA which are especially important in the domain of agriculture, where the SEEA conceptualises agricultural area and plants as part of the economy (cultivated biological resources) and EW-MFA as part of the environment. Consequently, the SEEA treats water, carbon dioxide, and nutrients as a natural input whereas EW-MFA interprets the harvest of crops as natural input.

Similar to the system of national accounts, material flow accounts serve two major purposes. The detailed accounts provide a rich empirical database for many analytical studies. They are also used to compile different extensive and intensive² material flow indicators for national economies at various levels of aggregation. EW-MFA is also closely related to other physical flow modules of the SEEA system, such as the Air Emissions Accounts, Physical Energy Flow Accounts, Water Accounts, etc. EW-MFA concepts, accounting rules and classifications are harmonized as far as possible with SEEA and the above-mentioned sub-modules. A more explicit integration of EW-MFA into the SEEA framework in the future would be worthwhile to yield the full explanatory strength of both approaches.

1.3.2 First national MFA's and international harmonisation of accounting standards

The **first** EW-MFA, in the contemporary sense, were published in the early 1990s for Austria (Steurer 1992), Japan (Ministry of the Environment, Government of Japan 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 EW-MFA indicators, Adriaanse *et al.* (1997) and Matthews *et al.* (2000).

Methodological harmonization has been promoted by the EU since the early 1990s, which led to the publication "Economy-wide material flow accounts and derived indicators: A methodological guide" (Eurostat 2001) and further specification in the

Eurostat Compilation Guide (first published in 2007, and the latest version from 2018; Eurostat 2018). In July 2011 the European Parliament established 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. EW-MFA data for the EU Member States have been published since 2002 by Eurostat and have been part of country reporting routines since 2011. At the international level, Material Flow Accounting has also been addressed by the OECD, where a broader conceptual Guide was published in 2008 (OECD 2008). Finally, sustainable resource use and EW-MFA are significant in the UN International Resource Panel, with three reports based on EW-MFA data published (UNEP 2011; UNEP 2015; UNEP 2016).

Alongside the methodological development, numerous empirical studies have been performed and published. For an overview see Krausmann *et al.* (2017). Since 2000, comprehensive **global data sets** have been available, compiled by research institutes (Giljum *et al.* 2014; Schaffartzik *et al.* 2014b; Schandl and West 2010; Schandl *et al.* 2017) as well as international bodies such as Eurostat (Eurostat 2017) and the UN International Resource Panel (UNEP 2017). Publications by Fischer-Kowalski and colleagues (2011) and Krausmann and colleagues (2017) summarize the state of the art of material flow accounting.

1.3.3 Fundamentals

1.3.3.1 The concept of social metabolism

Economy-wide material flow accounting is conceptually based on a simple systemic model of an economy (referred to as national economy

² Extensive indicators directly measure the magnitude of one variable e.g. total GDP or population, whereas intensive indicators relate one variable to another e.g. GDP per capita.

in the following document) as a biophysical and socioeconomic system embedded in its socioeconomic and biophysical environment.

The term embedded indicates that socioeconomic 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 socioeconomic system is commonly referred to as **social or industrial metabolism** (Ayres and Simonis 1994; Fischer-Kowalski 1998).

The concept of social metabolism (Krausmann *et al.* 2017) describes societies as being in permanent interaction with the natural environment, exchanging material and energy flows. Societies need material and energy in their socioeconomic production and consumption processes to build up, maintain and reproduce their human and livestock populations, as well as man-made artefacts. For this reason, natural resources are extracted from the natural environment, transformed in economic processing, and either accumulated in physical stocks or transformed to wastes and emissions that are released back to the natural environment. Such a system perspective requires that all material inputs must equal material outputs, corrected by stock changes (mass balance principle, (Ayres and Simonis 1994)).

Socioeconomic patterns such as economic production structures, technology, lifestyles, cultural characteristics, etc. shape these society-nature interactions and environmental problems occur as a result of the quantity and quality of physical flows, both on the input side and the output side. The natural environment serves two functions, i.e. as a source of natural resource inputs and a sink for outputs in the form of wastes and emissions.

1.3.3.2 Conventions of Material Flow Accounts

MFA covers all flows of solid, gaseous and liquid materials except for bulk water and air that enter and/or leave the economy; the unit of measurement is metric tonnes per year. For the purposes of EW-MFA compilation, the specific socioeconomic system under investigation is the national economy into or out of 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 (SEEA; UN 2017). 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. 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 EW-MFA and balances. This means that the national economy is treated as a black box in EW-MFA and, for example, inter-industry deliveries of products are not described.

1.3.3.3 Used and unused domestic 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, 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 EW-MFA on purpose and by means of technology but not for use” (Eurostat 2001, p.20). Examples of unused extraction are soil and rock excavated during construction or overburden from mining, unused parts of tree cutting in forestry, unused by-catch in fishery, unused parts of the straw harvest in agriculture, and natural gas flared or vented. The commonly used term “domestic extraction” – abbreviated as 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 publications on EW-MFA “unused extraction” is also called “hidden flows”. This manual does not include unused extraction.

1.3.3.4 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 over a time period**, whereas a **stock** is a variable that measures a **quantity at**

a point in time. EW-MFA is a pure flow concept. It measures the flows of material inputs, outputs and stock changes within the national economy in the unit of metric tonnes per year. This means that stock changes are accounted for in EW-MFA but not the quantity of the socioeconomic stock itself.

Although EW-MFA is a flow concept, it is still important to carefully define what is regarded as a material stock of a national economy because additions to stocks and removals from stock are essential parts of the EW-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. This leads to an alternative definition of the system boundary. Input flows are all material flows that serve as inputs to produce or reproduce socioeconomic material stocks measured at the point where they cross the EW-MFA specific system boundary. Output flows are discharges into the environment of the focal socioeconomic system. This implies that they are measured at the point where society loses control over the further location and composition of the materials.

In EW-MFA, **three types** of socioeconomic material **stocks** are distinguished: artefacts, animal livestock, and humans. **Artefacts** are mainly man-made fixed assets as defined in the national accounts such as infrastructure, 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 material stocks in EW-MFA.

Also, the **human population** and **animal livestock** are regarded as socioeconomic stocks in EW-

MFA. This means that for a full national material balance not only all food and feed (including non-marketed feed such as grass directly consumed by ruminants on pastures) but also the respiration of humans and animals must be taken into account as material inputs and outputs (most importantly, carbon dioxide (CO₂) emissions).

Theoretically, the calculation of net stock changes should also include changes in human population and animal livestock. However, experience shows that these stock changes are very small compared to, for example, stock accumulation through buildings, machinery or consumer durables. In practice, therefore, changes in human population and animal livestock are often ignored.

As a consequence of this definition of socioeconomic stocks, some material stocks are considered natural and not socioeconomic despite being part of the economic production system. This applies to **agricultural plants and forests**³, including cultivated forests, and to **fish stocks** (unless they are cultivated in aquaculture). It is indeed not the socioeconomic importance of the stock that determines its attribution to the socioeconomic 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 (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 socioeconomic system is intended to follow a gradient of colonization intensities. The livestock production system can be considered a more intensively colonized system than the plant and timber production system in many cases, although extensive rangeland grazing systems are clearly much less intensive than a plant production system such as paddy rice cultivation.

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, CO₂ 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, CO₂ 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. Finally, the meaning of material extraction as a pressure indicator, which serves as a proxy for the resulting environmental impact, would be lost. Forest growth would be interpreted as an “increase in material use”. It is hard to imagine how such data could possibly be interpreted in a meaningful way, given

3 According to UN SEEA forests are regarded a socioeconomic 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 a memorandum item in EW-MFA.

the limitations of a black box accounting system such as EW-MFA.

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 socioeconomic stocks, which means that treatment of these stocks is an activity within the socioeconomic system. Any leaking of substances into the soil or water vapour exhausting from organic wastes, in particular, should be considered outputs to nature. In practical

terms, these flows are considered small and thus negligible. Aquaculture systems should also be treated as socioeconomic stocks. In this case, not the fish production but the nutrients and other inputs as well as the outputs in wastes would have to be taken into account.

1.3.3.5 Material balance principle

As EW-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)

THE MASS BALANCE PRINCIPLE CAN BE FORMULATED AS:

$$\begin{aligned}\text{INPUT} &= \text{output} + \text{additions to stock} - \text{removals from stock} \\ &= \text{output} + \text{net stock changes}\end{aligned}$$

it is a sufficiently appropriate formulation for the material exchange relations of macro systems.

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.

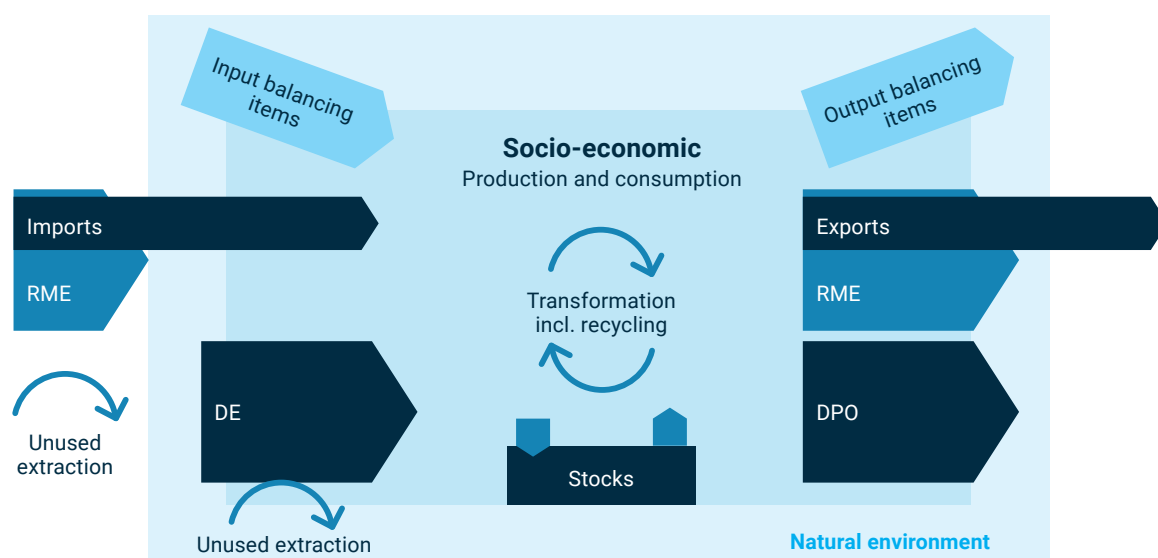
In EW-MFA, the mass balance principle is used to check the **consistency** of the accounts. It also provides one possibility to estimate NAS. It has to be noted, though, that the compilation of a full national material balance is not inevitably the outcome of an economy-wide material flow

account. Often partial accounts are compiled, mostly focusing on the input side and trade flows.

1.3.3.6 Typology of flows

Figure 1.2 provides a schematic representation of the material flow accounting framework and its main flow categories. All flows that cross the border of the socioeconomic system are called direct flows. In Figure 1.2 these flows are coloured in dark blue.

On the **input side** we distinguish between DE, imports, and the input balancing items comprising those water and air inflows that must be taken into account in order to complete the material balance (mainly in combustion processes). On

Figure 1.2 Schematic representation of EW-MFA**Legend**

DE = domestic extraction; DPO = domestic processed outputs, i.e. wastes, emissions, dissipative uses and losses;
RME = raw material equivalents

Source: (Matthews et al. 2000, modified).

the **output side**, we distinguish between exports, 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, with the respective table(s) of UNEP's EW-MFA Compiler (see Annex 1) noted in brackets:

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. These materials consist of biomass, non-metallic minerals (sometimes also termed construction and industrial minerals), metal ores and fossil fuels. On 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 standardized water content of 15 per cent.

Direct physical imports and direct physical exports (Tables B and C respectively): These aggregates cover all imported or exported commodities in tonnes. Traded commodities comprise 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, infrastructure and materials incorporated into durable goods with a lifetime 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 are disposed of (removals). These decommissioned materials, if not recycled, are accounted for in DPO. Net additions to stock are therefore not calculated by balancing additions to stock and stock depletion (as the arrows in Figure 1.2 would suggest) but as a statistical balance between inputs and outputs. Apart from materials going into stocks in the use phase, products can also be put into stocks before being used or traded. This 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 has barely been observed in any industrialized countries, where stock changes mainly refer to increases in infrastructure and buildings.

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 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 socioeconomic stock), material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Also, materials such as fertilizers, which are deployed to ecosystems intentionally, have to be 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 outputs (nor inputs).

Input and Output balancing items: (Table E): Although bulk water and air flows are excluded from EW-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

$$\text{DE} + \text{Imports} + \text{Input Balancing Items} = \text{Exports} + \text{DPO} + \text{Output Balancing Items} + \text{NAS}$$

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. In the compilation of these flows, only a few quantitatively important processes are taken into account and the flows are estimated using generalized stoichiometric equations.

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

Apart from these direct flows, further flows can be considered in a broader EW-MFA view. These are: **unused extraction** associated with direct extraction activities (see section 1.3.3.3), and **upstream material use** associated with imports and exports (Eurostat 2001). The latter are usually termed RME

of imports and exports. Neither flow enters the focal socioeconomic system but the first, unused extraction, remains within the natural system, and the second, RME, remains in foreign economies.

To denote the upstream requirements of used extraction associated with imports or exports the term **RME** was coined (Eurostat 2001). With a consideration of upstream material use, global raw material extraction associated with final demand in a particular country can be calculated; this indicator is named **Material Footprint** (MF; Wiedmann *et al.* 2015) or **Raw Material Consumption** (RMC; Eisenmenger, Fischer-Kowalski and Weisz 2007; Muñoz, Giljum and Roca 2009; Schaffartzik *et al.* 2014a; Schoer *et al.* 2012). Methods to account for RME have developed fast in the past few years and can be grouped into three different approaches:

(1) single-region approaches, which apply material use patterns of domestic production (termed as domestic technology assumption, DTA) to imports (see examples; Muñoz, Giljum and Roca 2009); (2) multi-regional input-output models (MRIO), which integrate national IO models into one world model (see examples; Bruckner *et al.* 2012; Tukker *et al.* 2014; Wiebe *et al.* 2012; Wiedmann *et al.* 2015); (3) hybrid Life Cycle Assessment-Input-Output model (LCA-IO) approaches, which use the DTA approach but apply **Life Cycle Assessment** (LCA) coefficients to those imports that are not, or not sufficiently, represented by domestic IO structures (see examples; Schaffartzik *et al.* 2014a; Schoer *et al.* 2012; Weinzettel and Kovanda 2009). The different calculation methods provide varying results (Eisenmenger *et al.* 2016), thus, the development of methods is still ongoing.

1.4 Common data sources for national EW-MFA

The quality of data available to construct EW-MFA will vary greatly between the different material categories. For this reason, each of the detailed sections dealing with individual material categories has its own subsection on typical data sources for that material. This introductory section deals instead with a few illustrative examples and overarching guidelines.

Relatively good data on material flows in physical units tend to be available where an international agency exists which has been specifically charged with assembling data for that material, where the material is relatively easy to measure in physical terms, and where the individual country concerned has accorded some priority to complying with the reporting requirements of that agency. Perhaps the best example of this is for fossil fuels. As a general

rule, material flows that have a high economic value such as fossil fuels and metals or agricultural products are well documented whereas material flows that have a low unit value such as sand and gravel or waste flows are less well documented.

In a national context, several existing statistical datasets will be available to be utilized for the national-level EW-MFA. They include:

- Agriculture, forestry and fishery statistics – for domestic extraction of biomass including crops, timber and fish;
- Mining and quarrying statistics, energy statistics and industry statistics – for the domestic extraction of fossil fuels, metal ores and non-metallic minerals;
- Trade statistics – for traded primary materials,

semi-manufactured products and final goods;

- Waste statistics – for waste flows to land and water;
- Emissions inventories – for emissions to air.

These datasets are of varying quality and completeness and usually cover a time series that may cover many decades enabling the documentation of trend over time. **It is a good first step to investigate what kind of data is available in a national statistical office or other national institutions responsible for data collection. Such a qualitative pre-assessment helps to establish a suitable level of ambition and to test the practicality of establishing a material flow account at the outset.** Similar statistical databases exist internationally and they are built from the national datasets.

The International Energy Agency (IEA) has designed a system of energy flow accounting for individual national economies, and over two-thirds of the world's nations are reporting according to this scheme. Anyone seeking to compile EW-MFA for fossil fuels in a country that already reports to the IEA can be fairly confident that a domestic agency is already assembling data more than adequate for that purpose.

For biomass, the situation is good for many components such as major crops and crop products, livestock and animal products, forestry products and fish. This is because the Food and Agriculture Organization (FAO) of the United Nations collates and makes available such information via FAOSTAT portals. Where FAO data come from data compiled by a country's domestic agencies, it is flagged as official data, indicating to the compiler that the data should be directly available. Otherwise, the FAO commonly makes its own estimates, and the compiler will need to make their own judgement as to whether they can derive better estimates locally.

Where components are very difficult to measure directly, e.g. grazed biomass, the FAO will typically not have direct data. However, data reported to the FAO for animal products or livestock numbers are still likely to be useful for a compiler, as input data for making an estimate. In this example, the compiler would then need to find additional data on the grazing required per animal, or per kg of animal product, to complete the estimation process. Such data may be available from domestic agricultural agencies, or research institutions.

The situation for metal ores is much less favourable, as there is no real equivalent of the IEA or FAO. Agencies such as the United States Geological Survey (USGS) and the British Geological Survey (BGS) do collect data on metal production, and in some cases ore production. Unfortunately neither institution appears to have the level of systematic international response to questionnaires as the IEA or FAO, and the problem of accounting for metal ores has some inherent difficulties not shared by other materials. There is even less data on trade in metal ores available from the USGS and BGS, so it is likely that the best data currently being assembled in many countries is that for reporting to the United Nations Trade Statistics Database (UN Comtrade). The chapter on metal ores goes into detail on a proposed remedy for this generally poor data situation, one which relies on establishing new reporting systems at the local level.

The data situation for non-metallic minerals is generally poor as well. Not only are there no international agencies specializing in systematically collecting and collating most of these data, but the largest individual components of non-metallic minerals flows are often very low unit value (\$ per kg) materials. Construction aggregates in particular, while huge in total volume, are often extracted by many small individual operations,

frequently operating in the informal economy. While some have assembled good accounts, these tend to be high-income countries with well-resourced National Statistics Offices (NSOs). Less commonly, a low-income country will make a major effort to ensure compliance with reporting the extraction of such materials. Fiji provides a salient example here, demonstrating that there is no fundamental difficulty in assembling good accounts for this category if the government makes it a priority. In the absence of such government prioritization, it is likely that direct data will only be systematically recorded by individual operations for higher value, lower volume components such as chemical and fertilizer minerals, cement, etc. Volumes of low unit value items will probably need to be estimated by applying factors to more valuable associated flows, e.g. construction aggregates can be estimated from cement consumption, clay extraction from brick production.

Trade data is usually available in national trade statistics. It is different from extraction data in that it includes material flows at all stages of material processing from primary materials, semi-manufactures and final goods. Trade data is reported in mixed units which can either be tonnes, volumes, or other physical units (such as e.g. sheets, packets, or numbers). In some cases, the reporting is confined to monetary values and does not provide a physical measure at all. All different units need to be converted to metric tonnes which is often a time-consuming process. A first step would be to establish a reliable account of imports and exports of primary materials which in many cases would cover more than 80 per cent of the total (physical) trade volumes.

Data on waste and emission is usually covered by traditional environmental reporting with the best data quality for emissions to air (which can easily

be linked to technical processes transforming resource inputs into energy outputs). There is usually a lack of reliable data for emissions to water and in many countries waste data can also be of quite poor data quality.

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2

Domestic Extraction



2 Domestic Extraction

2.1 Biomass

2.1.1 Introduction

Biomass comprises organic non-fossil material of biological origin. It is an abundant and ubiquitous resource and all countries extract biomass. The largest share of the extracted biomass is used as food for humans and feed for livestock. In these applications biomass is a non-substitutable resource. Biomass is further used to provide technical energy (e.g. fuelwood) or as raw materials (e.g. textiles, paper and construction wood). For most of human history biomass was the main material resource for more than 95 per cent of all material input. Since industrialization, the share of biomass in material use has been declining to less than 30 per cent in most industrial countries, while the overall global extraction and use of biomass has been increasing. The global demand for biomass is rising due to population growth, changing diets and in recent years also due to the production of biofuels and the shift to biotic raw materials in the context of climate change mitigation and bio-economy strategies.

According to EW-MFA conventions, DE of biomass includes all biomass of vegetable origin extracted by humans and their livestock, capture of wild fish, and the biomass of hunted animals. Biomass of livestock and livestock products (e.g. milk, meat, eggs, hides) is not accounted for as domestic extraction but considered as flows within the economic system.

Biomass accounts for 30 per cent of total global DE (Schandl *et al.* 2017). Values of biomass extraction average at 3 t/cap/yr globally and range between 0.1 t/cap/yr and 20 t/cap/yr in countries. In the global average, the share of crops in total harvest amounts to 35 per cent, crop residues 20 per cent, fodder crops and grazed biomass 32 per cent, and wood 10 per cent. Fishing and hunting and gathering are of minor quantitative importance in most countries. 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 and high livestock numbers per capita (Krausmann *et al.* 2008).

The largest share of biomass is used domestically; only 10 per cent of global DE is traded internationally. The share of exports in global DE is, however, increasing rapidly, particularly for certain products (e.g. soybeans, wheat, fruits) and in some countries trade flows may be large. Countries with high population density typically have higher dependence on biomass imports while sparsely populated countries are often net exporters of biomass.

The production of biomass is related to a broad range of environmental problems comprising issues related to the expansion of agricultural areas and the intensity of land use. The expansion of farming drives deforestation and the loss of natural grasslands and other ecosystems. Land-use intensity involves, for

example, the use of agrochemicals, machinery and irrigation water. This may cause erosion and soil degradation, groundwater depletion and pollution and biodiversity loss. Farming is further considered

a major contributor to Greenhouse Gases (GHG) emissions, with emissions stemming from a range of processes such as land conversion, livestock husbandry, fertilizer application and fossil fuel use.

Table 2.1 Classification of domestic extraction of biomass.

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
A.1 BIOMASS	A.1.1 Crops	A.1.1.1 Cereals	A.1.1.1.1 Rice
			A.1.1.1.2 Wheat
			A.1.1.1.3 Maize
			A.1.1.1.4 Cereals n.e.c.
		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 Spice, beverage, pharmaceutical crops	
		A.1.1.11 Tobacco	
		A.1.1.12 Other crops n.e.c.	

Table 2.1 Classification of domestic extraction of biomass. (Cont.)

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
A.1 BIOMASS	A.1.2 Crop residues (used), fodder crops, grazed biomass	A.1.2.1 Straw	
		A.1.2.2 Other crop residues (sugar and fodder beet leaves, other)	
		A.1.2.3 Fodder crops (incl. harvest from grassland)	
		A.1.2.4 Grazed biomass	
	A.1.3 Wood	A.1.3.1 Timber (Industrial roundwood)	
		A.1.3.2 Wood fuel and other extraction	
	A.1.4 Wild harvest n.e.c.	A.1.4.1 Wild fish catch	
		A.1.4.2 All other wild aquatic animals catch	
		A.1.4.3 Wild aquatic plant harvest	
		A.1.4.4 Wild terrestrial plant harvest n.e.c. (incl. gathering)	
		A.1.4.5 Wild terrestrial animal catch (incl. hunting)	

Note: These items are compiled in Table A of UNEP's EW-MFA Compiler (see Annex 1).

2.1.2 Data sources and availability

Statistical reporting of biomass extraction has a long tradition. Most fractions of biomass harvest are reported by national statistical offices or national institutions concerned with agriculture, forestry and fisheries in their series of agricultural, forestry, and fishery statistics. The accounting frameworks for biomass harvest are well established and show a high degree of international standardization and accuracy. Both national and international

data sources generally cover the harvest of all types of crops (1.1) and wood (1.3), and biomass extraction by fishing and hunting activities (1.4). In some cases even crop residues (1.2.1 and 1.2.2), harvested fodder crops and biomass harvested from grassland (1.2.3) are reported in statistical sources. Grazed biomass (1.2.4) is not usually estimated by official statistics. For these items, which are usually of high quantitative significance, this guide provides standard estimation procedures.

The most consistent international source of data on biomass extraction is the statistical database provided by the United Nations Food and Agricultural Organization⁴ (FAOSTAT). FAOSTAT covers a huge range of data concerning agriculture, forestry, fisheries, and the land use and food system in general at the level of nation states and in time series from 1961 onwards. The structure of the EW-MFA tables is compatible with the data provided by the FAO.

As a first step, compilers should check data availability by reviewing which data sets are compiled by national agencies in compliance with (international) regulations. FAO provides data on

crop production, forest production and fisheries for all countries in the world. Wherever possible these data are based on information reported by countries. A download from FAOSTAT data (see “flags”) also reveals which data points are based on officially reported data and which are based on FAO estimates. In cases where FAOSTAT reports official data, there has to be a local source collecting and reporting official data to the FAO; this office can be contacted to provide data directly.

A decision tree to help work through alternative data sources preferentially is presented in Figure 2.1.

Figure 2.1 Decision tree for biomass extraction accounts.



4 <http://www.fao.org/faostat/en/#home>

In general, data reported to FAO contain a considerably higher level of detail than required for the EW-MFA. Hence, the reported data can be used to populate the EW-MFA and as data inputs for estimations procedures described below. The detailed data on livestock, land use and commodity balances provided in FAOSTAT are also important for providing input data for the estimation procedures described below and, in general, for a deeper understanding of the physical structure of the economy.

2.1.3 Accounting methods and practical guidelines for data compilation

2.1.3.1 MFA conventions

Terminology and classification: The terminology and classification of biomass items and aggregates used in this guide generally follow the terminology used by the FAO but 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 per cent of fresh living plant biomass. However, the moisture content is variable across plant parts, 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. haymaking). In accordance with agricultural statistics, biomass is accounted for at its “as is weight” at the time of harvest. In the case of the categories 1.2.3 fodder crops, 1.2.4 grazed biomass and 1.3 wood, the moisture content is standardized to 15 per cent according to EW-MFA conventions.

Primary harvest and crop residues: In many cases, the harvested primary product of a crop is only a fraction of total plant biomass. However, the

remaining crop residue or a certain fraction of it may be subject to further socioeconomic use and is also accounted for in EW-MFA. The most prominent example of this is (cereal) straw, which may be used as bedding material for livestock, feedstuff, for energy generation or as raw material used for other purposes. This also applies to wood harvest, where felling and removals are distinguished. Crop residues which are ploughed into the field or burned are not accounted for as DE.

Livestock: According to EW-MFA system boundaries and conventions, livestock is considered an element of the physical compartment of the socioeconomic system (stock). 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 capture of wild fish (excl. aquaculture), which are considered an extraction from the natural environment and, therefore, 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 crops (A.1.1), crop residues used for feed, fodder crops, grassland harvest and grazed biomass under A.1.2.

2.1.3.2 - A.1.1 Crops

The harvest of crops is comprised of the 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 and 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 crops (including fruits and nuts from permanent cultures). In most countries, the number of crops will be much smaller; for European countries, it typically ranges between 30 and 50.

Data on the extraction of crops are provided in good quality by national and international statistical sources and can be used directly for EW-MFA compilation without further processing. With respect to aggregation of the harvest of individual crops to the 4-digit level, we follow the classification scheme suggested by the FAO which is also compatible with the Central Product Classification (CPC) classification. The FAO correspondence table in UNEP's EW-MFA Compiler (see Annex 1) lists all common crop types (1.1.1 to 1.1.12). Crops not identified in this list but reported by national statistics should be classified with regard to the 4-digit level or, if this is not possible, subsumed under 1.1.12 (other crops) (e.g. flowers or nursery products).

The basis on which weight of A.1.1 crops should be recorded is the "as harvested" basis used by the FAO. This is noteworthy as it means that different varieties of crops will have very different dry matter: moisture ratios.

Note on subsistence production: In most countries, statistical data on crop production is based on information on land in farms and/or sown areas. A threshold for the minimum size of farm holdings may be applied in statistical reporting and data on agricultural land use may be fragmentary or of poor quality. In countries with a high significance of small-scale subsistence production official data may therefore underreport crop harvest. Also, the harvest from kitchen gardens is typically not included in harvest statistics. While in most industrial countries this is a comparatively small flow, it may contribute considerably to the food supply in low-income countries.

In cases where underreporting is likely, consult with the national institutions and experts responsible for agricultural and forestry statistics to get information on the completeness of the reported data.

2.1.3.3 - A 1.2 Crop residues (used), fodder crops, grazed biomass

A 1.2.1 and 1.2.2 Crop residues (used)

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., is often 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. Only the used fraction of crop residues is accounted for as DE. In many countries, this is a considerable flow which may account for 10 to 20 per cent 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:

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

1.2.2 All other crop residues: this can, for example, include tops and leaves of sugar crops.

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 cases where national statistics provide data on the used fraction of crop residues, these can directly be used for EW-MFA compilation without further processing. For most countries, however, crop-residue production and the

fraction recovered for socioeconomic use will have to be estimated:

Step 1: Identification of crops which provide residues for further socioeconomic use. In most cases this will include cereals (1.1.1), sugar crops (1.1.3) and some oil bearing crops (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 used to estimate the total amount of crop residues available is based on assumed relationships between the primary harvest, and associated residues for 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. These relations are specific to individual cultivars. They will be subject to change however due to variation in environmental conditions (e.g. weather), and over time as selective breeding aims to maximize the primary crop portion of different cultivars. Using these relationships, it is possible to estimate total biomass residue from primary crop harvest (equation (1)). In the absence of national information, the average harvest factors for crops in different world regions provided in Table 2.2 can be used.

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

Table 2.2 Standard values for harvest factors (a) and recovery rates (b) for common crop residues.

	E. ASIA	E. EUROPE	LATIN AMERICA AND THE CARIBBEAN	N. AFRICA W. ASIA	N. AMERICA OCEANIA	S. AND C. ASIA	SUB-SAHARAN AFRICA	W. EUROPE
A) HARVEST FACTORS. CROP RESIDUE [t (as is weight)] = PRIMARY CROP HARVEST [t (as is weight)] * 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	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sugar Cane	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16

Table 2.2 Standard values for harvest factors (a) and recovery rates (b) for common crop residues. (Cont.)

	E.ASIA	E. EUROPE	LATIN AMERICA AND THE CARIBBEAN	N. AFRICA W. ASIA	N. AMERICA OCEANIA	S. AND C. ASIA	SUB- SAHARAN AFRICA	W. EUROPE
Sugar Beets	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
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
Canola seed, oil crops	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9
B) RECOVERY RATES: USED CROP RESIDUES [t (as is weight)] = AVAILABLE RESIDUES [t (as is weight)] * 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 n.e.c.	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

Table 2.2 Standard values for harvest factors (a) and recovery rates (b) for common crop residues. (Cont.)

	E.ASIA	E. EUROPE	LATIN AMERICA AND THE CARIBBEAN	N. AFRICA W. ASIA	N. AMERICA OCEANIA	S. AND C. ASIA	SUB- SAHARAN AFRICA	W. EUROPE
Sunflower Seed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Canola seed	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Source: Based on data provided in the supporting information to Krausmann *et al.* (2013) and Wirsenius (2000).

Step 3: Estimation of fraction of used residues

In most cases, only a fraction of the total available crop residue will be recovered and subject to further use. The fraction of residues used (recovery rate) can be estimated based on expert knowledge, or from country-specific studies on crop residue use. In cases where no reliable information is available, the recovery rates provided in Table 2.2 can be applied, but note that these are only rough approximations. Furthermore, recovery rates may vary considerably across countries within a region, and over time. The amount of used crop residues is calculated using equation (2).

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

2.1.3.4 – A.1.2.3 and A.1.2.4 Fodder crops (incl. biomass harvest from grassland) and grazed biomass

These categories subsume 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 agricultural 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, grass harvested for silage or hay). Where national feed balances exist, estimates of biomass harvested from grassland and grazed biomass can be derived.

In cases where no reliable data for both fodder crops (1.2.3) and grazed biomass (1.2.4) exist, method A or B in section 1.2.4 can be used to estimate total roughage demand. In that case, no extraction is reported under 1.2.3, with the estimate for total roughage demand reported under 1.2.4

1.2.3 Fodder crops (incl. biomass 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, soybeans etc. which may also be used for food production or as industrial raw materials are not included in this category, since they are accounted for under A.1.1 crops. Fodder crops are often reported by national agricultural statistics. The FAO, however, stopped reporting fodder crops with the recent restructuring of the FAOSTAT database. In

some cases, standardization of moisture content is required:

Step 1: Fodder crops which require standardization of moisture content must be identified. Note that grass-type fodder crops and biomass harvested from meadows 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 EW-MFA conventions, these fodder crops must be accounted for at air dry weight, i.e., at a standardized moisture content of 15 per cent. In cases where 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 unit area. The yield of grass type fodder crops at air dry weight [t/ha/yr] is typically in the range of 2 to 3 times the yield of cereals (e.g. wheat or barley). The yields of fodder crops at fresh weight are much higher (roughly 5 to 15 times the yield of cereals).

Step 2: The weight of fodder crops, where reported in fresh weight (i.e. at a moisture content of 60 per cent to 80 per cent), must be reduced to a moisture content of 15 per cent by applying equations (3) and then (4):

$$(3) \text{Factor}_{\text{mc}} = (1 - \text{mc}_{\text{fresh}}) / 0.85$$

$$(4) \text{Air dry weight (at 15\% mc)} = \text{fresh weight (at e.g. 80\% mc)} * \text{Factor}_{\text{mc}}$$

1.2.4 Grazed biomass

Biomass grazed by livestock 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 EW-MFA; note that 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 equations (3) and (4). If no information on grazed biomass is available from statistical sources two estimation methods are available:

- A. Estimation of grazed biomass based on roughage intake per head
- B. Estimation of grazed biomass based on feed conversion efficiency

Estimation method (A) requires data on livestock numbers. Such data is available for many countries from livestock censuses, and usually of reasonable quality. Roughage demand is calculated using coefficients for average daily feed intake per head. Estimation method (B) requires data on the output of meat and milk, and coefficients for the feed required per kg of product output. While this method is more sensitive to changes in productivity over time, the data and coefficients are often less robust than those required for method (A).

Method A: Estimation of grazed biomass based on roughage intake per head

Data on livestock numbers are usually reported in the national agricultural statistics of most countries, and are also available from FAOSTAT. It is usually of reasonable quality. Using this data in combination with the average roughage intake of grazing animals, the demand for grazed biomass (and other roughage) can be estimated. Note that daily biomass intake through 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). It may therefore vary considerably within one species, 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 a description of a more detailed feed balances). Table 2.3 shows the range of roughage

uptake by livestock species in different production systems and Table 2.4 shows averages for various livestock species for different world regions.

Table 2.3 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)	1–2	4–6
Sheep and goats	0.43	0.64
Horses	3.0	4.3
Mules and asses	1.8	2.6a

Values represent annual intake of air dry weight biomass (15% mc) in t / head and year

Sources: The values are derived from national feed balances and literature (BMVEL 2001; Hohenecker 1981; Wheeler *et al.* 1981; Wirsenius 2000).

Table 2.4 Estimate of annual roughage intake by grazing animals.

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
Cattle and buffalo	1.2	4.5	2.8	5.9	5.9	2.0	3.6	4.1	3.0
Sheep and goats	0.3	0.6	0.3	0.6	0.6	0.3	0.3	0.4	0.3
Horses	2.8	4.0	3.4	4.1	4.2	3.0	3.5	4.3	3.2
Mules and asses	1.7	2.4	2.0	2.5	2.5	1.8	2.1	2.6	1.9

Data refer to 2010; roughage intake includes grazed biomass, hay and forage crops, values are given in t (at 15%mc) /head/year. Intake of market feed and crop residues is already discounted for.

Source: Derived from Krausmann *et al.* (2013).

The values refer to air dry weight (i.e. at a moisture content of 15 per cent) and 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 (on a dry matter basis, average across all species) ranges between 5 and 50 per cent. The coefficients in Table 2.3 and Table 2.4 can be used to calculate total roughage requirement for each species of roughage consuming livestock (equation (5)).

(5) Roughage requirement [t at 15% mc] = livestock [number] * annual roughage intake [t at 15% mc per head and year]

Roughage uptake may be covered from grass type fodder crops, hay or silage or from grazing. To estimate biomass uptake by grazing, total roughage uptake has to be reduced by the amount of available fodder crops and biomass harvest from grassland (item 1.2.3) (equation (6)).

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

Method B: Estimation based on feed conversion efficiency

Data on primary animal products, such as meat and milk, is commonly available from national agricultural statistics, and/or from FAOSTAT. For developing countries in particular, however, such data is probably less certain than livestock numbers. By applying appropriate feed conversion coefficients (feed demand per unit of product) to the animal product data, demand for feed, and subsequently also grazed biomass, can be estimated. It is important that the feed conversion

coefficients applied take the demographic structure of the herd into account. This means, for example, that in addition to feed consumed by the milk-producing dairy cows, the feed required by the calves, heifers and steers required to maintain the herd must be taken into account. Domestic production of animal products should be further corrected for trade in 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 consumed in the exporting rather than importing country. Therefore, the carcass weight equivalent of imported and exported live animals should be subtracted or added, respectively, from domestic meat production. FAOSTAT provides data on indigenous meat production which are corrected for traded animals⁵. One source of underestimation using this method results from the use of livestock for services other than meat and milk. Low-income countries in particular use a significant share of cattle and buffalo as draught animals. The feed used to provide these services will not be accounted for using this method.

Meat should be reported in terms of carcass weight, and milk in terms of whole milk production. The first step is to calculate the feed required to produce each type of primary animal product using the conversion coefficients given in Table 2.5 (or superior locally derived coefficients if available) and equation (7). In a second step, the share of roughage (fodder crops and grazed biomass) in total feed is calculated using equation (8), applying the region-specific shares of roughage in feed provided in Table 2.6, or superior locally derived coefficients if available. If information on the harvest of fodder crops (grasses, legumes, corn for

⁵ The indigenous production of meat relates to indigenous animals, i.e. they include the meat equivalent of exported live animals and exclude the meat equivalent of imported live animals. <https://www.fao.org/faostat/en/#home>

silage) is available, the mass of available fodder crops must be subtracted from total roughage demand, to arrive at the amount of grazed biomass (equation (9)).

(7) Feed requirement for product i [t at 15% mc]
 = product i [t as is weight] * feed conversion coefficient product i [t/t]

(8) Roughage demand product i [t at 15% mc] =
 Total feed requirement i [t at 15% mc] * share of roughage [%]

(9) Grazed biomass [t at 15% mc] = Roughage

demand [t at 15% mc] – fodder crops [t at 15% mc]

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 2.3.

Table 2.5 Feed conversion coefficients.

		SOUTH & CENTRAL ASIA	EAST EUROPE	NORTH AFRICA & WEST ASIA	NORTH AMERICA & OCEANIA	WEST EUROPE	SUB- SAHARAN AFRICA	LATIN AMERICA & CARIBB.	EAST ASIA
Cattle meat	t/t carcass	56.4	18.1	17.1	14.9	14.3	42.2	29.9	35.4
Cow milk	t/t milk	1.6	1.1	1.6	0.8	0.8	3.3	1.5	1.2
Sheep and goat meat	t/t carcass	112.9	36.2	64.5	29.9	28.5	84.4	59.7	70.8
Sheep and goat milk	t/t milk	3.1	2.3	3.2	1.6	1.7	6.6	3.0	2.5

Values refer to ca. 2000; feed requirement per unit of animal product (t of feed at 15% mc per t of product (as is weight)) by world region. Meat refers to carcass weight (slaughter weight), milk to whole, fresh milk.

Source: Table 3.9 in Wirsenius (2000) assuming an average energy content of feed of 10.4 MJ/kg.

Table 2.6 Share of roughage in feed 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%

Values refer to ca. 2000; roughage includes forage crops such as grasses, legumes, corn for silage and grazed biomass. Values in % of total digestible energy.

Source: Figure 3.28 in Wirsénus (2000, p. 139), weighted by digestible energy content (table B5 in Wirsénus (2003)).

Grazed biomass for horses, mules and asses and other grazing animals

Since method B only allows to calculate the roughage demand of animals that produce milk or meat, the roughage demands of other animals (e.g., horses, mules and asses or camels) has to be calculated by applying method A and using data on herd size (heads of animals) and information on average roughage intake per head and year provided in Table 2.3 and Table 2.4.

2.1.3.5 – A.1.3 Wood

This category comprises timber or industrial roundwood (1.3.1) and fuelwood and other

extraction (1.3.2). It includes wood harvest from forests and also from short rotation plantations or 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 data sets, because they also include wood harvested from non-forested land.

Table 2.7 Standard factors to convert quantities of wood.

	DENSITY [t at 15% mc / scm]
Coniferous	0.52
Non-coniferous	0.68
EU25 average (80% coniferous)	0.55

These factors refer to tonnes at 15% moisture content (mc) per solid cubic metre (scm) for coniferous and non-coniferous wood.

Source: Based on factors used in IPCC greenhouse gas inventories (IPCC 2003).

Wood is usually reported in terms of volume rather than weight. Units used are stacked (or piled) cubic metres and solid cubic metres (scm). One stacked cubic metre is considered equal 0.70 solid cubic metres. In EW-MFA, volume measures have to be converted into weight measures using standard conversion factors given in Table 2.7.

Felling versus removals, and bark fraction:

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

Special care must be taken concerning the issue of bark, which can account for up to 10 per cent of stem wood weight. Wood removals are usually reported in scm under bark (i.e. without bark), although wood is removed including bark and a significant fraction of the bark is subject to further socioeconomic use (e.g. energy production). In order to correct wood removals reported for bark, we use an extension factor derived from typical values for the bark fraction of stem wood (equation (10)):

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

Note on data quality and illegal logging: The quality of data on fuelwood extraction in forestry statistics is often poor. Forestry statistics commonly only record commercial wood harvest, ignoring fuelwood extracted for subsistence needs; where estimated, fuelwood extraction is often only a

rough estimate. National and international energy statistics may provide additional information and better estimates on the use of fuelwood. It should be noted, however, that reported data on the use of solid biomass for energy may include wood residues from wood processing, biomass other than wood (e.g. crop residues, dried manure), and secondary resources (e.g. recycled wood from demolition), none of which should be counted as DE (as double counting will result). In some countries, illegal logging may be a large flow of extraction, but it is not reported in forestry statistics. Where illegal logging is an issue, consult with local forestry experts or consult specific reports on illegal logging.

2.1.3.6 – A.1.4 Wild harvest not elsewhere considered (n.e.c)

Fish capture (1.4.1) and extraction of other aquatic animals (1.4.2) and plants (1.4.3) are reported in national fishery statistics and by FAO fishery statistics⁶ (FISHSTAT). Fish and seafood production from aquaculture is not considered domestic extraction but a secondary product of the livestock industry (see section fundamentals). Therefore, only fish capture (including recreational fishing) and other animals and plants extracted from unmanaged fresh and seawater systems should be reported under items 1.4.1 to 1.4.3.

Gathered wild terrestrial plants (1.4.4) and hunted wild terrestrial animals (1.4.5) are quantitatively of minor significance and only accounted for if data are available in national statistics. A conversion from individuals or other physical units into tonnes might be necessary. The 2018 version of the Eurostat EW-MFA compilation guide provides a long list of average weights of hunted animal species (see Eurostat (2018)).

6 <https://www.fao.org/fishery/en/fishstat>

2.2 Metal ores

2.2.1 Concepts and classification

2.2.1.1 Concepts

Metals in their pure and unalloyed form are chemical elements. They are generally solids at room temperature (with the exception of mercury) and tend to be good conductors of electricity and heat, ductile and malleable, hard, and shiny. They account for around three-quarters of the elements on the periodic table, although they constitute less than 30 per cent of the Earth's crust in mass.

The characteristics of hardness combined with malleability, which can be finely controlled and enhanced via various metallurgical processes, have made metals extremely important in mechanical technology for millennia. These qualities combined with their conductive qualities have made them indispensable in virtually all electricity-based technologies in recent centuries. Furthermore, the range of different metals which have found uses in recent years has expanded greatly, due to new electronic technologies, and also the requirement for new and better alloys for a range of highly physically demanding uses (e.g. in aerospace industry applications).

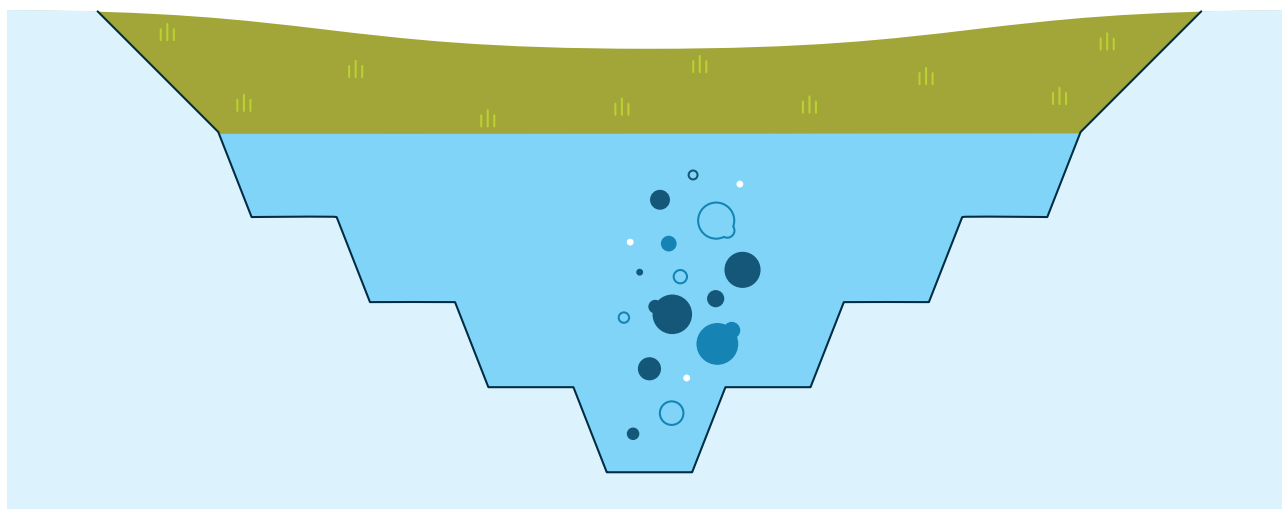
The only occurrences of metals of current economic significance to humans are those of the Earth's crust. Here they overwhelmingly occur in chemical combination with other non-metallic elements, as compounds. These forms generally require capital- and energy-intensive processing to obtain metals in economically useful forms. Metal "ores" can best be thought of as those deposits of metal compounds in the Earth's crust which can be processed to produce desired metals at an economically viable cost. Implicit in this definition

of ore is the fact that "ore" is as much an economic term as it is physical. If the market price for a metal increases, the concentration of contained metal (or "grade") at which a rock can be considered ore will decrease.

Ore deposits will generally be rock, but in certain important cases can be special soils or sand deposits as well.

An important concept when accounting for ore production is exactly what should be counted, and where. For EW-MFA purposes, only that portion of the excavated rock which is to be processed in some way, to obtain the desired metals, should be counted. This means that any soil or rock which is simply excavated and moved, to gain access to the metal ore itself, should not be counted as ore. In an open-cut mine setting (see Figure 2.2), this would include all pre-stripped overburden, and also any non-processed rock which is extracted as production proceeds. Typically, this means that the great majority (often a ratio > 3:1) of the soil and rock excavated in an open-cut operation is not counted at all as part of EW-MFA. Even after the removal of overburden, most rock excavated from each "bench" is often removed just to permit further access to the ore bodies while retaining adequately stable pit wall angles. Ore is selectively transported for further processing, while the waste rock is removed and dumped directly on a waste pile (typically as close to the point of excavation as possible without interfering with continued mining operations). In summary, while everything within the "pit outline" in Figure 2.2 is excavated, only the rock contained in the "ore bodies" would ideally be counted as metal ore.

Figure 2.2 Stylized open-cut mine cross section, showing the total excavated zone (everything within the pit outline), pre-stripping zone, and production level benches containing both waste rock and the targeted metal ore.



The large volumes of waste rock removed on upper benches are typically dictated by the need to maintain pit wall stability while accessing the lower levels. This is a major driver of the deteriorating economics of open-cutting versus underground tunnelling as a deposit gets deeper. In underground mining operations, which access ore bodies by tunnelling, the quantity of waste rock and overburden per tonne of ore extracted tends to be vastly less than for open-cut mining.

In some cases, ores from the same deposit may be processed in different ways, depending on metal content and the specific metallurgical characteristics of the ore. A common example of this is where high grade (high per cent Cu) copper ores go directly into a milling and flotation process, while low grade ores from the same deposit go to a “heap leaching” process. In both cases, post-excitation processing and extraction of metals is performed on the rock, and so both should be counted as mined ore.

Due to the limited ability of modern bulk mining methods to sharply delineate waste rock from ore,

considerable mixing of waste rock and ores occurs in the mining process, with some waste rock being included in the flow to further processing, and some ore being discarded as waste, without further processing. Fortunately, for the purposes of EW-MFA this problem can be largely ignored by accounting for ore on a “run of mine” (ROM) basis. ROM ore already includes those elements of waste rock which became mixed in with the ore (ore “dilution”) in the mining process. Tonnages of ROM ore will typically be recorded at one or more of the following locations:

At the “ore pad”, the initial place where ore is dumped at the surface after its initial excavation and any primary crushing required to enable it to be transported out of an underground mine.

As measured at a weighbridge, either as a truck leaves the mine to transport the ore to the plant for further processing, or at the entry to the processing plant, or before being dumped “on the heap” for heap leaching operations.

For those assembling EW-MFA, it will usually be sufficient to know that when a mining operation quotes an ore production figure, this is the basis on which it has been measured, and this is the primary material flow we seek to account for.

Note that waste rock and waste dumps should not be confused with mine “tailings”. Tailings are the main process waste left over *after* processing/beneficiation of the ore has taken place, and are included in EW-MFA accounts if the ore has been accounted for correctly. Tailings are composed mainly of those portions of the ore which are of little economic value, but which are too intimately associated with the valuable metal compounds to be separated in the initial excavation process. In comparison to waste rock, tailings will often still contain considerably higher concentrations of the metals of value than the waste rock, as ore processing only extracts a portion of the contained metal compound. The degree of metal recovery is the “recovery factor”, and usually given as the percentage of metal contained in the ore which enters processing which is subsequently retained in the concentrate extracted.

Tailings are usually of much greater economic and environmental significance than waste rock. As well as the pollution risks and potential economic opportunities posed by the residual metals in tailings, they often contain elevated levels of other contaminants which occur in association with the ore minerals e.g. arsenic, cadmium, associated sulphides, and sometimes remnants of chemicals used in processing e.g. cyanide. They are also usually much more finely ground than waste rock, and so more reactive and prone to releasing these contaminants into the surrounding environment.

One form of mining which is of much lesser importance than either open-cut or underground

mining is in situ leaching (not to be confused with heap leaching, or other forms of leaching, which just refer to specific processing methods which are applied to ore after it has been mined in a conventional manner). It is raised here mainly to pre-empt the question it raises for EW-MFA. In situ leaching involves injecting a solvent directly into an ore body, then recovering the solvent after it has dissolved the target metals, and extracting the metals from this leachate. As no ore is really extracted as such, this situation is best dealt with by entering the extracted metal tonnage as an ore tonnage, and setting the ROM grade to 1,000,000 parts per million (ppm) (i.e. 100 per cent). This will flow through appropriately to the “contained metal” calculation, which is outlined in the classification section below.

While the detailed system described subsequently, using questionnaire-based surveys of a country’s major minerals producers, is recommended, its success is contingent upon the cooperation of the mine operators. They will be, in effect, the primary source of all data. This system of accounting will be referred to henceforth as the operator questionnaire based (OQB) system. For nations where the required level of cooperation is not feasible, an alternative method of reporting is put forward in section 2.b. While the alternative system is simpler, it will be far less accurate and may capture little information beyond that directly applicable to the assembly of EW-MFA. This alternative will be referred to as the secondary mixed sources (SMS) system.

A flow chart to aid in deciding which approach is best for the compiler’s particular circumstances is set out in Figure 2.3.

Where possible, following a path to one of the three bright green FINISH nodes that include use of at least some of the OQB system tools is likely to yield the highest quality and most useful results.



2.2.1.2 Classification – detail

In previous classification schemes used for EW- MFA, e.g. Eurostat (2013), metal ores have been divided into two main categories, ferrous and non-ferrous, with the non-ferrous metal ores then further subcategorized according to each particular non-ferrous metal, e.g. into “aluminium ore”, “copper ore”, “zinc ore” etc. A major problem with this system was that it dealt poorly with the fact that in many economically important cases, metals typically occur in combination with each other, as co-products of polymetallic metal ores.

In this manual, this physical reality has been better recognized by creating three main metal ore categories, one each for ores of the two most volumetrically important economic metals (iron and aluminium), and one for all “other metal ores”. The practice of separately accounting for individual contained metals in Eurostat (2013) has been retained in a modified form in this system, and has become a more important component due to the loss of resolution at the ores level. The revised system of classification is used in both the OQB and SMS systems of accounting.

Table 2.8 Classification of domestic extraction of metal ores and contained metals.

1 DIGIT	2 DIGITS
A.2 METAL ORES	A.2.1 Iron ores
	A.2.2 Aluminium ores
	A.2.3 Other metal ores
M.2 CONTAINED METALS	M.2.Fe Iron ores metal content (<i>memo item</i>)
	M.2.Al Aluminium ores metal content (<i>memo item</i>)
	M.2.x X ores metal content, where X is a specific metallic element other than iron or aluminium (<i>memo item</i>)

Note: These items are compiled in Table A of UNEP's EW-MFA Compiler (see Annex 1).

With the revised classification system come revised guidelines on how data on metal ores should be

collected and compiled. The recommended OQB system, including the questionnaire worksheets to be sent to mine operators, is embodied in the spreadsheets “[Metal ore compilation worksheets for national statistical offices](#)” and “[Metal ores reporting questionnaire for mine operators](#)”. The main point to note about the revised system is that it requires compilation of an aggregated form of the sort of data recorded as part of the routine operational data

required for most metalliferous mining operations. While the data compilation requirement is greater than in previous EW-MFA guidelines, the underlying data collected are amenable to being reused in a number of other highly policy-relevant applications, in a way that simply was not possible using earlier methods.

2.2.1.3 - A.2.1 Iron ores and

A.2.2 Aluminium ores

Iron and aluminium ores have both been assigned their own categories due to a number of characteristics, including:

- They are the two most important metals in volumes used. Regarding contained metal tonnages, iron totally dominates the metals category globally, with volumes used far greater than all other metals combined. Estimates in USGS (2017) indicate that in 2015, iron ore containing 1.4 billion tonnes of iron was extracted globally. This is over 20 times the corresponding USGS estimates for the volume of aluminium, and over 70 times the copper metal produced in 2015 (the third most produced metal)⁷.
- Both metals are overwhelmingly produced from ores where they are the only significant economic metal produced. This is not the case for most other metals.
- The percentage of metal contained in economically exploited ores (its “grade”) is broadly similar among iron ores, and among aluminium ores. Within these two categories, it is uncommon for grades of competing ores to differ from each other by a factor of two (e.g. 65 per cent Fe would be a very high-grade iron ore, 25 per cent Fe usually an uneconomically low grade). In contrast, variations of a factor of five or more are common for the ores from which copper, gold, nickel etc. are extracted, in large part due to them often being extracted from polymetallic ores.

Copper, for example, is commonly an economic product from ores ranging from 0.2 per cent Cu to 2.0 per cent Cu.

- The change in grade between the ore as mined and the first commonly traded product is much less for these two metals than for most other metals. Both iron ore and bauxite (the only currently economically important aluminium ore) are often traded in a state little altered from how they are extracted, or after a beneficiation process which typically less than doubles their concentration. Bauxite as mined, or after rudimentary washing and screening, typically already contains more than 40 per cent alumina⁸.
- The profitable mining of both iron ore and bauxite are often exercises in minimizing the inclusion of contaminants as much as maximizing the inclusion of the target metal. This aspect is not usually as important for other metals, where contaminants are dealt with more at the processing and refining stages.

Using the spreadsheet “[Metal ore compilation worksheets for national statistical offices](#)” to compile ore accounts for iron and aluminium will thus probably only require the entry of one row for each year’s output from each individual deposit, similar to that shown in the first five lines of the (hypothetical) examples in Table 2.9. The structure of this spreadsheet, and filling it out, and its extensions and potential uses beyond EW-MFA are discussed in section A.2.3 on “Other metal ores”.

⁷ Iron’s primacy in terms of actual ore tonnages mined, however, is not at all clear cut. The quantity of copper ore mined to obtain the 19.1 million tonnes of copper metal produced in 2015 was estimated at over two billion tonnes in the UNEP *et al.* (2017) estimation.

⁸ Alumina (Al_2O_3) is perhaps the most heavily traded aluminium commodity in tonnage terms. It constitutes an intermediate stage in the production of refined metal from the extracted ore. Roughly speaking, 4 to 7 tonnes of bauxite will yield 2 tonnes of alumina, which will in turn yield one tonne of aluminium metal.

2.2.1.4 – A.2.3 Other metal ores

This combined category was created to reflect the fact that co-production of different metals from the same ores is extremely common, and so it makes little physical sense to talk of categories such as “copper ore” and “gold ore” when in many cases they are important co-products from the same ore. The alternative of trying to include specific categories for various mixed ores, for example adding something like an explicit “mixed copper – gold” ore category, is not feasible due to the sheer variety of different combinations of elements actually mined.

In light of this, the approach adopted here is to accept the aggregation of all remaining metal ores under one category, and then abstract out the (very important) information on what metals they actually contain into a separate estimation and compilation procedure. In doing this, the high level EW-MFA themselves will lose the ability to provide information on the quantity of “copper ore”,

“gold ore”, etc. which has been extracted, but this ability was always apparent rather than real. Earlier classification schemes unintentionally encourage the practice of back-calculating ore tonnages from produced metal (which often leads to multiple counting of the same ore, among other serious problems). Efforts to correct for this multiple counting problem introduced other problems, most notably the creation of imaginary single element ore parcels, which in turn implied much higher apparent ore grades than were being extracted in reality. The new approach should remove these sources of error.

As the ores in this category typically contain two or more metals of value, the simple one line per year per deposit reporting seen for iron and aluminium in Table 2.9 becomes more complex (if using the OQB system), with one line required for each economically significant metal contained in a deposit (ore stream), for each year of production. The last eight lines in Table 2.9 provide examples.

Table 2.9 Hypothetical deposit data and its entry into the “Mined ore for NSOs” worksheet.

ORE_STREAM_ID	YEAR	ROM ORE (tonnes)	ORE TYPE	METAL	ROMGRADE (ppm)	WASTEROCK (tonnes)
Iron Mine A	2015	25,000,000	A.2.1	M.2.Fe	580,000	62,500,000
Desert Mine A1	2015	10,000,000	A.2.1	M.2.Fe	570,000	13,000,000
Desert Mine A2	2015	7,000,000	A.2.1	M.2.Fe	470,000	21,000,000
Weipa A	2015	18,000,000	A.2.2	M.2.Al	200,000	27,000,000
AlMine	2015	10,000,000	A.2.2	M.2.Al	170,000	21,000,000
Bonanza A	2015	25,000,000	A.2.3	M.2.Cu	5,000	102,500,000
Bonanza A	2015	25,000,000	A.2.3	M.2.Au	0.9	102,500,000

Table 2.9 Hypothetical deposit data and its entry into the “Mined ore for NSOs” worksheet. (Cont.)

ORE_STREAM_ID	YEAR	ROM ORE (tonnes)	ORE TYPE	METAL	ROMGRADE (ppm)	WASTEROCK (tonnes)
Bonanza A	2015	25,000,000	A.2.3	M.2.Ag	5	102,500,000
Bonanza A	2015	25,000,000	A.2.3	M.2.Mo	105	102,500,000
Bonanza B	2015	13,000,000	A.2.3	M.2.Cu	12,000	78,000,000
Bonanza B	2015	13,000,000	A.2.3	M.2.Mo	300	78,000,000
Miscmines group A	2015	5,000,000	A.2.3	M.2.Zn	50,000	17,500,000
Miscmines group A	2015	5,000,000	A.2.3	M.2.Pb	30,000	17,500,000
Miscmines group A	2015	5,000,000	A.2.3	M.2.Ag	30	17,500,000
Iron Mine A	2016	29,000,000	A.2.1	M.2.Fe	603,200	58,750,000
Desert Mine A1	2016	9,200,000	A.2.1	M.2.Fe	524,400	10,660,000
Desert Mine A2	2016	7,700,000	A.2.1	M.2.Fe	460,600	21,840,000
Weipa A	2016	17,640,000	A.2.2	M.2.Al	228,000	21,600,000
AlMine	2016	10,000,000	A.2.2	M.2.Al	176,800	24,780,000
Bonanza A	2016	24,500,000	A.2.3	M.2.Cu	5,600	118,900,000
Bonanza A	2016	24,500,000	A.2.3	M.2.Au	1,0	118,900,000
Bonanza A	2016	24,500,000	A.2.3	M.2.Ag	4	118,900,000
Bonanza A	2016	24,500,000	A.2.3	M.2.Mo	126	118,900,000
Bonanza B	2016	10,400,000	A.2.3	M.2.Cu	10,800	82,680,000
Bonanza B	2016	10,400,000	A.2.3	M.2.Mo	246	82,680,000
Miscmines group A	2016	4,400,000	A.2.3	M.2.Zn	56,000	15,750,000
Miscmines group A	2016	4,400,000	A.2.3	M.2.Pb	25,200	15,750,000
...						

Source: Worksheet of “Metal ore compilation worksheets for national statistical offices.”

2.2.1.5 Contained metals

The convention of using the M.2 prefix for contained metals has been adopted from Eurostat (2013), however, the detail has changed. Where different metals were identified by adding further numbers in the earlier system (e.g. M.2.2.1 for copper, M.2.2.2 for nickel), in the system used here the symbol used for the metallic element in the periodic table is simply appended, so that M.2.Cu is for copper, M.2.Ni for Nickel. This has the advantages that the ID for each metal can be simply and logically derived, and is easily and logically extensible to include any elements which might become important for mining (both as product and as a contaminant).

If using the OQB system, contained metal can be manually calculated directly for each ore stream, if required, as the product of ROM tonnage * ROM grade / 1,000,000. Otherwise, the contained metal for each individual metal, totaled for all ore streams, is calculated by running the macro on the “Basic metal ore reporting tool” worksheet, where the result is given on the far righthand side.

2.2.2 Data sources and availability

2.2.2.1 Data sources and availability using OQB system

The source of data for those using the OQB system should be returned questionnaires from mine operators. The data required will generally have been recorded in a detailed form as part of the ongoing operation of almost all significant mining operations. The availability of this data will thus really depend upon the mining operators’ inclination to provide it, and/or the government’s inclination to mandate it being reported and made available to the relevant NSO.

The NSO should use the spreadsheet “[Metal ore compilation worksheets for national statistical](#)

[offices](#)” to guide the compilation of data from returned questionnaires. It has a notes page, and two main worksheets for data collation. The “*Mined ore for NSOs*” worksheet is the most essential for basic EW-MFA, as it deals directly with the tonnages of metal ores mined. For the individual country compiling the data, however, extending data collection to cover the fields on the “*Processed/Shipped ore for NSOs*” worksheet will greatly improve the utility of the data collected for many important policy formulation uses. This will be discussed further in section 2.2.3.

The spreadsheet “[Metal ores reporting questionnaire for mine operators](#)” is for use by the individual mining operators in reporting. Ideally, the mining operator will be in a position to fill out the worksheets *Mined ore for operator (yearly)* and *Process_Ship operator (yearly)* directly, however if the underlying more detailed information has not previously been aggregated up for reporting on an annual basis, then the worksheets *Mined ore for operator (batch)* and *Process_Ship operator (batch)* can be used, with the appropriate aggregation then performed.

2.2.2.2 Data sources and availability using SMS system

If using the OQB system is deemed impractical, then finding substitute data will often be a largely ad hoc process, and vary greatly depending on the current arrangements for the reporting of minerals production in each country.

The first step should be to find and refer to the relevant national authority charged with licensing and oversight of mining operations, to ascertain what level of reporting of minerals production is mandated. There may be more than one government authority holding relevant information, e.g. departments of mining, primary resources, environment etc. In some cases, governments

require that detailed data on the quantity and characteristics of ore mined be reported on an annual basis by all mining operators⁹. In other cases, it appears that little reporting on the physical outputs of mining is required, with mandatory reporting largely being restricted to financial reporting. This latter sort of data is not very useful for EW-MFA purposes, although it may be combined with other data on the geological characteristics of the mineral deposits exploited in a country, and metal prices, to back-calculate ore extracted¹⁰.

If direct and detailed reporting of physical mine products is not mandated, there may still be usable proxy data reported where a royalties / resource rental tax regime applies. This is especially useful where a royalty system uses a set payment per tonne of ore extracted, however even a system based on metals extracted might yield useful information. This information should be held by national or state/provincial taxation offices, or by the department responsible for administration of mining activities. These data are almost certainly held in jurisdictions where in-ground minerals deposits remain the property of the state, and their mining takes place under a government-issued concession system.

A third potential source of data is company reports. It is common for companies to provide considerable detail on production of ore, and tonnages of metal produced, in annual or quarterly reports. Again, the extent, quality and utility of the data obtained from such reports will vary greatly, and be heavily dependent on corporate reporting standards required in each individual jurisdiction. Even where reporting standards in the country where operations are physically based are low, it is possible that some better quality information may be available from company reports which may need to be filed in the country where the companies are domiciled.

In many countries, the volumetric output of the mining industry is dominated by a small number of large operations. In these cases, it may be possible to produce a good estimate of national domestic extraction of metal ores from relatively few individual company reports. In such cases, even where official company reports are lacking or have little detail, it may be possible to build a reasonable estimate of metal ores extraction from searching unofficial online sources¹¹.

9 For example, the Western Australian Department of Mines and Petroleum specifies that as part of an annual environmental report, details on exploration activity, ore processed, waste moved, minerals produced and recovery rates must all be reported by mine operators (see section 6.4. in <http://www.dmp.wa.gov.au/Documents/Environment/ENV-MEB-108.pdf>). Slightly less detail is required in Fiji (see “form 14” attached to http://www.pacilii.org/fj/legis/consol_act_OK/ma81/), while the level of reporting specified under Articles 37 and 38 of Mongolia’s minerals law (see <http://faolex.fao.org/docs/texts/mon37842.doc>) is an example where a financial emphasis renders the mandated reporting less useful for EW-MFA.

10 The process of back calculating DE of metal ores from metal produced is very error prone and really feasible only where the number of deposits dominating national production is very small. Back-calculating from financial data is even more tenuous, and should be a last resort.

11 Wikipedia, for instance, may have a listing of mining operations for a specific country, and the entries for those individual operations may then link to various reference sources, some of which include geological reports, historical assessments and prospectuses, any of which can contain detail on the type of mineral deposit and sometimes on actual operations. Detailed geological information on major deposits can be very important if ore extraction estimates ultimately need to be based on back- calculation from metal production / financial figures.

Finally, there are the international data sets compiled by agencies such as the USGS and the BGS. These data sets are largely of high quality in what they report, however, they mainly report only metal production (and trade) for most major metals. Ore tonnages are largely absent (iron ore and bauxite are exceptions here). This means that ore tonnages required for EW-MFA need to be back-calculated from metal production, and so are subject to the wide range of errors and uncertainties that this procedure introduces. Furthermore, the data sources used by these agencies to compile these data sets are largely limited by the quality of primary reporting required at the government and/or corporate level in each country¹². If these standards are low in a specific country, the NSO of that country should not expect data for their country from these sources (USGS, BGS) to be as good as data from the same sources for countries with high mandated reporting standards.

If using the SMS system to compile accounts, the responsible NSO should seek to source data on ore tonnages directly from the sources indicated above. If there is no option but to back-calculate ore extracted from metal extracted, then there are a number of major sources of error that must be controlled for as far as practicable. These are discussed in section 2.2.3.5.

2.2.3 Accounting methods and practical guidelines for data compilation

The following section concentrates on describing the two main worksheets used by an NSO to

compile data collected from mine operators via questionnaire. The questionnaires provided to the mine operators, also in the form of Excel spreadsheets, are also dealt with briefly, however the main documentation for using them is provided on the questionnaire spreadsheets themselves.

There is also a section which discusses where the largest sources of error are likely to arise for those who choose to use the SMS system of assembling metal ores accounts rather than the questionnaire based OQB system.

2.2.3.1 Using the OQB system

This section provides an extended description and some illustrative examples of how to use the two worksheets which are central to compiling metal ores accounts using the OQB system. Basic usage instructions are also provided on the spreadsheets themselves.

2.2.3.2 “Mined ore for NSOs” worksheet

The structure of the mined worksheet is shown in Table 2.9. All of the data specified in this section should ideally be sourced either directly from mine operators where possible, or from national agencies charged with collecting data from mining operations. If no such centralized reporting arrangements exist, establishing them should be considered. While highly detailed data on mine operations can be quite commercially sensitive, the more aggregated data required here should be less so, especially for years before the current year. The nature of the data required for each column is described below:

12 From the BGS website, <https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html>

“The information contained in the dataset, and associated publications, is compiled from a wide range of sources: home and overseas government departments, national statistical offices, specialist commodity authorities, company reports, and a network of contacts throughout the world.”

Ore_Stream_ID

This is simply an identifier field used to identify individual ore streams. In the simplest and most common cases, the Ore_Stream_ID should correspond to one mine or individual ore deposit's output for a year.

Unfortunately, it is not unusual for one mine to have multiple deposits, and/or multiple output streams of ore from the same deposit, which vary markedly in their key metallurgical characteristics and the treatment processes they undergo. In other cases, ore from several spatially distinct sources may end up mixed before reaching the location where they are first measured. That is why this field is not simply called "Deposit_ID" or "Mine_ID".

The label to be used here is best created by the agency compiling the account from the operational data sourced from individual mining operations. The key points in assigning an effective Ore_Stream_ID are that it reflects a point post-excavation where the ore's key characteristics (tonnage, grade) can be assessed/averaged over a year, prior to the ore entering into further beneficiation/processing.

In the examples given in Table 2.9, "Iron Mine A" would represent the simplest case, where a particular mine has one output stream, which is either sold directly or goes into one further processing stream. "Desert Mine A1" and "Desert Mine A2" would reflect one mine or mine group with two significantly different ore output streams, e.g. an iron ore mine where one high-grade ore stream goes directly to export, and another low-grade ore stream is stockpiled (separate from waste rock) for future beneficiation before sale.

The example of "Bonanza A" and "Bonanza B" demonstrate how, in the case of "2.3 other metal

ores", one line should be entered for each metal recorded for each Ore_Stream_ID. Here, Bonanza will be the name of the mine or group of mines. There are two distinct ore output streams from Bonanza, A and B. The Bonanza A ore stream has been analysed for its content of copper, gold, silver and molybdenum, while Bonanza B has analyses for copper and molybdenum only.

Year

This is the year for which the recorded data apply. Whether this conforms to calendar or financial years will be determined by how the aggregated data collected from mining operations are organized.

ROM Ore (tonnes)

The estimated total tonnage of ROM ore extracted via one Ore_Stream_ID for the relevant year.

Ore type

The ID code of the EW-MFA material category, i.e. one of A.2.1, A.2.2, or A.2.3, for Iron ores, Aluminium ores or Other metal ores respectively.

ROM Grade (ppm)

This is the estimated average concentration for one of the metals in an ore stream, averaged over the relevant year. There should be a value for each of the targeted metals, however, if there are also data for incidental metals, especially if they are of potential future economic interest, or are particularly environmentally sensitive, this should also be recorded. The number of such individual metals for which there are data ultimately determines the number of individual lines entered under one Ore_Stream_ID for one year.

The concentration is determined on a weight basis, in ppm, i.e. a grade of 1,500 for A.2.Cu would mean that there are 1,500 grams of pure copper contained in each tonne of ore.

For many metals, the original data will give the grade as a percentage. In these cases, the conversion is achieved simply by multiplying by 10,000. In some cases, grades may be given in a key compound of the metal e.g. U_3O_8 . To convert these grades to the metal-only basis used here, determine the weight fraction of the metal as shown in the examples in Table 2.10, and apply this additional factor to complete the grade conversion. A grade given as 37 per cent Cr_2O_3 should be converted as $37 \times 10,000 \times 0.684 = 253,080$ ppm.

Waste rock (tonnes)

If available, data on the quantity of waste rock and overburden excavated over the year to access the metal ores associated with each Ore_Stream_ID should be recorded here. While all fields up to this point are basic to establishing the EW-MFA metal ores accounts, this flow is not central to EW-MFA,

and so is optional. This quantity is of importance in some other reporting schemes for material flows, and does have environmental implications in its own right.

2.2.3.3 “Processed_Shipped ore for NSOs” worksheet

The data specified on the “*Processed_Shipped ore for NSOs*” worksheet is not required for basic EW-MFA. It is, however, crucial for making the data collected on “*Mined ore for NSOs*” worksheet much more useful in a number of non-EW-MFA related, practical, policy-relevant roles. If a national agency intends to set up the data-collection processes required to populate the “*Mined ore for NSOs*” worksheet, it will already be well positioned to collect the additional data required for this worksheet, and obtain much broader utility from the procedure.

Table 2.10 How to convert metal compound grades to a metal-only basis.

CONVERSION FACTORS FOR METAL COMPOUND GRADES TO A METAL-ONLY BASIS			
		ELEMENT 1	ELEMENT 2
Al_2O_3		Al	O
	Atomic Weight	26.982	15.999
	Atoms	2	3
	Total Wt.	53.964	47.997
	Weight fraction	0.529	0.471
Cr_2O_3		Cr	O
	Atomic Weight	51.996	15.999
	Atoms	2	3
	Total Wt.	103.992	47.997
	Weight fraction	0.684	0.316

Table 2.10 How to convert metal compound grades to a metal-only basis. (Cont.)

CONVERSION FACTORS FOR METAL COMPOUND GRADES TO A METAL-ONLY BASIS			
		ELEMENT 1	ELEMENT 2
TiO ₂		Ti	O
	Atomic Weight	47.867	15.999
	Atoms	1	2
	Total Wt.	47.867	31.998
	Weight fraction	0.599	0.401
U ₃ O ₈		U	O
	Atomic Weight	238.03	15.999
	Atoms	3	8
	Total Wt.	714.09	127.992
	Weight fraction	0.848	0.152

A hypothetical example of how this table might be filled out is presented in Table 2.11. In practice, many of the entries for the first six fields on this worksheet are likely to mirror, or be close to, entries for the same year on the “*Mined ore for NSOs*” worksheet, with the same “Source_ID”. As with the data for the “*Mined ore for NSOs*” worksheet,

the mine operators will likely have the required data recorded in much greater time detail than is required for this table. The questionnaire for mine operators contains optional worksheets which can be filled out if the operator does not have these data already summarized on a yearly basis.

Table 2.11 Hypothetical example of ore processing / sale data.

ORE_STREAM_ID	YEAR	INPUT (TONNES)	ORE TYPE	METAL	INPUT GRADE (ppm)	RECOVERY FACTOR	SOLD
Iron Mine A	2015	25,000,000	A.2.1	M.2.Fe	580,000	100%	1
Desert Mine A1	2015	10,200,000	A.2.1	M.2.Fe	575,000	70%	1
Weipa A	2015	17,800,000	A.2.2	M.2.Al	200,000	100%	1
AlMine	2015	10,600,000	A.2.2	M.2.Al	170,000	60%	1
Bonanza A	2015	30,000,000	A.2.3	M.2.Cu	5,200	75%	1
Bonanza A	2015	30,000,000	A.2.3	M.2.Au	1	55%	1
Bonanza A	2015	30,000,000	A.2.3	M.2.Ag	4	30%	1
Bonanza A	2015	30,000,000	A.2.3	M.2.Mo	95	50%	0
Bonanza B	2015	12,500,000	A.2.3	M.2.Cu	12,000	60%	1
Bonanza B	2015	12,500,000	A.2.3	M.2.Mo	300	70%	1
Eastern	2015	7,500,000	A.2.3	M.2.Zn	64,000	85%	1
Eastern	2015	7,500,000	A.2.3	M.2.Pb	28,000	65%	1
Eastern	2015	7,500,000	A.2.3	M.2.Ag	38	45%	0
Iron Mine A	2016	23,000,000	A.2.1	M.2.Fe	530,000	100%	1
Desert Mine A1	2016	9,800,000	A.2.1	M.2.Fe	520,000	72%	1
Weipa A	2016	18,000,000	A.2.2	M.2.Al	200,000	100%	1
AlMine	2016	11,200,000	A.2.2	M.2.Al	170,000	62%	1
Bonanza A	2016	28,000,000	A.2.3	M.2.Cu	4,900	77%	1
Bonanza A	2016	28,000,000	A.2.3	M.2.Au	1	53%	1
Bonanza A	2016	28,000,000	A.2.3	M.2.Ag	6	32%	1
Bonanza A	2016	28,000,000	A.2.3	M.2.Mo	95	70%	0

Table 2.11 Hypothetical example of ore processing / sale data. (Cont.)

ORE_STREAM_ID	YEAR	INPUT (TONNES)	ORE TYPE	METAL	INPUT GRADE (ppm)	RECOVERY FACTOR	SOLD
Bonanza B	2016	14,000,000	A.2.3	M.2.Cu	11,000	63%	1
Bonanza B	2016	14,000,000	A.2.3	M.2.Mo	290	71%	1
Bonanza C	2016	6,000,000	A.2.3	M.2.Cu	2,850	55%	1
Bonanza C	2016	6,000,000	A.2.3	M.2.Mo	400	35%	1
Eastern	2016	9,000,000	A.2.3	M.2.Zn	69,000	82%	1
Eastern	2016	9,000,000	A.2.3	M.2.Pb	31,000	62%	1
Eastern	2016	9,000,000	A.2.3	M.2.Ag	51	48%	0
...							

Source: Worksheet of "Metal ore compilation worksheets for national statistical offices".

Minor variations between mined ore and processed/shipped ore will occur where the ore is actually measured, analysed and recorded at two locations between exit from the mine and entry into processing, e.g. at a mine ore pad, and then again upon delivery to the processing plant. These minor variations will mainly be due to measurement error.

Common causes of larger divergences between the tonnages recorded for the ore streams on the "Mined ore for NSOs" and "Processed/Shipped ore for NSOs" worksheets include:

- Major stockpiling of ore streams: The absence of the mined ore stream "Desert Mine A2" from the list of processed/shipped ore streams is what we would expect to see if this ore was mined but then stockpiled (perhaps awaiting the construction and commissioning of a beneficiation plant designed to upgrade this low grade iron ore, and make it more marketable). Similarly, the appearance of a Bonanza C stream in the processed/shipped worksheet, where no corresponding ore stream occurs on the mined worksheet, would indicate that some ore from a distinctly different ore stream(s) at the Bonanza mine was mined and stockpiled in earlier years, but not processed until 2015.
- Partial stockpiling/destocking: The increase of 20 per cent in ore tonnage processed/shipped for Bonanza A likely indicates that ore mined from the Bonanza A ore stream in preceding years was temporarily stockpiled, then processed/shipped in 2015, along with the current year's mined output.
- Ore blending: The processed "Eastern" ore stream, which has no corresponding mined ore stream, would be consistent with having ore from a number of different mined ore streams blended before processing, and so not

attributable to any one mined ore stream. This ore could even be from other mine operators, milled under contract. In that case, there will be no matching mined ore tonnages on the operator's returned questionnaire.

The nature of the data required for the additional two columns in the "*Processed/Shipped ore for NSOs*" worksheet are described below:

Recovery factor

This is the percentage of the total metal contained in the ROM ore entering the processing plant which is retained in the metal concentrate. Where the ore is merely shipped rather than processed, this factor should always be approximately 100 per cent, however, virtually any beneficiation process will lead to some loss of contained metal, and in many cases that loss can be over 50 per cent¹³.

The recovery factor is a crucial performance metric in operating most metal ore processing plants, and so will generally have been recorded by the mine/processing operators in much greater detail than required for this worksheet.

Sold

This field just records whether the mining operator receives payment for this particular component of the ore or concentrate. It is common for mining operations to only be paid in full for some of the valuable metals contained in their ore or concentrates. Other metal components may be only partially paid for, not paid for at all, or even attract a penalty if they are seen as a contaminant, e.g. bismuth in a copper concentrate.

Note that this field is not important for the basic EW-MFA accounts. It has been included due to its value for other potentially important policy questions.

2.2.3.4 Questionnaire for mine operators/processors (for those using OQB system)

Collecting the detailed data required above will rely on the cooperation of mine operators. As stated previously, the sort of data required is really just an aggregated, less detailed version of the data which will be collected in the course of managing most mining operations. The questionnaire issued to individual operators thus closely resembles the guidance and worksheets outlined above, with some additional clarification on how aggregation should be performed.

"Mined ore for operator" worksheets

The mine operator is likely to only want to supply pre-aggregated data, due to the increased commercial sensitivity of more disaggregated data. This type of data would be filled out in the format shown in the "*Mined ore for operator (yearly)*" worksheet. Ideally, the data will be near identical to that required by the NSO, as presented on the "*Mined ore for NSOs*" worksheet, and could be transferred directly. The main difference is having a "Component" column in place of "Metal", as some operators' records are likely to be in terms of U_3O_8 , TiO_2 , etc., and the conversions to elemental metal contained could be left to the NSO to do on a consistent basis.

The mine operator may not have the data required calculated on an annual basis, however, and may instead only have more highly detailed data, which

13 This is one major source of error when attempts are made to back-calculate mined ore tonnages from metal production statistics, and a reason why this should be avoided where possible. The other main reasons are inadequate ore grade information, and the problem of co-production (already discussed).

relates to individual daily production from different deposits or even smaller subdivisions within deposits (individual “panels”, “stopes”, “headings”, “draw points”, etc.). In that case, the operator’s detailed data can be entered in the format shown in the “*Mined ore for operator (batch)*” worksheet of the “*Metal ores reporting questionnaire for mine operators*”. From there, either the operator or the NSO can combine these detailed data into a more aggregated form, making sure that appropriate volume-weighted grades are calculated.

“Process_Ship operator” worksheets

As for mined ore, ore processors may wish not to provide potentially commercially sensitive, highly detailed data on ore processing operations, and this would not really be desirable for EW-MFA purposes in any case. It is anticipated that the operator would generally report in the format outlined on the “*Process_Ship operator (yearly)*” worksheet. If so, the reported data should be more or less directly transferrable to the NSO’s national records.

If the ore processor does not have data already aggregated up into annual summary form, then they can enter more detailed operational type data into the format outlined on the “*Process_Ship operator (batch)*” worksheet, and combine the detailed data into a more aggregated annual form, while ensuring that appropriate volume-weighted grades, recovery factors and payable tonnages are calculated.

2.2.3.5 Using the SMS system

If using the SMS system to compile accounts, the NSO should seek to source direct data on ore tonnages from the sources outlined in section 2.2.2.2. If the NSO is satisfied that they have accounted for much of the ore produced simply by compiling and categorizing direct quotations

of ore tonnages from primary sources, they should think very carefully before trying to expand their account to give a broader coverage via back-calculation from metal production. This is because major errors can easily accumulate using back-calculation, errors which may greatly outweigh the benefits of apparent broader coverage. This is especially the case for minor metals, which are often produced as by-products of mines which are targeting other metal(s).

If forced to fall back on the SMS system, it is still recommended that the NSO compiler first consider using the “*Mined ore for NSOs*” worksheet to guide reporting. Filling this out in a way which provides reasonable accounts is quite feasible even without mine operators’ direct input, especially if the number of mines dominating national production is relatively small, and where there is at least some information available on mined tonnages and grades for those mines. In contrast, filling out the “*Processed_Shipped ore for NSOs*” is probably not feasible without mine operator input.

If there is no option but to back-calculate ore extracted from metal produced, or (even worse) from an estimate of metal produced back-calculated from the value of metals produced, then there are a number of major sources of error that must be controlled for as far as practicable. The most important sources of back-calculation error are listed below. A simple tool for back-calculation from metal tonnages is provided on the “*SMS Back calculation for NSOs*” worksheet.

Ore grade

This is the most obvious and straightforward source of error. If a default grade, such as those provided in Eurostat (2013), is used to back-calculate extracted ore, the error from this alone will be directly proportional to how far this default

grade differs from the true local average grade. For example, if the default copper grade of 1.04 per cent is used, back-calculation will underestimate ore extraction associated with copper production by a factor of two if true local copper grades are around 0.5 per cent (5000 ppm), and overestimate by a factor of two where the real grade is 2.0 per cent. Grades in the range of 0.5 per cent to 2.0 per cent are common for currently operating copper mines. Poor grade information can create such large errors that, for this manual, no default grades are provided for back-calculation of ore tonnages. This is to ensure that at least some local knowledge is used in their determination.

Particular care must be taken if trying to improve estimates of local grades in a situation where a nation's producing mines for the same commodity have very different grades. If, for example, a country has two copper mines, each of which produces 100,000 tonnes of copper per year, but one mine has a grade of 0.5 per cent and the other 2.0 per cent, the correct average grade for that country needs to be calculated as a volume-weighted average. Using the simple arithmetic average (1.25 per cent) will give an estimate of 16 million tonnes of ore, whereas the real figure would be 25 million. While it is unlikely that all the information is available to correctly volume-weight, having data on production from a small sample of the mines, particularly if they are dominant ones, can limit errors here.

Co-production

As discussed in section 2.2.1.2, metal ores often cannot be clearly categorized according to one primary product. In many cases, modern metal mines would not be economically viable without receiving payment for multiple products from the same ore. This reality has been recognized in the grouping together of all ores other than iron and

aluminium under the category of "A.2.3 Other metal ores". Unfortunately, this does not solve the problem of multiple counting of the same ore if back-calculating ore tonnages from metals production.

The best hope of dealing adequately with this problem using the SMS system is where it is possible to identify a relatively small number of major mines which have one metal clearly dominating production in value terms. If, for example, there are three major mines containing different combinations of copper and/or gold and/or another metal, one of which is copper dominant, one gold dominant, and the other indeterminate, one could proceed as follows:

- use the copper grade of the copper dominant mine as the grade to back-calculate the ore tonnage required to produce **all** national copper production;
- use the gold grade from the gold dominant mine to back-calculate gold ore required to produce **all** national gold production;
- do not attempt to back-calculate any ore for the other associated metal(s).

Note that the procedure recommended above departs markedly from the co-production procedures recommended in the current Eurostat guide.

If instead copper (or gold) were the dominant product in all three, estimate a volume-weighted average grade for copper (or gold) alone, use that grade to back-calculate the ore tonnage required to produce **all** national copper (or gold) production, and do not calculate any further ore for gold (or copper) and the other associated metals in this set. Note that this approach will probably not yield an accurate answer, but it will avoid the gross

over-estimation which can result from multiple counting.

Metal prices

This is relevant if trying to back-calculate metal production from data on the value of sales. Metal prices can be highly volatile. For example, copper prices varied by over 500 per cent from 2000 to 2010, and variations of 50 per cent or more within the same year sometimes occur. Unless good estimates of the average prices received for metals are available, resolved on at least a yearly basis, it may be better not to employ this method at all, even where there is no alternative.

Recovery factor

While an ore grade is always used in back-calculation of ore from metal production, recovery factors are often overlooked, a practice which tacitly assumes a 100 per cent recovery rate. In fact, recovery rates are often less than 80 per cent, especially for secondary co-product metals in metallurgically complex ores. This will lead to under-estimation of ore extraction. If metals production is dominated by a few major mines, and information on recovery factors can be sourced for the main metal product for these mines, it may be worth adjusting (i.e. increasing) the back-calculated ore in the light of this information.

Note that the recovery factor of relevance here is the recovery of metal from ore processed (e.g. in concentrates from flotation, crude metals recovered via heap leaching etc.). For ores that are shipped directly, the relevant recovery factor can be assumed to be effectively 100 per cent.

A second recovery factor often referred to in operational reports, the “mining” or “stope” recovery factor, **is not relevant to EW-MFA**. It refers to how much of the delineated ore body is

actually successfully excavated and available for subsequent processing or shipping. Using an ROM basis means that this has already been taken into account.

Imports

If back-calculating domestic ore extraction from domestic metal production, care must be taken not to include metal production that comes from ores or metal concentrates which have been imported, for local processing. Unfortunately, if an NSO is in the position where it needs to back-calculate domestic ore extraction from metal production, it is unlikely to have detailed data on the metal content in imports of ores and concentrates necessary to make this correction. If that is the case, and if it is known that imported ores for local processing are relatively large, it is probably best not to attempt to back-calculate domestic production of metal ores at all.

2.2.4 Specific issues of developing countries

A major issue for EW-MFA in most developing countries is the limited resources available to devote to the gathering and curation of statistics in general, and the low perceived relevance of EW-MFA to the more pressing, practical policy concerns of developing nations. Furthermore, current EW-MFA methodologies and practices were overwhelmingly designed by developed countries and reflect both the policy priorities and material flows of those countries. This is obvious in the treatment of DE of metal ores, where the mining industry is typically of relatively little direct economic importance in most developed economies.

This global manual has devoted more attention to metal ores accounting to reflect their greater relative importance for many developing countries. It has

also been designed to try and ensure that effort expended in assembling metal ores accounts is of practical use in multiple policy questions beyond those directly on material flow accounts. This is a large part of the reason behind advocating the OQB system of metal ores accounting. Using the OQB system will produce high-quality EW-MFA for metal ores, however the main motivation for a developing nation to use the system generally lies elsewhere. The greatest potential benefits flow from the fact that it will establish a high standard base level of information on the exploitation of a nation's non-renewable mineral resources, something that is not achieved using earlier systems or the alternative SMS system. By systematically collecting the data indicated in the questionnaires, a government will have data at its disposal which can be used to monitor or calculate:

- the rate at which it is exploiting its mineral resources base, with due regard to the quality of the resources being exploited;
- the efficiency with which current operators are extracting the primary resource, and the raw value of that resource stream;

- the extent to which potentially valuable by-products may be escaping consideration in taxation/royalty schemes;
- the quantity and key characteristics of potentially harmful wastes and/or future economic resources accumulating in mine tailings.

An additional benefit for developing countries of implementing the OQB system is that it will institutionalize the basic collection and compilation of this data as the responsibility of the mine operators. This is sensible because they are by far the best positioned to do so easily and accurately, using their existing internal reporting systems. It is also equitable, as they are generally the primary beneficiaries of the mining activity, and in many cases stand to benefit in the future from current data collection e.g. in having centralized data on the potential resources accumulated in mine tailings. Crucially, it also reduces demands on the limited resources of NSOs. Content from properly completed questionnaires from the mine operators can be transferred simply to the NSO's spreadsheets.

2.3 Non-metallic minerals

2.3.1 Concepts and classification

The OECD officially defines non-metallic minerals as “[...] stone quarries and clay and sand pits; chemical and fertilizer mineral deposits; salt deposits; deposits of quartz, gypsum, natural gem stones, asphalt and bitumen, peat and other non-metallic minerals other than coal and petroleum” (OECD 2001). These materials are widely available worldwide, and are mostly domestically sourced. If accounted by mass, the vast majority of the

materials of this category are sand, gravel, and clay used for construction, while the remainders are used either as decorative stones or for chemicals and fertilizers. Table 2.12 shows the proposed classification for non-metallic minerals. There is no clear distinction between those used for industrial purposes and those used for construction, since there is no clear and distinct differentiation between the two, and certain materials can be used for either industrial or construction purposes. Note that a category previously used in earlier EW-MFA for

slate, A.3.3, has been left vacant since this material category has been since been subdivided and incorporated as appropriate into A.3.1 and A.3.8.

The vast majority of non-metallic minerals are used for construction: sand, gravel, and clay are cheap materials widely available throughout the world, and provide suitable mechanical, thermal and

Table 2.12 Classification of domestic extraction of non-metallic minerals.

1 DIGIT	2 DIGITS	3 DIGITS	
A.3NON-METALLIC MINERALS	A.3.1 Ornamental or building stone		
	A.3.2 Carbonate minerals important in cement	A.3.2.1	Chalk
		A.3.2.2	Dolomite
		A.3.2.3	Limestone
	A.3.3 N/A		
	A.3.4 Chemical and fertilizer minerals		
	A.3.5 Salt		
	A.3.6 Gypsum		
	A.3.7 Clays	A.3.7.1	Structural clays
		A.3.7.2	Specialty clays
	A.3.8 Sand and gravel	A.3.8.1	Industrial sand and gravel
		A.3.8.2	Sand and gravel for construction
	A.3.9 Other non-metallic minerals n.e.c.		

Note: These items are compiled in Table A of UNEP's EW-MFA Compiler (see Annex 1).

durable characteristics to respond to constructors' requirements. In some cases, these materials are used without any further mechanical, thermal, or chemical processes: sand and gravel are used in road beddings or, in certain instances, to create a separating layer between buildings and the soil underneath; clay can be moulded into a cuboid

shape and dried in the open air to form a mudbrick (an unfired brick). More commonly, though, sand and gravel are mixed with cement, water and additives to form concrete, or with bitumen to form asphalt concrete, while clay, mixed with sand and other additives, is fired in a kiln to produce fired bricks.

Of all the materials extracted and produced each year, the category of non-metallic minerals grew the fastest in the past 40 years, and now constitutes most natural resources consumed every year (Schandl *et al.* 2017). At the same time, it is also the most underreported material category (Fischer-Kowalski *et al.* 2011), and many countries do not report on it at all. For this reason, a new methodology has been developed (Miatto *et al.* 2016) which uses cement, bitumen, and brick consumption as proxies to calculate raw non-metallic mineral consumption.

Being materials that are so extensively common in the Earth's crust, we assume that non-metallic mineral domestic extraction of a country coincides with its consumption. This is true for most countries in the world, given the very low economic value and high weight and volume of non-metallic minerals, with a few notable exceptions for very small and densely populated countries (e.g. Monaco, Singapore, Hong Kong).

2.3.2 Decision tree, data sources and availability

When compiling the EW-MFA, it will likely be necessary to source from a wide range of existing datasets, some of which might be already available in the government statistics, while others might need to be sourced from industrial association reports. To help the streamlining of this work, we prepared a flowchart (see figure 2.4) to guide the compilation of the EW-MFA.

In the case of ready available official government statistics of non-metallic minerals, these should be preferred. Ideally, these accounts will provide data in mass units, but when these are not available it is possible to apply conversion factors to convert the available units (volume or monetary) into

mass units. When non-metallic mineral accounts are not available in official government statistics, they might be retrieved from industrial association reports, with the same recommendations given above.

Unfortunately, official extraction statistics of non-metallic minerals are often scarcely available, since sand and gravel are often sourced from the overburden of ore mining, thus tending not to be reported. In these cases, an indirect accounting method should be used. Calculating the apparent consumption of cement, bitumen and bricks for a country can indirectly indicate its consumption of non-metallic minerals. Accounting for these materials is much more widely available, given their strategic importance and high economic value. These can be retrieved in official national statistical reports, but also from industry associations. The same caveats mentioned in the previous paragraph should be noted.

When none of the previous options is possible, major international data sets might be available (e.g. the British Geological Survey or the United States Geological Survey) where it is possible to find either a direct account of non-metallic minerals, or an account of their proxies (e.g. cement). These institutions compile their data sets from a multitude of sources, which are cross-checked for consistency, but this should be used as a last option when all others have failed to provide sufficient national data.

```

graph TD
    Q1{Do you have any government statistical reports in mass units for any 2-digit classification?}
    Q2{Do you have any government statistics in volume units for any 2-digit classification?}
    Q3{Do you have any detailed report in monetary units for any 2-digit classification?}
    Q4{Do you have any non-metallic minerals production reports from national industrial associations?}
    Q5{Do you have any alternative reports that you can use to empirically calculate the domestic consumption of non-metallic minerals?}
    
    Q1 -- YES --> A1[Report the 2-digit categories that are available in terms of tonnes/year in the MFA account]
    Q1 -- NO --> Q2
    Q2 -- YES --> A2[Apply a conversion factor (some noteworthy ones are available in the manual), then report the converted 2-digit categories in terms of tonnes/year in the MFA account.]
    Q2 -- NO --> Q3
    Q3 -- YES --> A3[Apply a conversion factor based on the national market value of the good, then report the converted 2-digit categories in terms of tonnes/year in the MFA account]
    Q3 -- NO --> Q4
    Q4 -- YES --> A4[Report the 2-digit categories that are available in terms of tonnes/year in the MFA account.]
    Q4 -- YES --> A5[Apply a conversion factor (some noteworthy ones are available in the manual), then report the converted 2-digit categories in terms of tonnes/year in the MFA account.]
    Q4 -- YES --> A6[Apply a conversion factor based on the national market value of the good, then report the converted 2-digit categories in terms of tonnes/year in the MFA account]
    Q4 -- NO --> Q5
    Q5 -- YES --> A7[Convert the report (e.g. cement, bitumen, bricks) to corresponding usage of non-metallic minerals using the conversion factors provided in the manual. Compile the results in the MFA account.]
    Q5 -- YES --> A8[Convert the report (e.g. cement, bitumen, bricks) to corresponding usage of non-metallic minerals using the conversion factors provided in the manual. Compile the results in the MFA account.]
    Q5 -- YES --> A9[Convert the report (e.g. cement, bitumen, bricks) to corresponding usage of non-metallic minerals using the conversion factors provided in the manual. Compile the results in the MFA account.]
    Q5 -- NO --> STOP[STOP  
No account can be constructed]
    
    A1 --- L1[YES, reported in mass units]
    A2 --- L2[YES, reported in volume units]
    A3 --- L3[YES, reported in monetary units]
    A4 --- L4[YES, from government statistics]
    A5 --- L5[YES, from national industrial sector reports]
    A6 --- L6[YES, from international statistics]
    
    L1 --- C1[Ideal]
    L2 --- C2[Good]
    L3 --- C3[Good]
    L4 --- C4[Good]
    L5 --- C5[Fair]
    L6 --- C6[Fair]
    STOP --- C7[Impossible]
  
```

Legend

- Ideal
- Good
- Fair
- Poor
- Impossible

2.3.3 Accounting methods and practical guidelines for data compilation

All data should be reported in mass units (e.g. tonnes). This is relatively common for the mining industry, but at times this may be reported in

volume units (e.g. cubic metres). In this case, the data should be converted to tonnes. Table 2.13 shows the conversion factors for some common non-metallic minerals, but ideally these values should be specific to the minerals extracted in the area of analysis.

Table 2.13 Specific densities for notable non-metallic minerals.

MATERIAL	DENSITY [t/m ³]
ORNAMENTAL AND BUILDING STONE	
Marble, solid	2.563
Granite, solid	2.691
Sandstone, solid	2.323
Porphyry, solid	2.547
Basalt, solid	3.011
Stone (default value if no other specifications are available)	2.5
CHALK AND DOLOMITE	
Chalk, lumpy	1.442
Dolomite, lumpy	1.522
Chalk and dolomite (default value if no other specifications are available)	1.5
SLATE	
Slate, solid	2.691
Slate, broken	1.29–1.45
Slate, pulverized	1.362

Table 2.13 Specific densities for notable non-metallic minerals. (Cont.)

MATERIAL	DENSITY [t/m ³]
Slate (default value if no other specifications are available)	1.4
LIMESTONE AND GYPSUM	
Gypsum, crushed	1.602
Limestone, broken	1.554
Limestone (default value if no other specifications are available)	1.5
CLAY	
Clay, dry excavated	1.089
Clay, wet excavated	1.826
Clay, dry lump	1.073
Clay, fire	1.362
Clay, wet lump	1.602
Clay, compacted	1.746
Clay (default value if no other specifications are available)	1.5
SAND AND GRAVEL	
Gravel, loose, dry	1.522
Gravel, with sand, natural	1.922
Gravel, dry 1.3 to 5.1 cm	1.682
Gravel, wet 1.3 to 5.1 cm	2.002
Sand, wet	1.922
Sand, wet, packed	2.082
Sand, dry	1.602

Table 2.13 Specific densities for notable non-metallic minerals. (Cont.)

MATERIAL	DENSITY [t/m ³]
Sand, loose	1.442
Sand, rammed	1.682
Sand, water filled	1.922
Sand with gravel, dry	1.65
Sand with gravel, wet	2.02
Sand and gravel (default value if no other specifications are available)	1.9

Source: (Eurostat 2013)

2.3.3.1 - A.3.1 Ornamental or building stone

This category consists of rocks that may be used in the form of tiles, slabs or blocks, for either structural or decorative purposes. It includes marble and other calcareous ornamental or building stone (e.g. travertine and alabaster), and granite, sandstone, and other ornamental or building stone (e.g. porphyry, basalt), as well as roofing stone. For these materials, data are often provided in cubic metres, and have to be converted to tonnes (see Table 2.13 for some notable conversion factors).

2.3.3.2 - A.3.2 Carbonate minerals important in cement

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. Dolomite is commonly used as crushed-rock aggregate, for cement production, and for other industrial and agricultural uses. Dolomite is often combined with limestone in statistical reporting. They are, however, differentiated in statistics by CPC codes at the 5-digit level.

Limestone is mostly used for cement production, followed by its use as crushed-rock aggregate. Limestone used for industrial purposes (e.g. production of lime or cement) is reported under EW-MFA classification item A.3.2, whereas crushed limestone aggregate is allocated to item A.3.8 (sand and gravel), and limestone as a dimension stone is assigned to item A.3.1 (ornamental or building stone).

Statistical reports have often underestimated limestone extracted for construction purposes, in particular for cement production. To check if it is necessary to correct for missing limestone extraction for cement production, the following estimation can be applied: take the corresponding

production figures for cement, and multiply these by a factor of 1.216. The ratio of 1.216 tonnes of limestone for the production of 1 tonne of Portland cement can be used as a typical value. Comparing this empirical value with that obtained from statistics will give a good indication of whether the reported values will need corrections. The higher number should be selected as data for the domestic material extraction of limestone (with a tolerance of ± 10 per cent in favour of using the original statistics figure). If limestone for other uses than cement is clearly indicated in statistics, this figure has to be added to the estimate for limestone for cement.

Limestone may be partially replaced by dolomite for cement production; this is referred to as dolomitic limestone. In cases where data for limestone are derived from an estimate described above, it should be verified whether this estimate includes use of dolomite (for cement production). Data reported for dolomite under A.3.2, if needed, has to be corrected for double counts.

2.3.3.3 - A.3.4 Chemical and fertilizer minerals

This group of minerals mainly comprises many types of minerals used in industry, including:

- Natural calcium or aluminium calcium phosphates, often combined under the heading “phosphate rock”, mostly used to produce fertilizers. These are also used in the production of detergents, animal feedstock, and a multitude of other minor applications.
- Carnallite, sylvite, and other crude natural potassium salts, often combined under the heading “potash”. Potassium is essential in fertilizers 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.

- 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, a fundamental feedstock to the chemical industry. Technical note: not all domestic sulphur production is accounted for in category A.3.4. Chemical and fertilizer minerals. For EW-MFA three principal types of sulphur can be distinguished: (1) Sulphur from mining: This sulphur should be accounted for in category A.3.4. (2) Sulphur produced in the refinery through desulphurization of petroleum resources. This sulphur is included in the amounts of extracted petroleum resources and should not be reported under A.3.4. (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.
- Baryte, which is 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. It is used for the preparation of rat poison, in the manufacture of glass and porcelain, and formerly for refining sugar.
- Borates, which are chemical products from borate minerals, which are used as wood preservatives. The most common borate mineral is boron.
- Fluorspar (fluorite), a colourful mineral which is industrially used as a flux for smelting, and in the production of certain glasses and enamels.

2.3.3.4 - A.3.5 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, and to prevent the formation of ice on roads.

2.3.3.5 - A.3.7 Clays

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 of kaolin 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 of clays and kaolin are in ceramics, medicine, bricks, as a food additive, in toothpaste, in other cosmetics, and 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, attapulgite, ceramic clay, fire (refractory) clay, flint clay, fuller’s earth, hectorite, illite clay, palygorskite, pottery clay, saponite, shale, special clay and slate clay. These should be accounted for in section A.3.7.2 Specialty clays.

Kaolin and other special clays are commonly well documented in statistics. Common clays and loams for construction purposes in particular for bricks and tiles are distinguished from special or industrial clays. Clay and loams for construction should be accounted for in A.3.7.1 Structural clays, but are often under-represented or excluded from statistics. production of clay products into amounts of crude clay. It is strongly advised to look for specific national sources (e.g. industrial associations) to convert data on production of clay products into amounts of crude clay. If national sources are not available conversion factors as shown in Table 2.14 could be used.

Table 2.14 Conversion factors for manufacture of bricks, tiles, and construction products, in baked clay.

PRODUCT	TYPICAL REPORTED UNIT	CONVERSION FACTOR ORIGINAL UNITS TO TONNES OF PRODUCT	CONVERSION FACTORS TONNES OF PRODUCT TO TONNES OF RAW CLAY	CONVERSION FACTOR PRODUCT IN ORIGINAL UNITS TO TONNES OF RAW CLAY
Non-refractory clay building bricks (excluding siliceous fossil meals or earths)	m ³	1.35135	1.349	1.822973
Non-refractory clay flooring blocks, support of filler tiles and the like (excluding siliceous fossil meals or earths)	kg	0.001	1.349	0.001349
Non-refractory clay roofing tiles	p/st (number of items)	0.00237	1.349	0.003197
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)	kg	0.001	1.349	0.001349
Ceramic pipes, conduits, guttering and pipe fittings: drain pipes and guttering with fittings	kg	0.001	1.349	0.001349

Table 2.14 shows the estimated average conversion factors to tonnes of crude clay for clay products as typically listed in statistical reports. The general conversion factor from kg of clay product to tonnes of crude clay was obtained from the existing EW-MFA manual used in Europe (Eurostat 2013). According to this manual, 1.349 tonnes of clay are required to produce 1 tonne of clay product.

Converting bricks reported in volume, or tiles reported in number of pieces, can be very challenging due to the large range of products available on the market. Ideally, a country-specific coefficient should be developed, but where not enough data are available, use a factor of 1,351 kg/m³ for bricks, or 2.37 kg/tile for clay roofing tiles. Note that these factors are derived from typical European commodities, and their values might differ from the typical bricks and tiles produced in other parts of the world.

The estimation result should be compared against the figures 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 of common clay and loam (with an eventual tolerance of about 10 per cent for using the original statistics figure).

2.3.3.6 - A.3.8 Sand and gravel

There are two major groups of sand and gravel which are distinguished by their principal uses: Industrial sand and gravel (A.3.8.1) and Sand and gravel for construction (A.3.8.2).

Industrial sands and gravels 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. Some statistical sources (e.g. the USGS) explicitly report sand and gravel in industrial production processes.

Sand and gravel for construction are used in structural engineering (e.g. buildings) and civil engineering (e.g. roads). The 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 layers in road construction, in concrete elements and for asphalt production.

Statistics for sand and gravel often under-report or fail to report the total amount extracted for both industrial and construction use. Frequently, only special sand and gravel for industrial use is included (see above). The following checks can be performed to find out if sand and gravel is inadequately reported or underestimated in statistical sources:

Table 2.15 Average consumption of non-metallic minerals per capita by world region.

WORLD REGION	YEARLY CONSUMPTION OF NON-METALLIC MINERALS PER CAPITA [t/cap] FOR 2010
Africa	1.5
Asia and the Pacific	6
Eastern Europe, Caucasus and Central Asia	3.5
Europe	5
Latin America and Caribbean	2.5
North America	5.3
West Asia	8.2
World (average)	4.8

Note: These values have been taken from Miatto *et al.* (2016), and refer to the year 2010

Source: (Miatto *et al.*, 2016).

The amount of sand and gravel per capita of the population in the respective year can be taken as an indicator. As a rule of thumb, if this amount significantly differs from the values shown in Table 2.15, it can be assumed that sand and gravel for construction purposes is not adequately reported and needs 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 should be estimated.

The following simple procedure to estimate sand and gravel for construction takes into account the most significant uses of sand and gravel. It combines an estimate of sand and gravel required for the production of concrete (step 1), sand and gravel

used in layers in road construction (step 2), gravel used in railway construction (step 3), and gravel used as a separation layer under buildings (step 4). In step 5 the total amount of sand and gravel is calculated as the sum of the results obtained from steps 1 to 4.

Step 1: Estimation of sand and gravel required for the production of concrete

Concrete is a mixture of cement, sand, gravel, water and additives. There are hundreds of different possible combinations of concrete, depending on the desired final characteristics and application. Ideally, to estimate sand and gravel used in concrete, constructors and experts in national construction habits should be consulted. If this is not viable, sand and gravel could be estimated as:

$$Sand_and_gravel_y = Cement_apparent_consumption_y \times 5.26$$

Where *Sand_and_gravel* is the amount of sand and gravel consumed in the year *y*, while *Cement_apparent_consumption* is the apparent consumption of cement in the year *y*. 5.26 is a coefficient that is used to find the corresponding sand and gravel

used to produce concrete.

Note that the apparent consumption of a generic substance/good is defined as:

$$X_{apparent_consumption} = X_{import} + X_{domestic_extraction} - X_{export}$$

Therefore, to calculate the apparent consumption of cement in year *y* it is necessary to sum all the cement imports and domestic production for year *y*, and subtract exports of cement for the same year.

Step 2: Estimation of sand and gravel required for the production and maintenance of roads

Based on information on the length of newly built roads (by type of road and year) it is possible to estimate sand and gravel used in road construction. Sand and gravel required for annual maintenance of the total existing kilometres of roads should also be

included.

In addition to information on the length of the road network, data on sand and gravel required to build one kilometre of a certain road type must be acquired. Each country has its own characteristics (e.g. typical soil, average traffic) which will determine the “typical” road type, therefore a consultation with national experts and local constructors is advisable to find the most realistic road type built in one’s country. If this is not possible, Table 2.16 provides data on sand and gravel requirements per km for construction and maintenance of roads.

Table 2.16 Requirements of sand and gravel for construction and maintenance of roads.

TYPE		SAND AND GRAVEL FOR CONSTRUCTION [t/km]	SAND AND GRAVEL FOR MAINTENANCE [t/km]
Non-surfaced	Rural	0	$0 \times \text{maintenance_interval}^{-1}$
	Urban	0	$0 \times \text{maintenance_interval}^{-1}$
Surfaced non-paved	Rural	210	$84 \times \text{maintenance_interval}^{-1}$
	Urban	252	$101 \times \text{maintenance_interval}^{-1}$
Low type pavement	Rural	355	$103 \times \text{maintenance_interval}^{-1}$
	Urban	532	$154 \times \text{maintenance_interval}^{-1}$
Intermediate type pavement	Rural	1722	$359 \times \text{maintenance_interval}^{-1}$
	Urban	1722	$359 \times \text{maintenance_interval}^{-1}$
High flexible type pavement	Rural	5265	$1026 \times \text{maintenance_interval}^{-1}$
	Urban	3948	$770 \times \text{maintenance_interval}^{-1}$
High composite type pavement	Rural	4988	$616 \times \text{maintenance_interval}^{-1}$
	Urban	4988	$616 \times \text{maintenance_interval}^{-1}$
High rigid type pavement	Rural	4821	$3811 \times \text{maintenance_interval}^{-1}$
	Urban	4821	$3811 \times \text{maintenance_interval}^{-1}$

The parameter *maintenance_interval* is the interval of time expressed in years between two scheduled maintenance events. Note that the column “Sand and gravel for maintenance [t/km]” calculates the material requirement for maintenance, but gives no information on the sources of these materials, i.e. whether these are extracted from virgin sources or down-cycled. When compiling EW-MFA reports

it is thus necessary to assess the origin of these materials to avoid double counting.

If sufficient data on road width is available, it is better to calculate the requirements of sand and gravel for roads using Table 2.17. The parameter *w* indicates the average road width and is expressed in metres.

Table 2.17 Sand and gravel requirements for construction and maintenance of roads per unit of width.

TYPE	SAND AND GRAVEL FOR CONSTRUCTION [t/km]	SAND AND GRAVEL FOR MAINTENANCE [t/km]
Non-surfaced	$0 \times w$	$0 \times w \times \text{maintenance_interval}^{-1}$
Surfaced non-paved	$84 \times w$	$34 \times w \times \text{maintenance_interval}^{-1}$
Low type pavement	$118 \times w$	$34 \times w \times \text{maintenance_interval}^{-1}$
Intermediate type pavement	$287 \times w$	$60 \times w \times \text{maintenance_interval}^{-1}$
High flexible type pavement	$439 \times w$	$86 \times w \times \text{maintenance_interval}^{-1}$
High composite type pavement	$416 \times w$	$51 \times w \times \text{maintenance_interval}^{-1}$
High rigid type pavement	$402 \times w$	$318 \times w \times \text{maintenance_interval}^{-1}$

A considerable amount of gravel is used as ballast under train tracks. National standards and experts should be consulted to obtain realistic values. If this

is not viable, the following formula can be used to calculate the indicative amount of gravel required to build 1 km of railway.

$$\text{Gravel_railway}_y = 2119.3 \times \Delta l \times g - 581.2$$

Where Gravel_railway_y indicates the amount of gravel used in the year y for railway construction expressed in tonnes, Δl is the length difference for the railway between two consecutive years (i.e. the length that has been built in a year) expressed in kilometres, and g is the width of the rail gauge expressed in metres.

This formula is derived from Japanese railway statistics, and a more detailed explanation can be found in Miatto *et al.* (2016).

Step 4: Estimation of sand and gravel required for building sublayers

Estimating gravel used in building sublayers is extremely complicated, given the vast variability in soil composition, groundwater depth, weather patterns, typical construction methods and average building loads which change not only from country to country, but from region to region within the same nation. A consultation with local experts is highly recommended.

For a rough estimation, it is possible to apply a very simple formula that converts concrete produced

in a country to the amount of gravel that goes into building sublayers.

$$\text{Gravel_sublayers}_y = \text{Sand_and_gravel}_y \times 0.08$$

Where Sand_and_gravel_y is the amount of sand and gravel used for concrete calculated in step 1, $\text{Gravel_sublayers}_y$ is the yearly amount of gravel used for building sublayers, and 0.08 is a conversion factor.

Step 5: Sum of all the previous estimates

Estimated figures for sand and gravel for concrete production (step 1), sand and gravel for road construction and maintenance (step 2), gravel for railway construction (step 3), and gravel for building sublayers (step 4) are finally added and compared with the figure for sand and gravel reported in the 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 per cent in favour of using the original statistics figure). If sand and gravel for industrial uses is given as a specific value in the statistics, this figure needs to be added to the estimated figure.

We note once again that the use of recycled sand and gravel should also be taken into account and subtracted.

2.3.3.7 - A.3.9 Other non-metallic minerals not elsewhere classified (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.3.9 are listed below.

Bitumen and asphalt, natural asphaltites and asphaltic rock: the largest use of asphalt is for making asphalt concrete for road surfaces. Only natural asphalt and bitumen are accounted for in this category. Note that bitumen for road construction is usually recycled, and this part should not be taken into account when calculating material extraction.

Precious and semi-precious stones: different stones such as pumice stone, emery; natural corundum, natural garnet and other natural abrasives are used for various industrial purposes. Synthetic diamonds are not reported under item 3.9 and they are not regarded as domestic extraction.

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

Quartz and quartzite: special types of silicon used e.g. in the optical industry and in metal manufacturing.

Siliceous fossil meals: minerals such as Kieselgur, Tripolite, Diatomite and other siliceous earths, used, for instance, as absorption agents or materials for heat insulation.

Asbestos: a fibrous mineral, now restricted in its use due to serious health hazards.

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

Feldspar: an essential component in glass and ceramic manufacture.

2.3.4 Specific issue: crushed rock

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 building 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 (carbonate minerals important in cement), A.3.6 (gypsum), A.3.8 (sand and gravel), and under A.3.9 (other non-metallic minerals n.e.c.). In addition, crushed rock may comprise other natural stones like sandstone, volcanic stones, basalt, granite, quartzite, gneiss and others.

The EW-MFA classification of stone minerals in Table 2.12 is not fully consistent with classifications specifying crushed stone (or rock) in national and international mining statistics. Possible other classifications may have the following characteristics:

- 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 double counting occurs.

It is therefore difficult to assess whether the production of crushed stone reported in various statistical sources is complete and without double counts. We recommend acquiring data on the domestic extraction of non-metallic minerals as described in this guide. Crushed rock should then be mainly covered by gypsum, chalk, dolomite, and limestone, and bitumen and asphalt rock.

The total for these minerals may then be compared with the total amount of crushed rock shown in national statistics. Where 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 of additional domestic extraction of crushed rock which cannot be further identified.

If so, add the additional amount of crushed stones to A.3.6 and add a footnote stating what amount of additional crushed stone had been added and by which method it has been estimated.

2.4 Fossil fuels

2.4.1 Introduction

Energy plays an essential role in almost all forms of human activity. A reliable and efficient energy supply is a prerequisite to a successful economy. Households need affordable and reliable energy for heating, light and domestic devices, while

businesses rely on energy to produce goods and services. However, growing worldwide demand for energy challenges the sustainability of supply and the impacts on the environment. It is essential for countries to monitor and manage their energy resources as well as aspects of energy production and use. Policy decisions in this context depend

on reliable and comprehensive data based on internationally agreed standards, classifications and other frameworks to ensure cross-country comparability and consistency over time (UNSD 2018).

Fossil fuels are still the major energy carriers worldwide. They are materials formed from biomass in the geological past and comprise solid, liquid and gaseous materials. The largest share in worldwide energy production is provided via burning different kinds of coal. Petroleum resources are mainly used to provide energy, but they also serve as base materials for industrial processes (e.g. for the production of organic chemical compounds and synthetic materials or fibres). Natural gas is used as an energy source for heating, cooking and electricity generation, but also as fuel for vehicles and for the manufacture of plastics and other commercially important organic chemicals.

In 2016, fossil fuels accounted for about 17 per cent of global material extraction. Coal accounted for more than half the of total DE of fossil energy carriers, followed by natural gas (~30%) and oil (~20%). The extraction of peat only has regional significance, for example, in Canada and some European Union countries (UNEP 2017).

The combustion of fossil fuels, principally coal, oil and natural gas, together with deforestation, soil erosion and animal agriculture, are the main sources for anthropogenic CO₂ emissions (i.e. emissions

produced by human activities). CO₂ is the most important anthropogenic greenhouse gas. Between 1970 and 2004 annual emissions grew by about 80 per cent. According to the International Panel on Climate Change (IPCC), atmospheric concentrations of CO₂ and CH₄ in 2005 exceeded by far the natural range over the last 650,000 years, with the global increases in CO₂ concentrations being caused primarily by fossil fuel use. As most of the observed increase in global average temperatures since the mid-20th century can very likely be attributed to the increase in anthropogenic GHG concentrations (IPCC 2007a), there is an urgent need to better manage and decrease worldwide use of fossil fuels.

Energy statistics and energy balances such as those reported to the IEA provide a comprehensive illustration of the supply and use of all energy carriers. In EW-MFA the domestic extraction of energy materials/carriers is limited to the extraction of fossil energy carriers. Hence, primary renewable energy carriers, such as hydro, wind, solar and geothermal energy are not included, although the materials required to construct e.g. hydropower plants, wind turbines or solar panels are considered in the metal or mineral accounts of the country where they are extracted. Biomass used for energy purposes is reported under biomass. The domestic extraction of the energy carrier uranium is reported under metals. Table 2.18 shows the classification of material flows for domestic extraction of fossil energy materials/carriers.

Table 2.18 Classification of domestic extraction of fossil fuels

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
A.4 FOSSIL FUELS	A.4.1 Coal and peat	A.4.1.1 Brown coal	A.4.1.1.1 Lignite (brown coal)
			A.4.1.1.2 Other sub-bituminous coal
		A.4.1.2 Hard coal	A.4.1.2.1 Anthracite
			A.4.1.2.2 Coking coal
			A.4.1.2.3 Other bituminous coal
		A.4.1.3 Peat	
	A.4.2 Crude oil, natural gas and natural gas liquids	A.4.2.1 Crude oil	
		A.4.2.2 Natural gas	
		A.4.2.3 Natural gas liquids	
	A.4.3 Oil shale and tar sands		

Note: These items are compiled in Table A of UNEP's EW-MFA Compiler (see Annex 1).

2.4.2 Data sources and availability

2.4.2.1 -Data sources and data collection

According to the UNSD (2018), four main sources of energy statistics exist (see Table 2.19). For the compiler of EW-MFA on fossil fuels, the most straightforward approach is to start by checking

whether the IEA and/or UNSD provide data for the country under observation. If yes, it is very likely that data are collected already by an official body, and thus can be adjusted to fit the EW-MFA structures (see below). If such data do not exist, other sources can be used.

Table 2.19 Sources for energy statistics.

DATA SOURCE	CHARACTERISTICS
Administrative data	Derived from an administrative source, that is, by an “organizational unit responsible for implementing an administrative regulation (or group of regulations) for which the corresponding register of units and the transactions are viewed as a source of statistical data” ¹⁴
Statistical surveys	Sample surveys and censuses
Modelling	Estimation of a variable/data item which cannot be measured directly, but is estimated based on measurable and observable data
In situ measurements	Techniques to collect detailed consumption data based on a measuring device which, for example, can be installed at the point of final consumption

Source: (UNSD 2018)

Each of these data sources has advantages and disadvantages. The objective should be to collect data by the most efficient means possible. In the best case, data are already available from an administrative source or an existing survey. Where such information of suitable quality is not available, existing surveys could be complemented by additional questions, or a new survey could be

considered. Another data source is administrative systems, as the production of energy is often a licensed activity (UNSD 2018).

The UNSD Manual identifies the following suitable instruments and respondents for data on primary production of solid, liquid and gaseous energy products.

Table 2.20 Suitable instruments and respondents depending on information needs identified.

DATA COLLECTION METHOD	DATA SOURCES	POTENTIAL DATA OBSERVED
Administrative data	Data owners	Coal production
Census/sample survey	Entities in the mining industry (coal, oil, gas)	Crude oil production Natural gas production

Source: (UNSD 2018)

¹⁴ OECD Glossary of Statistical Terms <http://stats.oecd.org/glossary/>

2.4.2.2 - Existing reporting

Mining statistics, energy statistics and balances compiled by national statistical institutions provide data on the extraction of petroleum resources and other fossil energy carriers. Data quality is usually high for all subcategories. Also, the structure of the EW-MFA tables is compatible with the data provided to, for instance, the IEA (see below).

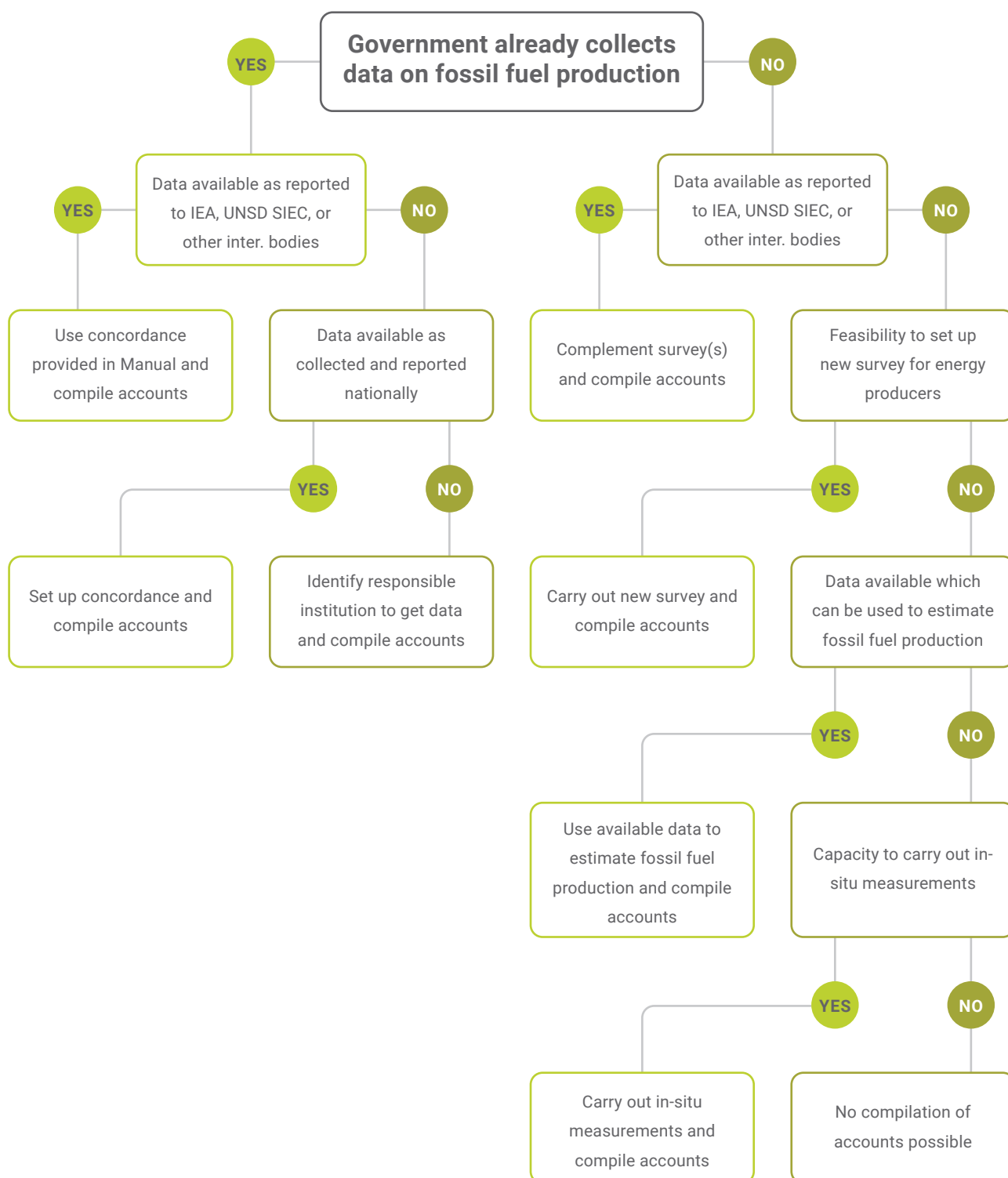
As a first step, compilers should check data availability by reviewing which data sets have already been compiled in compliance with (international) regulations. If the IEA or UNSD reports data on a specific country (<https://www.iea.org/data-and-statistics>, <https://unstats.un.org/unsd/energystats/pubs/yearbook/>), it is very likely that some local source is already reporting official data to the IEA. It should thus be possible to get these data directly from that source.

The two main international reporting requirements on fossil fuels are:

- Reporting to the IEA
- Reporting to UNSD for the Energy Statistics Database¹⁵

In general, data reported to international organizations such as the IEA or UNSD contain a considerably higher level of detail than needed for EW-MFA. Hence, the reported data can be used to populate material flow accounts. But reporting to IEA is not only beneficial for completing EW-MFA accounts. The detailed, industry-specific data reported to the IEA is important for improving footprinting work (see Chapter 7), and it allows a greater understanding of the physical structure of the economy.

¹⁵ The UNSD Annual Questionnaire on Energy Statistics is sent every year to national statistical offices, ministries of energy and other authorities responsible for energy statistics in countries.

Figure 2.5 Decision tree for sourcing data for fossil fuel extraction accounts.

2.4.3 Fossil fuels classification in EW-MFA versus UNSD SIEC

In 2016 the UN Statistical Division published the UNSD Standard International Energy Product Classification (SIEC) as part of the International Recommendations for Energy Statistics (IRES) (UNSD 2016). Data compiled under the SIEC perfectly

fit the EW-MFA structure; however, only a small section needs to be used, as the SIEC also discerns energy products in addition to energy carriers.

Table 2.21 illustrates the SIEC items that can be used for completing EW-MFA.

Table 2.21 Fossil fuels in EW-MFA versus UNSD SIEC.

EW-MFA CODE	EW-MFA NAME	SIEC CODE	SIEC NAME	UNSD
A.4.1.1.1	Lignite (brown coal)	022	Lignite	LN
A.4.1.1.2	Other Sub-Bituminous Coal	021	Sub-bituminous coal	SB
A.4.1.2.1	Anthracite	011	Anthracite	AT
A.4.1.2.2	Coking coal	0121	Coking coal	CC
A.4.1.2.3	Other bituminous coal	0129	Other bituminous coal	OB
A.4.1.3	Peat	111	Sod peat	PT
		112	Milled peat	PT
A.4.2.1	Crude oil	410	Conventional crude oil	CR
A.4.2.2	Natural gas	300	Natural gas	NG
A.4.2.3	Natural gas liquids	420	Natural gas liquids (NGL)	GL
A.4.3	Oil shale and tar sands	200	Oil shale / oil sands	OS

2.4.3.1 - Alternative sources

Where there is a lack of data, international databases for fossil energy materials are provided by the International Energy Agency, the United Nations Energy Statistics, the US Energy Information Administration (EIA) and the data collections of the USGS and the BGS.

Extraction of the various types of coal, crude oil, and natural gas is reported by all of these databases and can be used to compile material flow accounts. Differences in the reported values across sources normally stem from variances in definition or unit conversion procedures. It is strongly recommended that EW-MFA practitioners collaborate with the

personnel responsible for compiling the energy data reported to the sources mentioned above.

Where data on the extraction of all petroleum resources and other fossil energy carriers are reported in mass units, they can be integrated into EW-MFA without further processing. Values given in volume or energy content have to be converted into mass units. Country-specific factors should be applied for these conversions, as the technical characteristics of petroleum resources vary from region to region.

2.4.4 Accounting methods and practical guidelines for data compilation

Some countries report energy balances giving the supply and use of energy by different specific industries. For compiling EW-MFA data on domestic material extraction of fossil energy materials/carriers, energy balance data on domestic production of fossil energy carriers should be used as the primary source. In the following, the definitions for all categories are provided based on the Eurostat compilation guide (Eurostat 2013).

Category A.4.1 includes all forms of coal. The grouping of coals here is based largely on the

concept of coal “rank”. Peat can be thought of as the lowest rank of coal, or more properly as its precursor. Peat (A.4.1.3) is a soft, often spongy organic material composed mainly of partly decayed plant material, minor mineral matter, and having a very high moisture content (see below). Placing peat under increased levels of pressure and temperature over prolonged (geological) timescales increases the rank of coal.

Increasing rank roughly translates to a major reduction in moisture content and volatile organic components, which also increases both the hardness and effective useful heat content per tonne of coal (especially as we move from lignite up to the bituminous coals). The lowest ranked true coal, lignite (A.4.1.1.1), tends to have a soft, brown, earthy texture and still have a high moisture content. Higher ranked sub-bituminous coals (A.4.1.1.2) tend to be dull black, while bituminous coals (A.4.1.2) are shiny and black with high heating value (thus very effective for thermal electricity generation). The highest ranked coal, anthracite (A.4.1.2.1), is hard, black and shiny and has very low moisture and volatiles content, making it preferred for high value metallurgical uses.

2.4.4.1 - A.4.1.1 Brown coal

Table 2.22 Materials included in the brown coal category.

RAW MATERIAL	DEFINITION
Lignite / brown coal	Non-agglomerating coal with a gross calorific value <17.4 MJ/kg containing more than 31 per cent volatile matter on a dry mineral matter free basis
Other sub-bituminous coal	Non-agglomerating coals with a gross calorific value of 17.4–23.9 MJ/kg, containing more than 31 per cent volatile matter on a dry mineral matter free basis

2.4.4.2 - A.4.1.2 Hard coal

Table 2.23 Materials included in the hard coal category.

RAW MATERIAL	DEFINITION
Anthracite	
Coking coal	Gross calorific value >23.9 MJ/kg
Other bituminous coal	

2.4.4.3 - A.4.1.3 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 purposes. Non-energetic use accounts for a substantial proportion of total peat extraction. Hence, under this category, all kinds of peat – for energetic as well as non-energetic use – have to be reported.

Note: In cases where there are no national sources available, USGS can be used as comprehensive source¹⁶.

For the conversion of cubic metres of dry peat into tonnes the following conversion factor can be used (UN 1987): 1 m³ = 0.753 t.

¹⁶ The USGS Minerals Information has a section on Peat Statistics and Information available at <https://www.usgs.gov/centers/national-minerals-information-center/peat-statistics-and-information>. For data on worldwide national production refer to the Mineral Yearbook, Table 9.

2.4.4.4 - A.4.2 Crude oil, natural gas and natural gas liquids

Table 2.24 Materials included in the crude oil, natural gas and natural gas liquids category.

RAW MATERIAL	DEFINITION
Crude oil	Mineral oil consisting of a mixture of hydrocarbons of natural origin
Natural gas	Liquefied or gaseous gases occurring in underground deposits, consisting mainly of methane; including 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)
Natural gas liquids (NGL)	Liquid hydrocarbons, generally three to eight carbon atoms per molecule dissolved in natural gas in a hydrocarbon reservoir, extracted with the gas stream. The lighter components (three to four carbon atoms, largely propane, butane, butylenes, propylene and isomers thereof) are gaseous at standard temperatures. The heavier components (five to eight carbon atoms), generally liquid at standard temperature and pressure, constitute the "condensates".

In addition to crude oil recovered from conventional oil wells, and using enhanced recovery techniques including hydraulic fracturing (fracking), the crude oil component of this category will also include all extraction of petroleum from oil sands which takes place in situ i.e. where the oil sand is left in place, but the petroleum component is extracted directly by such techniques as steam and/or solvent injection. The same principle applies to oil shales, if/where there is any direct extraction of petroleum products without first physically excavating the host rock. Quantities of produced natural gas are measured after purification and extraction of NGL and sulphur.

Re-injected gas, quantities vented or flared (so-called total dry production) are reported separately in energy statistics and should be included where possible.

Note: Data in mass units can be integrated without further processing into the EW-MFA. However, the production of natural gas is often reported in volume or energy content ("gross calorific value", GCV). For conversion into metric tonnes ideally region-specific factors should be applied. Where no such data are available, average factors can be applied.

Table 2.25 Conversion factors of natural gas.

kg / m ³ (STANDARD CUBIC METRE AT 15 °C)	GCV [MJ/kg]	GCV [MJ/m ³]
0.8	50	40

Source: (Eurostat 2013)

NGL are light hydrocarbons, generally containing three to eight carbon atoms per molecule dissolved in associated or non-associated natural gas in a hydrocarbon reservoir, extracted within a gas stream. The lighter components (three to four carbon atoms, largely propane, butane, butylenes, propylene and isomers thereof), which are gaseous at standard temperatures, are generally separated in processing or refining as the LPG product. The heavier (five to eight carbon atom) components,

which tend to be liquids at standard temperature and pressure, are the “condensates”. If both condensates (particularly “lease condensates”) and NGL are recorded separately, they should generally be added together to get DE of NGL. In contrast, where LPG is recorded separately, it should NOT be added to DE. LPG is generally a refinery product, and so should already have been included as part of the NGL. Adding LPG would be double counting.

2.4.4.5 - A.4.3 Oil shale and tar sands

Table 2.26 Materials included in the oil shale and tar sands category.

RAW MATERIAL	DEFINITION
Oil shale	Sedimentary rock containing kerogen, a solid organic material
Tar sands	Naturally occurring bitumen-impregnated sands that yield mixtures of liquid hydrocarbon and require further processing other than mechanical blending before becoming finished petroleum products

As outlined under A.4.2, petroleum products extracted directly from oil sands or oil shales left in situ should be accounted for directly as part of that category. It is only where the oil sand or oil shale is physically excavated, and then either processed or used directly, that it should be accounted for in category A.4.3. When the oil sand or oil shale is physically excavated, all of the excavated component which is then processed or used directly should be counted, not just the petroleum component extracted. If only the petroleum product extracted is recorded in this instance, a default factor of 2 tonnes of oil sand per barrel of oil can be applied (Eurostat 2013), however, it is much better to try to source local coefficients. For oil shale, the factors are likely to be considerably different to this and highly specific to location. At the time of writing, however, petroleum production

from true oil shales was insignificant, with world production dominated by production from one country (Estonia) where most of the production was burned directly to produce thermal electricity.

Note: the name “oil shale” is a possible source of confusion in this category. The important defining characteristic of the oil shales in category A.4.3 is that they do not in fact really contain oil, but rather kerogens which need to be further heat treated before they become petroleum. In recent years, however, hydraulic fracturing technologies have been successfully employed to extract a lot of ordinary petroleum directly from oil reservoirs which previously had insufficient permeability to permit conventional extraction. These “tight” reservoirs are also frequently referred to as “shale” reservoirs, and the extracted product loosely

termed “shale oil”. This process and product are totally distinct from oil shales, and belong entirely with the conventionally produced oil in category A.4.2.



3 Trade of Materials

3.1 Concepts and classification

3.1.1 Concepts

The method of accounting for the trade of materials outlined in this guide aims to capture the maximum amount practicable in physical mass terms, in categories closely aligned to those used for the domestic extraction sections, while not introducing large errors from excessive back calculation / modelling of tonnages, or miscategorization of traded materials.

A major difference in assembling physical trade accounts compared to domestic extraction accounts is that there is little risk of multiple counting of the same material in trade accounts. For example, when assembling DE accounts, care must be taken not to include wood when it is first harvested, then again possibly as sawn wood, wood chips or pulp, and possibly a third time as paper or other wood products. This is generally not a problem for trade, as once a product is exported in one form, it cannot logically be exported again in another (at least not unless it is re-imported first). As a result of this, the scope of materials and products accounted for in the EW-MFA trade accounts is much larger. Where DE only accounts for wood as it is extracted from the environment, the trade account will seek to include processed wood and wood products. Similarly, where DE accounts for petroleum count mainly crude oil and natural gas liquids, traded petroleum accounts should also include refined fuels and other secondary petroleum products.

While the scope of products in the EW-MFA trade accounts is much broader than DE accounts, no attempt is made to account for the “embodiment” of natural resources in physical trade, apart from those materials which are directly, physically traded. The tonnages of materials required to produce a product, but which are not a physical part of the final traded product, are not counted for in physical trade. For example, while one tonne of aluminium metal may have required several tonnes of bauxite and several tonnes of coal (for the required electricity) to produce, only the single tonne of traded aluminium is counted in the trade account. Accounting for embodied materials in energy is the concern of different methodologies, notably of material footprinting.

While the range of products counted for trade is much wider than for DE, the scope of actual materials which should be included is the same, that is, care should be taken not to include materials such as additional water, or gases from the atmosphere, which are not counted in DE. The former can be of importance for some biomass products, while the latter can matter for fertilizers (discussed in sections 3.3.1 and 3.3.3 respectively).

Materials which enter and leave a country merely en route to their destination are known as transit flows, and should not be counted in either import or export accounts.

3.1.2 Classification – detail

The classification scheme used for physical trade is given in Table 3.1. In this case, the classifications are for imports, which are defined with a B prefix, but correspond directly to the system used for exports, which simply uses a C prefix in the code.

The categories have been chosen to correspond as closely as possible with the categories used for domestic extraction, but there are a few additional categories. This is to allow the capture of additional goods which have been processed to some degree,

and even some manufactured goods where they are dominated by specific material categories. This is mainly reflected in the categories which have a “compound” suffix. As an example, B.4.compound would allow the compiler to record significant tonnages of tyre imports, which are usually composed mainly of rubber, or of petrochemical origin, but also have significant components of metals, and perhaps some biomass-based rubber.

More detailed information on how to use this system when constructing physical trade accounts is given in the materials-specific sections below.

Table 3.1 Classification of physical trade.

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
B.1 BIOMASS	B.1.1 Crops, raw and processed	B.1.1.1 Cereals	B.1.1.1.1 Rice
			B.1.1.1.2 Wheat
			B.1.1.1.3 Maize
			B.1.1.1.4 Cereals n.e.c.
		B.1.1.2 Roots, tubers	
		B.1.1.3 Sugar crops	
		B.1.1.4 Pulses	
		B.1.1.5 Nuts	
		B.1.1.6 Oil bearing crops	
		B.1.1.7 Vegetables	
		B.1.1.8 Fruits	
		B.1.1.9 Fibres	
		B.1.1.10 Spice, beverage, pharmaceutical crops	
		B.1.1.11 Tobacco	
		B.1.1.12 Other crops n.e.c.	

Table 3.1 Classification of physical trade. (Cont.)

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
B.1 BIOMASS	B.1.2 Crop residues (used) and fodder crops	B.1.2.1. Straw	
		B.1.2.2 Other crop residues (sugar and fodder beet leaves, other)	
		B.1.2.3 Fodder crops (including biomass harvest from grassland)	
	B.1.3 Wood and wood products	B.1.3.1 Timber (Industrial roundwood)	
		B.1.3.2 Wood fuel and other extraction	
	B.1.4 Wild fish, aquatic animals and plants	B.1.4.1 Wild fish catch	
		B.1.4.2 All other wild aquatic animals	
		B.1.4.3 Aquatic plants	
	B.1.5 Live animals and products (excluding wild fish, aquatic animals and plants)	B.1.5.1 Live animals (excluding wild fish and animals)	
		B.1.5.2 Meat and meat preparations	
		B.1.5.3 Dairy products, birds eggs, and honey	
		B.1.5.4 Other products from animals	
	B.1.compound Mixed /compounded products mainly from biomass		

Table 3.1 Classification of physical trade. (Cont.)

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
B.2 METAL ORES	B.2.Fe Iron ores and concentrates, iron and steel, products dominated by iron content		
	B.2.Al Aluminium ores and concentrates, aluminium metal, products dominated by aluminium content		
	B.2.x X ores and concentrates, X metal, products dominated by X (where X is a specific metallic element other than iron or aluminium)		
	B.2.compound Mixed /compounded products mainly from metal		
B.2.MMETAL CONTENT	<i>B.2.Fe.m Iron ores metal content (memo item)</i>		
	<i>B.2.Al m Aluminium ores and metal content (memo item)</i>		
	<i>B.2.x m X ores metal content, where X is a specific metallic element other than iron or aluminium (memo item)</i>		
B.3 NON-METALLIC MINERALS	B.3.1 Ornamental or building stone		
		B.3.2.1 Chalk	
		B.3.2.2 Dolomite	
	B.3.2 Carbonate minerals important in cement	B.3.2.3 Limestone	
		B.3.2.4 Cement and its products	
	B.3.4 Chemical and fertilizer minerals		
	B.3.5 Salt		
	B.3.6 Gypsum and its products		

Table 3.1 Classification of physical trade. (Cont.)

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
B.3 NON-METALLIC MINERALS	B.3.7 Clays	B.3.7.1 Structural clays and their products	
		B.3.7.2 Specialty clays	
	B.3.8 Sand and gravel	B.3.8.1 Industrial sand and gravel	
		B.3.8.2 Sand and gravel for construction	
	B.3.9 Other non-metallic minerals n.e.c.		
	B.3.compound Mixed /compounded products mainly from non-metallic mineral		
B.4 FOSSIL FUELS	B.4.1 Coal and peat	B.4.1.1 Brown coal	B.4.1.1.1 Lignite (brown coal)
			B.4.1.1.2 Other sub-bituminous coal
		B.4.1.2 Hard coal	B.4.1.2.1 Anthracite
			B.4.1.2.2 Cooking coal
			B.4.1.2.3 Other bituminous coal
		B.4.1.3 Peat	
		B.4.1.4 Coal derived products n.e.c.	
	B.4.2 Conventional petroleum and gas	B.4.2.1 Crude oil and liquid petroleum products	
		B.4.2.2 Natural gas and gaseous petroleum products	

Table 3.1 Classification of physical trade. (Cont.)

1 DIGIT	2 DIGITS	3 DIGITS	4 DIGITS
B.4 FOSSIL FUELS	B.4.3 Oil shale and tar sands		
	B.4.compound Mixed /compounded products mainly from fossil fuels		
B.5 MIXED/ COMPLEX PRODUCTS n.e.c.			
B.6 WASTE FOR FINAL TREATMENT AND DISPOSAL			

Note: Imports of items are compiled in Table B of UNEP's EW-MFA Compiler (see Annex 1), while exports should be compiled in Table C.

3.2 Data sources

The statistical agencies of around 200 countries are already reporting trade statistics to the UN Comtrade. This means that in most countries, a practical first step is to determine who within the NSO is currently responsible for this, then ask how they source their primary data.

Locating the local source for data being reported to Comtrade is a good first step, however for biomass and fossil fuels, in many cases the local NSO or other government agencies may be reporting separate trade data to the FAO (biomass), or to the IEA (fossil fuels), in response to questionnaires. If so, it is good practice to locate the local agents responding to the FAO and/or IEA, as the trade data held by these agencies for their specific materials often appears superior to that reported to Comtrade, perhaps due to the greater domain-specific focus of these organizations. The FAO makes its trade data

freely available online, so it makes sense to obtain a copy of this for your country, however this should then be compared against original data provided by your local agencies. The reason is that the FAO does considerable quality control work, and also makes its own estimates for categories. The origin of each entry in FAO data is usually clearly indicated. The local agencies compiling the EW-MFA should be well placed to source local expertise to determine which estimate should be adopted.

Where there is no organized reporting by local agencies to Comtrade, the FAO, IEA etc., it is still likely that a local authority is recording measures of imports and exports for certain materials for the purposes of taxation. This may be the responsibility of local port authorities, customs/border control agencies, or taxation departments. The ability to reconstruct physical trade accounts from such

data will largely depend on how well the taxation categories can be mapped to physical categories, whether taxes are levied on a physical or financial

basis (\$ per tonne versus percentage of dollar value) and how reliably monetary values can be converted to physical tonnes.

3.3 Accounting methods and practical guidelines for data compilation

The most important practical matter to keep in mind when compiling EW-MFA trade accounts is that they are physical accounts, measured in tonnages, and that the great bulk of traded tonnage is accounted for by a relatively small number of low unit value (\$ per kg), primary or near primary commodities¹⁷. This situation is almost the reverse of financial accounts, where many of the largest value items relate to activities with very high unit values (in some cases, these products and services have little or no direct material content at all).

As a consequence, when compiling EW-MFA, the same effort invested in ensuring that a few major bulk commodities accounts are correct will yield a vastly greater improvement to the accuracy of the accounts than the same effort expended on trying to refine accounts for high unit value products. While the classification systems used in reporting trade typically have many thousands of categories, for most countries less than 1 per cent (and often

<0.1 per cent) of these categories will account for >90 per cent of the total tonnage of trade.

Another reason not to devote much effort to accounting for higher unit value goods in physical trade accounts is that many of the more elaborately transformed goods tend to contain materials from many different materials categories, and the proportions of these are difficult to determine and highly variable. To illustrate, \$1,000 worth of smart phones will contain less than 0.5 kg of materials, split across at least four different major materials categories (ferrous ores, non-ferrous ores, non-metallic minerals and fossil fuels). \$1,000 worth of iron ore (or rice, or crude oil) will account for thousands of times this material, all of which can be cleanly allocated to one specific category.

A final reason not to devote much effort to accounting for higher unit value goods is that they are rarely recorded in weight terms, but rather as

¹⁷ The term “Near primary” commodities is used here to indicate proximity to the original primary materials along a value-adding chain. Where iron ore and coal are primary commodities, things like pig iron and crude steel can be thought of as near primary, being early stages of subsequent economic transformation, and having a substantial portion of their monetary value accounted for by the cost of inputs of primary materials. Things like smartphones, aircraft, and scalpel blades get almost all of their monetary value from more and more elaborate transformations further along a value-adding chain, and so are nowhere near primary.

counts of individual units, and/or in monetary value terms. The relationship between individual product items, or their values, and their physical mass is often highly variable, so any attempt to convert to physical trade is perhaps as likely to introduce error as improve the account¹⁸.

The following sections dealing with compiling each of the major traded materials categories will refer repeatedly to the classification scheme presented in Table 3.1. While Table 3.1 refers specifically to imports, the structure of the exports table is identical except that the prefix B and word “Imports” should be substituted for C and “Exports” respectively. The four major material categories are named so as to align exactly with those used in the DE accounts, however, trade category names can reflect either a primary material directly, or the primary material from which a product was mainly derived. This is made clear in the 2-4-digit level subcategory names. The 2-digit subcategories include an extra subcategory, with suffix “.compound”, over those present in DE accounting. This category is provided to accumulate tonnages of traded products which are judged to be clearly dominated by one of the main material categories, but which are mixed and impractical to attribute accurately across more specific subcategories.

3.3.1 Traded biomass

For biomass, the 2-4-digit level descriptions should cover the great bulk of the relevant biomass primary and near primary materials. For example, things like wheat, wheat flour, rye bread, pre-mixed bread doughs, kibble etc. would go under B.1.1.1.2

or B.1.1.1.4 depending on the degree to which the compiler is able to ascertain the cereal(s) used. While bread has other components besides cereals, in most cases the cereal component is sufficiently dominant that placing it under B.1.1.12 or B.1.compound would probably unnecessarily lose information. As always, local information should take precedence, so if the compiler happens to have good information indicating that the great majority of flour or bread internationally traded in their country actually uses mainly banana flour, for example, then they should not hesitate to classify the tonnage of traded bread under B.1.1.8. The goal is to reflect the dominant original primary materials as closely as practicable.

Similarly, if the compiler has ready access to data which indicates that they trade large volumes of a mainly cereal product which is 30 per cent wheat, 30 per cent rice, 20 per cent other crop-based materials (non-specified), and 20 per cent meat processing by-products, then the optimum solution would be to allocate those percentages of the traded weight of that product to B.1.1.1.2, B.1.1.1.1, B.1.1.12, and B.1.5.2 respectively. In the absence of such detailed compositional information, a similar product could be classified under B.1.compound. In a third case for a similar product where the compiler knows the product is 50 per cent wheat and 50 per cent other things dominated by unspecified biomass, then splitting the total tonnage evenly between B.1.1.1.2 and B.1.compound would be appropriate.

The above examples illustrate the general approach to take. Again, at all times the compiler

¹⁸ Tables which convert products classified under the CN system to weights have been assembled in some of the annexes to Eurostat (2013). These may provide some guidance to the compiler, however, whether these factors accurately reflect local products, whether broadening the accounts is likely to introduce more error than it removes, and whether it is a worthwhile expenditure of effort, are all questions the compiler should consider before using them.

should consider whether the time spent finding the information required to perform such detailed allocations would not be better spent checking and refining large tonnage items elsewhere in the accounts, e.g. perhaps ensuring bulk cereals trade is correct to within a few per cent.

One issue which can affect some biomass products that the compiler needs to be aware of relates to beverages. The bulk of many beverages is water which has been added to relatively minor quantities of crop-derived products, and so should not be counted. This is the case for things like sugary soft drinks and beer. On the other hand, for wine and fruit juice concentrates, the contained water is actually derived from the crop as it was harvested, and so should be counted to remain consistent with the DE accounts. While volumes of such liquids can be converted reasonably well to tonnes (usually in the range of 1.0–1.5 tonnes per m³), unless the compiler can exclude the major added water products (beer and soft drinks), or is sure they are a relatively minor component, it may be best to exclude beverages from the trade account entirely. Similarly, while most dairy products should be counted under B.1.5.3, liquid milk should be either be excluded entirely, as it is >85 per cent water, or have its apparent tonnage reduced accordingly. This is because the great majority of that water is not derived from the cow's biomass intake, but instead from additional water it drinks.

Most high tonnage biomass product flows will be recorded in tonnes or other mass units, however a number of products are recorded in volumetric units, individual pieces, or even area or length units. This is common with wood products. For example, of the major categories most countries will already be reporting to the FAO, the various types of wood pulp and paper are typically recorded in tonnes,

and can enter the accounts directly. Industrial round wood, fuelwood, sawn wood, particle board and other components are recorded in m³, and by type (coniferous or non-coniferous), so these must be converted to tonnes using coefficients, such as those provided in the Wood DE section, or by using specific local coefficients where possible.

While things like wood chips and particle board appear in FAO statistics as either tonnes or m³, a compiler should check whether the original data supplied by the local agency was provided in these units. Things like particle board and sawn wood are quite often originally recorded in m² or linear metres. If so, the compiler should independently check if the conversion to m³ or tonnes appears reasonable given local knowledge. Note that the densities of wood, wood particles, and particle board per m³ will all vary widely, even where made from identical tree species. This is due to the introduction of air-filled voids for the granulated products, and compression for the board products. Again, locally relevant coefficients are best here, but a good range of densities for different woodchips is available at https://www.simetric.co.uk/si_wood.htm (along with a wide variety of densities for other bulk commodities, both biomass and mineral).

3.3.2 Traded metal ores

There is no equivalent international agency which has achieved a standard of centralized reporting on minerals, either metallic or non-metallic, comparable to what the FAO or IEA have achieved for biomass and fossil fuel respectively. There should be a local agency responding to Comtrade questionnaires, which have categories for metal ores and concentrates, and for a wide variety of metal products. Unfortunately, the categories used by Comtrade do not distinguish well between some large tonnage, very different products (e.g. the ores

and concentrates of individual metals are pooled). Also, deriving adequate factors to convert the units used to record many products (e.g. number of items) to tonnages can be difficult and subject to large error. As a result, accounting comprehensively for this category can be very challenging, and the risk of increasing error through trying to include too many products is high. The compiler should reflect often on whether they have reached the point where attempting accounting for more products is likely to introduce more error than it removes.

The existing harmonized system (HS) scheme of reporting to Comtrade already uses a classification system based on a relatively detailed disaggregation of ores and concentrates according to the main metal contained, e.g. “2603. Copper ores and concentrates”. Consequently, it is more practical for the EW-MFA categories for metal ores trade to follow the system used for contained metals rather than the mined ores outlined in section 2.2.1. The resulting categories are thus constructed as B.2.x where x is the main metal e.g. B.2.Fe for iron ores and concentrates.

Much less emphasis is placed on trying to record the detailed composition of metal ores traded than was the case for domestic extraction. This is because there is unlikely to be any data recorded for trade comparable to the detailed operational data that mine operators routinely assemble. In the event that such detailed data on the metal content in traded ores and concentrates are available, or can be calculated, this should be accounted for using the appropriate contained metals code. These additional codes deal with the pure metal content that can be accounted for, and are constructed B.2.x.m, where x is the main metal e.g. B.2.Cu.m and C.2.Cu.m for contained copper in imports and exports respectively. As with DE, the contained metals accounts are kept separate

from the main trade account, and **not** added when creating totals, as this would be double counting. While traded metal ores are categorized using individual metals, these are aggregated under the three-category system B.2.Fe (for iron), B.2.Al (for aluminium), and B.2.x (for all others), plus one additional category B.2.compound (for compound products made mainly of metals).

The main tonnages that can safely be accounted for will be in primary or near primary products. For example iron ore and concentrates, pig iron, steel, scrap iron and steel, basic steel products such as bars, beams etc. (if recorded in tonnes) should account for the bulk of B.2.Fe; bauxite, alumina, aluminium ingots, basic aluminium products are allocated to B.2.Al; and other metal ores, concentrates, basic products, and compounds such as copper sulphate, titanium oxide, rutile, etc. for the bulk of materials under B.2.x.

In some cases, it may be worth trying to account for some complex manufactured items where it is clear they contain significant quantities of materials which can reasonably be separated. For example, while the exact average composition and weight of cars traded differs between nations and years, rather than ignoring this flow completely, the compiler could attempt allocation in one of two ways. The simplest would be to allocate a tonnage equal to the estimated average weight per vehicle x the number of vehicles to B.2.compound. Given better data on vehicle composition, a more detailed allocation could be performed by splitting the total estimated tonnage of vehicles into, say, 60 per cent steel (allocate to both B.2.Fe and B.2.Fe.m), 10 per cent aluminium (allocate to both B.2.Al and B.2.Al.m), 15 per cent rubber and plastic (allocate to B.4.compound Mixed/compounded products mainly from fossil fuels), and leaving 15 per cent unallocated. In a case such as this,

where a reasonable (or conservative) estimate of both the average size of the item, and its composition, can be made, the item is probably worth including.

In cases where the items are of highly variable individual mass (e.g. vehicles other than automobiles, pots, pipes, boats, refrigerators etc.), attempting such a calculation could easily introduce more error than it removes. The decision will depend on the raw data available to the compiler. Tables of standard weights for products have been established for certain product classification schemes, and presented for use in EW-MFA, most notably in the annexes to Eurostat (2013), however, it is strongly recommended that the compiler makes their own judgement as to whether these compilations apply to their local situation, and whether the flows involved are likely to be significant. Often, the effort required to apply such schemes would be better-spent refining estimates on large tonnage, basic commodity flows.

3.3.3 Traded non-metallic minerals

Non-metallic minerals are similar to metal ores in that there is no major international agency which specializes in establishing trade accounts for this category. Comtrade does request data for the trade of most non-metallic minerals, so a compiler should first check which local agency(ies) are responsible for reporting trade data to Comtrade, and what data is being compiled for that purpose in this category. The allocation to EW-MFA categories is likely to be best if the detailed original national data are used, rather than any aggregates reported to Comtrade. The compiler should then decide how

to best allocate those material categories to the categories listed in Table 3.1.

One area where caution must be exercised is for fertilizer minerals. While some bulk fertilizers, such as those containing phosphorous and potassium, are largely of mineral origin, the major class of nitrogenous fertilizers is in most cases predominantly sourced from the artificial Haber process. Most of the mass thus comes from either atmospheric nitrogen or oxygen, neither of which should be counted. Unless the compiler knows that the source is likely to be nitrate mineral deposits, nitrate fertilizers such as ammonium nitrate should be excluded from the physical trade account. Further complicating this are mixed fertilizers e.g. MAP (Monoammonium Phosphate), and DAP (Diammonium Phosphate). The ratios of mineral-derived components for most of these mixed fertilizers are higher than the atmospheric-derived components, and so they should be accounted for as fertilizer minerals. The B.3.compound category is available at the compiler's discretion.

3.3.4 Traded fossil fuels

As with domestic extraction, the first step for a compiler of traded material flow accounts for fossil fuels is to check whether their country is already reporting to the IEA or responding to the UNSD Annual Questionnaire on Energy Statistics¹⁹. If so, the level of data already being compiled for those purposes should be much more than adequate for the main body of the material flows accounts. Constructing the material flow accounts should then be largely a matter of allocating the detailed traded fossil fuel categories recorded for IEA/UNSD reporting to the fossil fuel categories listed

¹⁹ The UNSD questionnaire is available at <https://unstats.un.org/unsd/energy/quest.htm>, along with guidance on compilation.

in Table 3.1, although in some cases it may be necessary to convert units, e.g. converting natural gas from contained energy or volume to mass unit (use conversion factors provided in the domestic extraction of fossil fuels section).

If a country is not currently reporting to either agency, and has very limited resources to do so, it is recommended that at a minimum the compiler downloads the UNSD questionnaire and associated guidelines, and endeavours to complete at least the production, import, and export fields for each of the main commodities given on the worksheets “Coal and Peat”, “Oil”, and “Gases”. Tools to assist in converting the data compiled for UNSD energy reporting to that used in material flow accounts are provided in the worksheets ‘Fossil Fuels Tool_Imp’ and ‘Fossil Fuels Tool_Exp’ of UNEP’s EW-MFA Compiler (see Annex 1).

As with the other material categories, traded fossil fuels should account for both fossil fuels extracted from the environment, and for any products subsequently derived from them. Thus, for example, traded gasoline, kerosene, diesel etc. will all be counted under petroleum in the trade accounts, not just crude oil and NGL.

The only aspect of the material flows accounts for fossil fuels that will not be adequately covered by collecting data required to fill out the UNSD questionnaire is the B.4.compound category. This category will include mainly bulk plastics, plastic precursors and resins, and plastic-dominated products (if viable estimates for tonnages are possible). For plastic-dominated products, the approach should be similar to that described for the compound metal products in the preceding section. For example, a country may have a large tyre trade. It may be reasonable to assume a conservative average weight for imported/

exported tyres (say 10 kg), use this to calculate total tonnages from the number of tyres traded, and attribute this all to B.4.compound / C.4.compound respectively. Trying to calculate tonnages of more variable items, e.g. plastic toys and containers, on the other hand, is unlikely to be worth the effort required. Local knowledge would be important in making this judgement.



4 Material outflows

4.1 Concepts and classification

On the output side of the economy, EW-MFA considers the total mass of materials released to the environment as wastes and emissions after having been used in the domestic economy. Output flows occur at the processing, manufacturing, use and final disposal stages of the economic production and consumption chain. In EW-MFA, outputs to the environment are summarized as DPO.

A first attempt to compile a consistent and cross-country comparative data set was made by an international team of experts and resulted in the

publication “The Weight of Nations” (Matthews *et al.* 2000), presenting DPO data for the USA, Japan, Austria, Germany and the Netherlands. Since then, several attempts have been made to compile further empirical data and develop methods. Among the case studies published are a study for Finland (Muukkonen 2000), for the EU-15 (Bringezu and Schütz 2001), for the Czech Republic (Ščasný, Kovanda and Hák 2003) and for Italy (Barbiero *et al.* 2003). In addition, since 2007 the EU has encouraged Member States to report DPO in the EW-MFA questionnaire.

Table 4.1 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
thereof: CO ₂	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
thereof: 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

Table 4.1 Selected results for DPO. (Cont.)

TONNES PER CAPITA	AUSTRIA	JAPAN	GERMANY	NETHER- LANDS	USA	FINLAND	ITALY
	1996	1996	1996	1996	1996	1997	1997
thereof: organic fertilizer	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, DPO was defined as including waste to landfills. In this Guide, waste to controlled landfills is excluded from DPO.

The DPO account comprises five 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, not fully attributable to a specific gateway but attributed to a type of release, dissipative or deliberate, rather 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. N₂O emissions from product use and NMVOC emissions from solvents are accounted for in “dissipative use of products” and not in “emissions to air”.
2. Emissions to air from fertilizer application – such as N₂O and NH₃ – are excluded from D.1. Emissions to air. The related primary output is fertilizer spread on agricultural soil which is already accounted for under D.4. Dissipative use of products.

4.1.1 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 2018). 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 EW-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, Kovanda and Hák 2003), China (Xu and Zhang 2008) and Finland (Muukkonen 2000).

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 following guidelines are of a general nature and will inevitably leave questions unanswered. 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.

4.2 Emissions to air

4.2.1 Concepts and classifications

Emissions to air are gaseous or particulate materials released to the atmosphere from production or

consumption processes in the economy. In EW-MFA, emissions to air comprise of 15 main material categories at the 2-digit level, as shown in Table 4.2

Table 4.2 Domestic processed output: Emissions to air.

1 DIGIT	2 DIGITS	3DIGITS
D.1 EMISSIONS TO AIR	D.1.1 Carbon dioxide (CO ₂)	D.1.1.1 Carbon dioxide (CO ₂) from biomass combustion
		D.1.1.2 Carbon dioxide (CO ₂) excluding biomass combustion
	D.1.2 Methane (CH ₄)	
	D.1.3 Dinitrogen oxide (N ₂ O)	
	D.1.4 Nitrous oxides (NO _x)	
	D.1.5 Hydrofluorocarbons (HFCs)	
	D.1.6 Perfluorocarbons (PFCs)	
	D.1.7 Sulphur hexafluoride (SF ₆)	
	D.1.8 Carbon monoxide (CO)	
	D.1.9 Non-methane volatile organic compounds (NMVOC)	
	D.1.10 Sulphur dioxide (SO ₂)	
	D.1.11 Ammonia (NH ₃)	
	D.1.12 Heavy metals	
	D.1.13 Persistent organic pollutants (POPs)	
	D.1.14 Particles (e.g. PM10, Dust)	
	D.1.15 Other emissions to air	

Note: These items are compiled in Table D of UNEP's EW-MFA Compiler (see Annex 1).

4.2.2 Typical data sources and assessment of data availability

In comparison to agricultural, mining or trade statistics, expertise in statistical reporting on air

emissions has developed in a relatively short period of time. Consequently, data from different sources are less harmonized and gaps in the historical record are likely to occur. In general, for the compilation of EW-MFA, national data sources should be used.

As in other categories, there are a number of international reporting requirements and standards which statistical institutions have to comply with. The data compiled in these contexts can be used to fill the EW-MFA; however, in some cases, data manipulation will be required, as data from different sources are less harmonized and gaps in the historical record are likely to occur.

In the following, three significant inventories for emissions to air are described. These are based on national data, and subsequently compiled in international databases.

4.2.3 Existing reporting

National greenhouse gas inventories in the common framework of IPCC

Countries which signed the UN Framework Convention on Climate Change (UNFCCC) are asked to compile their national greenhouse gas inventories according to the respective IPCC guidelines, i.e. in the common reporting format (CRF).

The national inventories cover emissions to air that have a greenhouse gas potential, i.e. contribute directly and indirectly to global warming. The latest refinement of these guidelines was published in 2019 (IPCC 2019) and covers sources and sinks of the following direct greenhouse gases:

- CO₂ (carbon dioxide)
- CH₄ (methane)
- N₂O (dinitrogen oxide)
- HFC (hydrofluorocarbons)
- PFC (perfluorocarbons)
- SF₆ (sulphur hexafluoride)

as well as the indirect greenhouse gases:

- NO_x (nitrogen oxides)
- NMVOC (non-methane volatile organic compounds)
- CO (carbon monoxide)
- SO₂ (sulphur dioxide)

Country-specific data are available at UNFCCC²⁰.

Note: Data reported to the IPCC (i.e. UNFCCC) are based on the territory principle, accounting only for emissions produced on the specific territory. To use these data for EW-MFA, the data need to be converted to the residence principle, where emissions by emitters of a specific nationality but outside of the territory are included. For this aim, the Eurostat developed “bridge tables” as described in the Eurostat Manual for Air Emissions Accounts (Eurostat 2015).

General information on the residence principle and its implications for DPO can be found in the Eurostat handbook on economy-wide material flow accounts (Eurostat 2018), chapters 2.3 and 4.7.

UNECE Convention on long-range transboundary air pollutants (CLRTAP)

CLRTAP was signed in 1979 and entered into force in 1983. With 51 parties out of UNECE's 56 Member States, the Convention covers most of the region – in Europe, North America and Asia. The focus of this Convention is on classical air pollutants.

The reporting obligation covers the following substances:

- SO_x (sulphur oxides)
- NO_x

²⁰ <https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/what-is-greenhouse-gas-data>

- CO
- NMVOCs
- NH₃
- PM2.5
- PM10
- Pb (lead)
- Cd (cadmium)
- Hg (mercury)
- PAHs (Sum of the four indicator polycyclic aromatic hydrocarbons)
- PCDD/F
- HCB (hexachlorobenzene)
- PCBs (polychlorinated biphenyls)

Note: Like UNFCCC data, UNECE data are based on the territory principle. To use these data for EW-MFA accounts, the data need to be converted to the residence principle. For this aim, Eurostat developed “bridge tables” as described in the Eurostat Manual for Air Emissions Accounts (Eurostat 2015).

General information on the residence principle and its implications for DPO can be found in the Eurostat handbook on economy-wide material flow accounts (Eurostat 2018), chapters 2.3 and 4.7.

Air emission accounts

AEA record flows of gaseous and particulate materials (six greenhouse gases including CO₂ and seven air pollutants) emitted by the economy into the atmosphere.

AEA are consistent with the supply and use framework of the system of national accounts, broken down into 64 emitting industries plus households. By following the national accounts' residence principle, emissions by resident economic units are included even if these occur outside the territory (for example, resident airlines and shipping companies operating in the rest

of the world). These two features make AEA in particular suitable for integrated environmental-economic analyses and modelling, for example of “carbon footprints” and climate-change modelling scenarios, which is their main purpose. On the other hand, the data structure and the applied conventions are different from the traditional emission inventories, for example, UNECE and IPCC statistics.

Note: AEA data are in line with the residence principle, and if available should be used as the primary data source for EW-MFA. Please refer to the Eurostat Manual for Air Emissions Accounts (Eurostat 2015).

As the three accounting systems serve different purposes, their coverage and applied conventions differ from each other. In practical terms, a combination of data sources will be necessary to complete the EW-MFA accounts. The most relevant issues to consider will be described in the following section.

Conventions

The terminology for emissions to air follows international harmonized standards of IPCC, UNECE or AEA.

For system boundaries, a general rule to be applied is that the category “emissions to air” indicates the total weight of materials which are released to the air by national resident units on a national economic territory and abroad. The following are exceptions:

- All emissions to air listed as “output balancing items” are not included in DPO.
- Emissions from fertilizer applications are not included in D.1, as this would represent double counting with “dissipative use of products”.

- N₂O emissions from product use and NMVOC emissions by solvents are accounted for in “dissipative use of products”.
- Emissions to air arising from automobile tyre and brake wear and road abrasion are accounted for in “dissipative losses”.
- “International bunkers” describe emissions from fuel for use on ships or aircraft in international transport. They predominantly consist of CO₂ from fossil fuel combustion. Their quantity may be very significant for some countries. Hence, they should be included in DPO.

Note: When using emissions inventories, there are several points to consider, as the EW-MFA system boundary is not necessarily identical with the system boundaries applied in the above-mentioned emission inventories:

- As mentioned above, IPCC and UNECE inventories are based on the territory principle, in contrast to the AEA which applies the residence principle accounting for economic activities of residents, regardless of whether they are active on the national economic territory or abroad (i.e. including CO₂ emissions from international bunkers). Hence, it is recommended that AEA be used as the primary data source for all relevant emissions of greenhouse gases and air pollutants. In cases where IPCC and/or UNECE data are used, adjustments are required, for instance, by applying the “bridge tables” of air emissions accounts in the Eurostat Manual for Air Emissions Accounts (Eurostat 2015).
- As IPCC usually reports GWP (global warming potential) totals calculated following a complex set of rules and in CO₂ equivalents instead of metric tonnes, it is necessary to use the

underlying inventories rather than the totals for compiling emissions to air. Cross-checking with the methodological guidelines (IPCC 2019) is advisable. Moreover, IPCC recommends reporting emissions from international bunkers separately and not as part of the totals.

Estimations

There are a number of cases where data on emissions have to be estimated: (1) if data are not available in tonnes, (2) if no data are available and emissions have to be estimated applying coefficients to input data, (3) when data are missing for longer time series, and (4) when data are reported without oxygen content (e.g. as carbon instead of CO₂).

A good example for the estimation of emissions to air is provided by the Eurostat Manual for Air Emission Accounts (Eurostat 2015).

Oxygen content

Oxygen is drawn from the atmosphere during fossil-fuel combustion and other industrial processes. Overall, oxygen uptake from the atmosphere during production and consumption is substantial and accounts for approximately 20 per cent by weight of material inputs to industrial economies (Matthews *et al.* 2000). In EW-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 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 an input balance item.

4.2.4 Accounting methods and practical guidelines for data compilation

In the following the definitions for categories are provided based on the Eurostat compilation guide (Eurostat 2013).

4.2.4.1 Carbon dioxide (CO₂) from biomass combustion

This subcategory includes CO₂ emissions from the combustion of biomass from the following sources:

- Biofuels such as biodiesel and bioethanol
- Biogas used as biofuel or 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 firewood and residuals or wastes from agriculture and forestry (also referred to as traditional biomass) (REN21 2005).

This subcategory does **not** include CO₂ emissions from:

- Land use and land use changes (considered flows within the environment)
- Human or animal respiration (considered as output balancing items)

4.2.4.2 Carbon dioxide (CO₂) excluding biomass combustion

This subcategory includes CO₂ emissions from the combustion of fossil fuels from the following sources:

- Energetic sources (e.g. oil)
- Non-energetic non-biotic sources (industry, agriculture, waste)

- International bunkers – estimation following (IPCC 2019); It is recommended that the accountant provides information about which estimation method has been used in a footnote.

4.2.4.3 Methane (CH₄)

This subcategory includes CH₄ emissions from the following sources:

- Anaerobic (without oxygen) decomposition of waste in landfills
- Animal digestion
- Decomposition of animal wastes
- Production and distribution of natural gas and oil
- Coal production
- Incomplete fossil-fuel combustion

Note: CH₄ emissions from uncontrolled landfills are not included in the “emissions to air” total. They may be reported as a separate memorandum item.

4.2.4.4 Dinitrogen oxide (N₂O)

This subcategory includes N₂O emissions from the following sources (IPCC 2017):

- Fossil-fuel combustion
- Industrial processes
- Biomass burning
- Cattle and feedlots

Dinitrogen oxide is a colourless, non-flammable gas, with a slightly sweet odour. It is used in surgery and dentistry for its anaesthetic and analgesic effects. It is also used as an oxidizer in internal-combustion engines. N₂O acts as a powerful greenhouse gas, as its global warming potential is 300 times higher compared to CO₂ (IPCC 2007).

This subcategory does **not** include N₂O emissions from:

- Product use (should be allocated to "dissipative use of products")
- Agriculture
- Wastes to uncontrolled landfills

4.2.4.5 Nitrous oxides (NO_x)

This subcategory includes NO_x emissions from the following sources (EEA 2017a):

- Road transport
- Energy production and distribution
- Commercial institutions and households
- Energy use in industry
- Non-road transport
- Industrial processes
- Agriculture
- Solvent and product use
- Waste

Nitrogen dioxide is the chemical compound NO₂. This orange/brown gas is one of several NO_x, with a characteristic sharp, biting odour. NO₂ is one of the most prominent air pollutants and a respiratory poison.

4.2.4.6 Hydrofluorocarbons (HFCs)

This subcategory includes HFC emissions from the following sources:

- Manufacturing process and throughout product life of refrigerators, air conditioners, etc.
- Production of metals and semiconductors

HFCs are commercially produced gases used as a substitute for chlorofluorocarbons.

4.2.4.7 Perfluorocarbons (PFCs)

This subcategory includes PFC emissions from the following sources:

- Aluminium smelting

- Uranium enrichment
- Manufacturing semiconductors

4.2.4.8 Sulphur hexafluoride (SF₆)

This subcategory includes SF₆ emissions from the following sources:

- Insulation of high voltage equipment
- Manufacturing of cable-cooling systems

4.2.4.9 Carbon monoxide (CO)

This subcategory includes CO emissions from the following source:

- Incomplete combustion of carbon containing compounds, notably in internal-combustion engines

CO 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 a large number of products, such as bulk chemicals manufacturing.

4.2.4.10 Sulphur dioxide (SO₂)

This subcategory includes SO₂ emissions from the following sources:

- Energy production and distribution
- Energy use in industry (industrial processes such as extracting metal from ore)
- Industrial processes and product use
- Commercial, institutional, households
- Non-road transport (locomotives, ships and other vehicles and heavy equipment that burn fuel with a high sulphur content)

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.

4.2.4.11 Heavy metals

This subcategory includes heavy metal emissions from the following sources:

- Road transport
- “Industrial processes and product use” sector

Heavy metals are a group of elements between copper and bismuth on the periodic table of the elements having specific gravities greater than 5.0 (EIONET 2017). All of the more well-known elements with the exception of bismuth and gold are toxic.

4.2.4.12 Persistent organic pollutants (POPs)

This subcategory includes POP emissions from the following sources (EEA 2017b):

- “Commercial, institutional and households” sector
- “Industrial processes and product use” sector

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, to 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 decided to start 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 TOMP (Toxic Organic Micro Pollutants).

4.2.4.13 Particles (e.g. PM10, Dust)

This subcategory includes PM10 emissions from the following sources (EEA 2017a):

- Road transport
- Agriculture
- “Energy Production and Distribution” sector

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

4.2.5 Specific issues of developing countries

It is recommendable to investigate whether subsistence economy activities are covered by the emission accounts at least as imputed values and if not it would be advisable to look for case studies that provide missing information.

4.3 Waste landfilled

4.3.1 Introduction

By definition, waste refers to materials that are of no further use to the generator for production, transformation or consumption. Waste 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.

In industrialized countries, most waste flows are deposited to controlled landfills, which are subject to management and treatment. 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. A controlled landfill is one whose operation is subject to a permit system and to technical control procedures under the national legislation in force. For the purposes of EW-MFA, waste flows into controlled landfills are considered flows within the socioeconomic system and are not accounted for in DPO.

Only waste disposed of outside of these controlled sites should be accounted for, i.e. uncontrolled land deposits or “wild” dumping. These waste flows should be reported under D.2. The respective quantities are considered small in industrialized countries due to strict regulations, but can be significant in other countries.

4.3.2 Conventions and system boundaries

System boundaries: Only waste deposited in uncontrolled landfills (wild dumping) is considered an output to nature and therefore part of DPO. Consequently, emissions from uncontrolled landfills are not considered as this would constitute double counting. In contrast, **controlled**, i.e. maintained, landfills must be considered part of the socioeconomic system. Therefore, wastes deposited in controlled landfills should be accounted for as an addition to stock. At the same time, outputs to the environment from waste deposits, i.e. emissions to water or air from controlled landfills, should be considered as DPO. This might comprise unintentional flows such as leakages and seeping water (conceptually part of D.5 dissipative losses) as well as controlled emissions to air or water.

Table 4.3 Domestic processed output: waste landfilled.

1 DIGIT	2 DIGITS	3 DIGITS
D.2 WASTE LANDFILLED (UNCONTROLLED)	D.2.1 municipal waste (uncontrolled)	
	D.2.2 industrial waste (uncontrolled)	
WASTE DISPOSAL TO CONTROLLED LANDFILLS (MEMO ITEM)		

Note: These items are compiled in Table D of UNEP’s EW-MFA Compiler (see Annex 1).

While this distinction between controlled and uncontrolled landfills is accepted on conceptual grounds, there are reasons to take account of **controlled landfills as a memorandum item**. First, it might be difficult to separate controlled from

uncontrolled landfills in national statistics. In that case, information on both might help in estimating a time series of waste to uncontrolled landfills. Second, data on the 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 waste disposal to controlled landfills be shown as a memorandum item.

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

4.3.3 Data compilation

If possible, waste flows should be distinguished according to **municipal and industrial wastes**. Often, waste statistics or other sources only report total waste to uncontrolled landfills directly. If so, the figures for waste landfilled should be taken as totals

for the accounting of D.2 without further distinction.

Construction and demolition waste 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, unused 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 EW-MFA input side as well as the output side.

4.4 Emissions to water

4.4.1 Introduction

Emissions to water are materials which cross the boundary from the economy back into the environment with water as a gateway. They include substances and materials released to natural waters by human activities after or without passing wastewater treatment. This category more or less includes outflows from municipal or industrial sewage treatment plants. The only exception is category D.3.5. "Dumping of materials at sea".

Accounting for only 1 per cent, emissions to water represent the smallest category of DPO (Matthews *et al.* 2000).

Emissions to water comprise five major categories, listed in Table 4.4:

4.4.2 Conventions and system boundaries

Reporting unit: Statistics on water pollution commonly use a specific reporting terminology.

Table 4.4 Domestic processed output: emissions to water.

1 DIGIT	2 DIGITS	3 DIGITS
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	

Note: These items are compiled in Table D of UNEP's EW-MFA Compiler (see Annex 1).

Statistics on water pollutants have traditionally focused on the concentration of pollutants in water bodies, measured in quantity per volume. However, in EW-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 of products".

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 in the state they are in upon discharge to the environment. Where wastewater treatment occurs, this refers to the post-treatment state. Otherwise, it refers to the substances or materials directly released into the environment via water.

4.4.3 Data compilation

Nitrogen (N), Phosphorus (P), and Heavy metals

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 fertilizers. N-emissions to water include emissions by wastewater from households and industry.

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

Heavy metals may come from municipal and industrial discharges.

Two **accounting approaches** can be applied to 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 pollutants 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.

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), and
- AOX (adsorbable organic halogen compounds).

Please note that all of these indicators measure organic substances in water using a different indirect method. The values reported for these indicators should therefore neither be included directly in EW-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 organic substances, into the quantity of the organic substance itself by using a simplified stoichiometric equation.

Dumping of materials at sea

Dumping of materials at sea is not a common reporting format. The category includes a complex compound of very different flows from various data sources, which are often inconsistent and incomplete. Data may also be totally unavailable. Attention has to be paid not to include materials which are part of unused domestic extraction, such as dredging, in order to be consistent with the material input side.

Below is some information that might help in the data compilation process.

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).

4.5 Dissipative use of products

4.5.1 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). Products used in a dissipative role are listed in Table 4.5:

Table 4.5 Domestic processed output: dissipative use of products.

1 DIGIT	2 DIGITS	3 DIGITS
D. 4 DISSIPATIVE USE OF PRODUCTS	D.4.1 Organic fertilizer (manure)	
	D.4.2 Mineral fertilizer	
	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	
	D.4.8 Solvents, laughing gas and other	

Note: These items are compiled in Table D of UNEP's EW-MFA Compiler (see Annex 1).

Matthews *et al.* (2000) were the first to attempt to account for these flows as part of an EW-MFA. Their results for 1996 show, for example, that applied mineral fertilizer ranged from 17 kilograms per capita (kg/cap) and year in Japan to around 110 kg/cap in Austria and Germany, spread manure from 105 kg/cap in Japan to 2,282 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.

4.5.2 Conventions and system boundaries

Water content: Organic fertilizer (manure) spread on agricultural land should be reported in dry weight. Hence, data with water content should be converted to dry matter. The same holds true for sewage sludge and compost.

4.5.3 Data compilation

Organic fertilizer

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

Manure spread on agricultural land is usually not

reported or insufficiently 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 4.6.

Table 4.6 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 feasible estimates of these losses 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 domestic extraction on the input side) needs to be carefully estimated, in particular, to be consistent with the input flows.

Mineral fertilizer

The fertilizer industry is essentially concerned with providing 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 products such as superphosphate and ammonium sulphate.

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

In principle, accounting for fertilizers and pesticides needs to be for total masses. Statistics, however, commonly report fertilizers in nutrient contents (e.g. N, P, K) and pesticides in active ingredients contents. Multipliers should be applied to derive total weights.

Sewage sludge

Sewage sludge refers to any solid, semi-solid or liquid residue removed during the treatment of municipal wastewater or domestic sewage. Although it is useful as a fertilizer 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 EW-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 per cent may be assumed for conversion to dry weight.

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 D.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 per cent may be assumed for conversion to dry weight.

Note: private households may compost organic materials previously purchased (i.e. biomass that was recorded on the input side). Such composting

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 on pesticides are provided by the Pesticide Action Network (PAN) (<https://www.pesticideinfo.org/>) or the EU Pesticides Database.

Agricultural statistics commonly report quantities of pesticides used in (or sold to) the agricultural industry. Figures are generally expressed in active ingredients. Multipliers should be applied to convert these figures to total mass.

Seeds

Seeds are the encapsulated embryos of flowering plants. Seeds for agricultural production are commonly recorded in agricultural statistics (e.g. in FAO food commodity balance sheets).

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. First estimations for these flows were carried out for Austria and the US (Matthews *et al.* 2000). In countries with rigorous winters D.4.7. can account for significant amounts. In Switzerland, D.4.7. makes up for about 10 per cent of D.4.

So far, only a few attempts have been made to estimate thawing materials spread on roads (e.g. Matthews *et al.* 2000).

A possible estimation approach could be developed based on the length of roads in each European country differentiated by street types (under consideration of altitude and slope), average amount of frost days per year, and average materials deployed.

Solvents, laughing gas and others

This category includes emissions from diverse dissipative use of products, e.g. use of solvents, laughing gas, road paving, N₂O for anaesthesia.

Data for NMVOC solvents emissions can, for example, 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

N₂O (laughing gas) for anaesthesia is included in 3.D and its specific values may be extracted from detailed countries' air emissions databases.

4.6 Dissipative losses

4.6.1 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 accidents. 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 little data available internationally. Matthews *et al.* (2000) report estimated data for the abrasion from tyres for Austria, Germany and USA.

4.6.2 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 environmental relevance. Another significant unknown flow is the loss of lubricants, which is estimated at about 50 per

cent of total lubricant use.

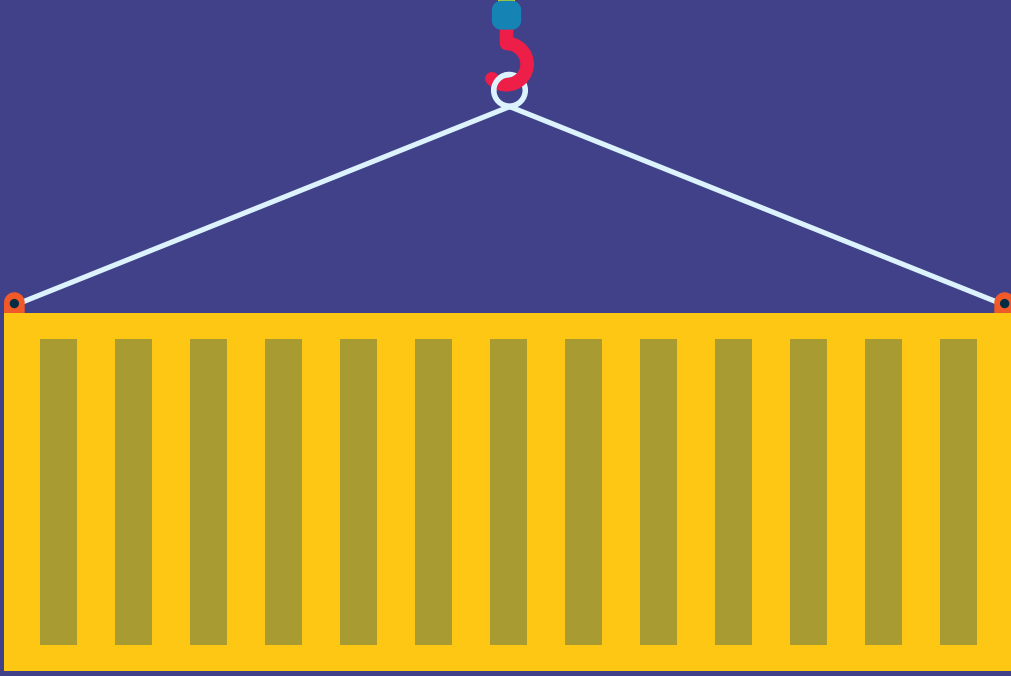
Many of these flows have never been quantified. It is recommended that only those data that can be provided with justifiable effort be completed. The air emission submissions to the UNECE Convention on Long Range Transboundary Air Pollutants (CLRTAP) are the most significant data source for this item. 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).

An attempt should be made to develop a comprehensive approach to account for these flows.

- Abrasion from tyres is rubber worn away from car tyres. 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 tyre, taken from a special study on ecology and road traffic in Austria.
- Particles worn from friction products, such as brakes and clutches, have never yet been addressed in EW-MFA.
- Losses of materials due to corrosion, abrasion, and erosion of buildings and infrastructure are probably quantitatively relevant, and they appear to be relevant under environmental aspects as well. So far, there is no comprehensive approach to account for these flows. Single aspects such as losses due to leaching 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. German statistics, for example, report chemicals irreversibly lost due

to accidents during transport.

- Another relevant flow may be leakages during (natural) gas pipeline transport (if not reported as emissions to air). Data may be reported in specific studies.



Material balance

5

5 Material balance

A main advantage of organizing environmental statistics employing a material flow accounting approach is the ability for coherence checks of individual data sets by establishing a material balance of inputs and outputs. The material balance is established by adding domestic

extraction, imports and balancing items which equal exports, domestic processed output, net additions to stock (NAS) and balancing items, where NAS includes intermediate consumption, final consumption and accumulation (or stock).

$$DE + \text{Imports} + \text{Balancing items (input side)} = \text{Exports} + \text{DPO} + \text{NAS} + \text{Balancing items (output side)}$$

Balancing items are defined as the additional inputs and outputs necessary to establish a material balance. On the input side, these can be:

- Oxygen for combustion processes;
- Oxygen for respiration of human and livestock; bacterial respiration from solid waste and wastewater;
- Nitrogen for Haber-Bosch process;
- Water requirements for the domestic production of exported beverages.

On the output side, balancing items are comprised of:

- Water vapor from combustion;
- Gases from respiration of humans and livestock (CO₂ and H₂O), and from bacterial respiration from solid waste and wastewater (H₂O);
- Excorporated water from biomass and products.

Balancing items are compiled in Table E of UNEP's EW-MFA Compiler (see Annex 1). A detailed and comprehensive explanation of balancing items is provided in section 4.8 of the Eurostat handbook

on economy-wide material flow accounts (Eurostat 2018).

In practice, NAS would be calculated as the residual of the material balance identity. As a consequence, NAS would contain all calculation errors. It is possible to calculate material stock and changes in material stock directly using a combination of bottom-up and top-down accounting principles which would allow running quality checks on the material balance.

The material balance also reveals important relationships among the different indicators and provides a sense of whether an economy invests in establishing physical stocks or is fuelled by a large throughput of materials.



6 Headline indicators

6.1 Background

In the past few years, resource efficiency has developed into a core topic in international policy debate. A number of countries have emphasized the urgent need for greater resource productivity and reduced material use as part of their economic development strategies and environmental policy plans. Most notably, Japan, the European Union and China have implemented high-level policy agendas for reducing material use and increasing resource efficiency (UNEP 2016).

(SDGs) (UN 2015) state that sustainable natural resource use and management are a necessary condition to achieve a better future for current and future generations. In two SDGs – Goal 8 “Sustainable economic growth, employment and decent work for all”, and Goal 12 “Sustainable consumption and production patterns” – sub-targets which specifically require material flow-based indicators for monitoring have been defined, for instance targets 8.4 and 12.2 (see text box).

Also, the United Nations 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals

SDG Target 8.4: Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead.

SDG Target 12.2: By 2030, achieve the sustainable management and efficient use of natural resources.

A large number of indicators can be established from economy-wide material flow accounts. These indicators generally correspond to the main variables of the EW-MFA and describe material use at different stages of economic activities, from material extraction via international trade and material consumption to the generation of waste and emissions. In line with the materials balance scheme, the main types of indicators can be defined as: input indicators, consumption indicators, trade and balancing indicators, and output indicators.

These different types of indicators deliver complementary information about various aspects related to national material use. They can also be combined with each other to provide a more comprehensive depiction of the related issues. Furthermore, they can be combined with economic indicators, such as Gross Domestic Product (GDP), to construct indicators of material productivity.

Depending on the scope of material flows considered, the indicators can be grouped into several categories:

- A. Indicators based on accounts of direct material flows, i.e. domestic extraction and physical imports and exports. material extraction, both of domestic and foreign origin.
- B. Indicators which also include indirect material flows associated with direct imports and exports – these flows are also called raw material equivalents (RME). As this manual focuses on establishing accounts for direct material flows, indicator group (A) will receive most attention in this chapter. However, summary information is also provided for indicator groups (B) and (C).
- C. Indicators which in addition consider unused

6.2 Indicators on direct material flows

6.2.1 Technical description

Table 6.1 provides a description of the various indicators that can be calculated based on EW-MFA of direct material flows. The descriptions of the indicators are adapted from the OECD

guide for measuring material flows and resource productivity (OECD 2008). Note that the respective indicators can either be presented as a total sum across all material categories, or disaggregated by main material group, in order to identify the main constituents underlying the aggregated number.

Table 6.1 Indicators based on EW-MFA data as covered in this manual.

INDICATOR	ABBREVIATION	CALCULATION	DESCRIPTION
Domestic Extraction	DE	-	Domestic Extraction measures the flows of materials that originate from the environment and that physically enter the economic system for further processing or direct consumption. They are converted into or incorporated in products, and are usually of economic value, i.e. they are "used" by the economy (therefore, sometimes also described as DEU, in order to separate these flows from unused domestic extraction).
Direct Material Input	DMI	DE+IMP	DMI measures the direct input of materials used in the economy, i.e. all materials which are of economic value and are used in production and consumption activities; DMI equals domestic extraction used plus imports.
Domestic Material Consumption	DMC	DMI-EXP	DMC measures the total amount of material directly used in an economy (i.e. excluding indirect flows). DMC is defined in the same way as other key physical indicators such as gross inland energy consumption. DMC equals DMI minus exports.

Table 6.1 Indicators based on EW-MFA data as covered in this manual. (Cont.)

INDICATOR	ABBREVIATION	CALCULATION	DESCRIPTION
Physical Trade Balance	PTB	IMP–EXP	The PTB reflects the physical trade surplus or deficit of an economy. It is defined as imports minus exports.
Domestic Processed Output	DPO		DPO measures the total weight of materials extracted from the domestic environment or imported, which after use in the economy flow back to the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included are emissions to air, industrial and household wastes deposited in uncontrolled landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows).
Material Productivity		GDP/DMC	Material productivity is defined as the ratio between GDP and DMC. It indicates the economic value generated per unit of material consumption. Over time, the indicator illustrates whether decoupling of material use from economic growth is achieved. This indicator is also called resource efficiency, e.g. in the European policy context.
Material Intensity		DMC/GDP	Material Intensity is the reciprocal indicator of Material Productivity. It is calculated as DMC/GDP, illustrating the material consumption required to produce one unit of GDP.

6.2.2 Policy questions

Aggregated material flow-based indicators are particularly useful for the monitoring of broad, overarching policy goals and targets, such as those defined in the context of the SDGs. Most notably, aggregated indicators allow measurement of the overall physical size of an economy and identification of its main constituents in material groups. Further, aggregated indicators can be set in relation to economic indicators, allowing

assessment of the overall material productivity and decoupling performance of an economy.

Another strength of aggregated measures of material flows is their potential to simplify the public communication process and to reach audiences that usually receive little information about complex economy-environment interactions. This is useful for policymakers and the public at large who need synthesized information without being provided too much detail (OECD 2008).

The various indicators listed in Table 6.1 above allow different policy questions to be addressed. These are summarized in Table 6.2.

Table 6.2 Main policy questions addressed by indicators of direct material flows

INDICATOR	MAIN POLICY QUESTIONS
DE	What quantities of raw materials are extracted on the domestic territory to sustain economic activities? What is the composition of domestically extracted raw materials and how has this composition changed over time?
DMI	Which raw materials form the material basis of the domestic economic system, i.e. production for domestic demand and for exports? What is the relation of domestically extracted versus imported materials, i.e. how dependent is an economy on raw material imports?
DMC (as DMC/cap relevant for SDG 12.2)	Which raw materials serve the apparent consumption of a country, i.e. excluding materials and products that are exported abroad? Which environmental pressures occur within the territory due to materials used in an economic system (which either end up as increases in physical stock or as waste and emissions back to the environment)? Which are the (policy) hot spots for resource management measures related to the domestic consumption of materials?
PTB	Is the country a physical net-importer or a physical net-exporter of raw materials? Which raw material groups feature high net imports, pointing to a potential hot spot of import dependency?
DPO	Which material outflows are related to production and consumption activities of a given country? What quantities of air emissions are being emitted on the national territory? How have climate-related emissions changed over time? Are streams of waste flows back to the environment decreasing or increasing?
GDP/DMC (relevant for SDG 8.4)	How much economic value is generated by a unit of material consumed by the domestic economy? Has the economy achieved decoupling between economic growth and direct resource use?

6.3 Indicators including indirect and unused material flows

In addition to the indicators based on direct material flow accounts, other indicators can be derived from the larger EW-MFA framework. These indicators refer to groups (B) and (C) as introduced above.

The first step of enlarging the scope of indicators (Group B) refers to the inclusion of indirect material flows associated with direct imports and exports. For example, an imported car will not be measured according to its actual weight, but by weight of all materials that were required along the full international production chains (such as most of the coal and iron ore needed to produce steel in third countries, which was then imported as steel to the car manufacturing country, for further fabrication into the car's body). This is achieved by transforming the weights of the direct import and export flows into their RMEs.

The two indicators which include RMEs are:

- Raw material input (RMI), which adds the raw material equivalents of imports (IMP_{RME}) to DMI.
- Raw material consumption (RMC), also termed "material footprint" (see next chapter), which deducts the RMEs of exports (EXP_{RME}) from RMI.

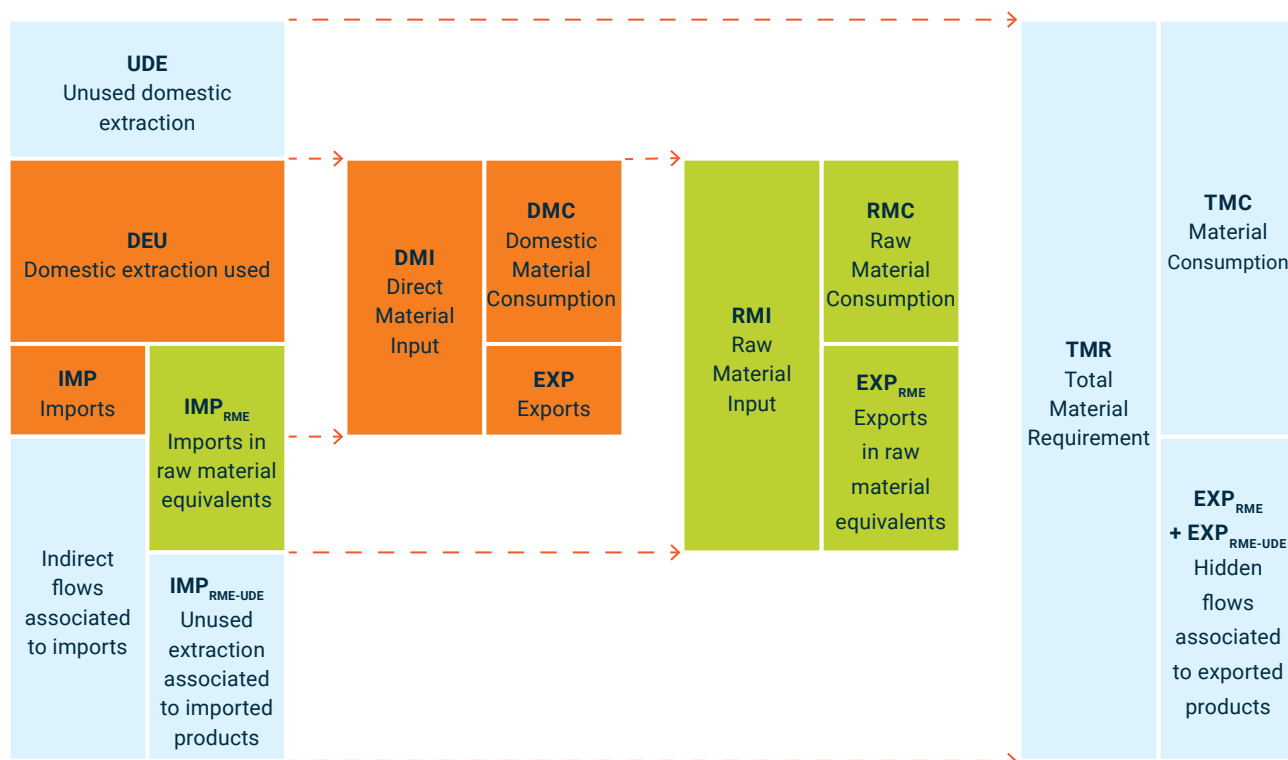
A further expansion of the system boundaries considered by the material flow-based indicators concerns the inclusion of so-called "unused domestic extraction (UDE)" (Group C). This category of material flows comprises three main components (Eurostat 2001): (1) unused extraction from mining and quarrying (mining/quarrying extraction wastes such as overburden or parting materials); (2) unused extraction from biomass

harvest (discarded by-catch, wood harvesting losses and other harvesting wastes); (3) soil (and rock) excavation and dredged materials (materials extracted during construction and dredging activities).

The two indicators which include unused material extraction are:

- Total material requirement (TMR) includes – in addition to RMI – unused domestic extraction (UDE) and the unused extraction related to the RMEs of imports ($IMP_{RME+UDE}$).
- Total material consumption (TMC), which, in addition to RMC, also accounts for unused extraction related to RMEs of both imports and exports. TMC equals TMR minus exports, their RMEs and related UDE.

Figure 6.1 provides an overview of all available input and consumption indicators, applicable to the European statistical system. The figure depicts the European state of statistical implementation of EW-MFA (Eurostat 2013): direct materials flows (in orange colour) are covered by a legal regulation, raw material equivalents are estimated by the European Statistical Office (Eurostat) and indicators including unused material flows are currently not available in the European Statistical System.

Figure 6.1 Overview of the “family” of material flow-based indicators**Legend**

- Covered by legal base (regulation No 691/2011 on European Environmental Economic Accounts)
- Estimated by Eurostat (aggregated EU27)
- Not available in European Statistical System

6.4 Strengths and limitations of indicators with different scope

Indicators based on direct material flows, most notably the DMC indicator, are currently the most widely used MFA-based indicators in policy processes, for example, in the context of the implementation of the European “Roadmap to a Resource Efficient Europe” (EC 2011), where GDP over DMC was selected as the headline indicator.

DMC is a widely accepted EW-MFA indicator, in particular in statistical institutions, as it can be calculated to a large extent based on official national production and trade statistics, as illustrated in this manual. DMC data have thus been compiled for a much larger number of countries and from a large variety of statistical and academic institutions compared to other more

complex indicators, which consider up-stream material flows of imports and exports and often build on modelled data, such as RMC.

DMC has high environmental relevance as an indicator of potential environmental pressure on a domestic territory. DMC covers all materials used on the input side, which actually flow through the domestic economy and which are either emitted back to the environment as waste and emissions or contribute to the increase of the national physical stock with potential flows of waste and emissions in the future (Marra Campanale and Femia 2013). Furthermore, when designing national strategies for resource management, DMC and its components are easier for governments to address compared with indicators which include indirect material flows in other countries along the supply chains of imported products and thus require international policy cooperation.

However, it has to be clearly stated that indicators of direct material flows, such as the DMC indicator, do not account for all global material flows related to final consumption in a country or region, as indirect (or embodied) materials of imported and exported products are not considered. In a globalized economy, supply chains are becoming increasingly international, often involving a large number of countries along a product's life cycle from the extraction of raw materials, via processing and manufacturing to the delivery of the product to the final consumer. Hence, indicators of direct material flows cannot account for the actual environmental consequences generated by the consumption of certain products, as material flows can be located in other world regions.

Countries can therefore apparently reduce their material consumption, as measured with the DMC indicator, by outsourcing material-intensive

extraction and processing abroad. Assessing global material use related to final consumption requires other MFA-based indicators, such as RMC (see also the next chapter on "material footprints"). These aspects need to be considered when evaluating DMC results across countries, for example, on achievements in decoupling material consumption from economic growth.

Furthermore, it needs to be emphasized that indicators of direct material flows do not account for unused material extraction, such as overburden from metal or coal mining or harvest residues in agriculture. However, these unused material flows cause various environmental pressures, such as water pollution and landscape changes. In order to consider these flows, indicators such as TMR or TMC need to be applied.

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7 Material footprint of consumption

7.1 Introduction

Environmental assessments generally apply a territorial – or production-based – perspective to analyse environmental pressures and impacts that occur within the borders of a country or region. Consequently, monitoring of current environmental policies mostly relies on indicators applying this perspective. Examples include the resource efficiency indicator GDP/DMC applied by the European Commission (Chapter 6), accounting for greenhouse gas emissions in the context of the UNFCCC climate treaties, assessments of water abstraction compared to available water or changes of land cover, and related impacts on ecosystems and biodiversity.

However, in the era of globalization, supply chains are increasingly organized on the international level, thus disconnecting the location of production from final consumption. Various local environmental and social impacts in countries, which extract and process raw materials or manufactured products, are therefore often related to final demand in other countries. Production-oriented indicators cannot account for the totality of the actual environmental consequences induced by the consumption of certain products, as they do not include those impacts which are located in other world regions.

The indicator RMC or “material footprint” (see also previous chapter) responds to this need to better understand these “teleconnections” between distant places of production and consumption. The RMC indicator is calculated by transforming the

weights of direct import and export flows into their respective RME. RME refers to the supply chain-wide primary material extractions required to produce a certain imported or exported product. For example, if a country imports a certain amount of beef, the respective RMEs refer, among other aspects, to the fodder plants that were required to feed the cattle. Or if a country imports cars, the RMEs comprise all primary raw material extractions that were required to produce the car (e.g. crude iron or copper ore to produce steel or copper wires; crude oil to produce plastic parts).

The RMC or “material footprint” indicator thus corrects the national material balance for international trade, accounting for both domestic and foreign material extraction with the same system boundaries. Using DMC, dislocating material-intensive production from the domestic territory away to other world regions, while keeping final demand for products and services constant, will result in better apparent performance. In contrast, using RMC, net-importers cannot improve their performance just by outsourcing. At the same time, for net-exporting countries with small domestic final demand, RMC figures will be lower compared to the results for DMC.

In recent years, the RMC indicator has received considerable attention in publications by academic and statistical institutions. Also in policy debates, the indicator is being suggested to monitor material use and productivity of a country in a global context.

Examples are discussions on setting targets for resource productivity in the context of the EU “Roadmap for a resource-efficient Europe” (EC 2011; EC 2014), or providing demand-based indicators of material flows in the context of the OECD Green

Growth Indicators (OECD 2014). In the latter case especially, efforts have intensified in recent years to further develop RMC-type indicators in order to improve policymaking.

7.2 Summary of available methods

Three types of methods for the calculation of material footprint indicators are generally distinguished (see Lutter, Giljum and Bruckner 2016): (1) top-down approaches starting from the macroeconomic level in economic structures and material extraction, (2) bottom-up approaches using coefficients on material input per product unit, and (3) hybrid approaches combining the two previous approaches.

7.2.1 Top-down approach: input-output analysis

Top-down approaches build on input-output analysis (IOA) which focuses on the economic structure of a country in the form of matrices that depict inter-industry flows, i.e. input-output tables. Each column of an Input-Output (IO) model table can be interpreted as an inventory of production inputs. The environmental data on material use linked as extensions to an IO table can be considered an inventory of environmental inputs such as raw materials.

In general two main types are distinguished – single-region and MRIO models. Single-region IO models assume that imported products are produced with the same technology as domestic products. In MRIO models, country IO tables are linked together via bilateral trade data, considering different technologies applied in each country.

MRIO analysis allows product value chains and related material use to be tracked along the various life cycle stages of all products and services from material extraction to final demand, considering specific material intensities across countries.

IOA, in particular in its multi-regional form, has a number of key advantages. The main advantage is that it allows the calculation of material footprints for all products and industries, including those with very complex global supply chains. By following a top-down approach, input-output analysis also avoids double counting. A specific material input can only be allocated once to final demand, as the supply and use chains are completely represented. As a result, the global system is always consistent, i.e. the sum of all material footprints equals the sum of global material extraction.

A major disadvantage of IOA is the limited number of commodities and regions distinguished, which is determined by the sectoral / industrial and regional disaggregation of an IO model. Further, inaccurate results are produced by the assumption of homogenous environmental characteristics of all products within a product group. Another disadvantage is that most MRIO-based approaches use the monetary use structures of industries and products to allocate material extraction to final demand, assuming proportionality between monetary and physical flows, which should not be

assumed, e.g. price differences between different industries may occur.

Today, various global MRIO databases exist that can be extended with data on global material extraction, in order to track the flow of embodied materials along international supply chains to final demand (Lutter, Giljum and Bruckner 2016). For studies on material footprints based on MRIO data, including detailed technical descriptions, see Arto *et al.* 2013; Eisenmenger *et al.* 2016; Giljum *et al.* 2016; Giljum *et al.* 2017; Giljum, Bruckner and Martinez 2015; Wiedmann *et al.* 2015.

7.2.2 Bottom-up approach: material intensity coefficients

Bottom-up approaches comprise detailed data on bilateral trade and domestic production expressed in quantities (e.g. tonnes or units), and “apparent consumption” of a country is derived by calculating production plus imports minus exports. The quantities of each product consumed in a country are multiplied with coefficients reflecting the related upstream resource use. These coefficients, primarily obtained from Life Cycle Assessments, quantify the materials required along a product’s supply chain (see Wiesen and Wirges 2017).

The most important advantage of coefficient-based bottom-up methods in comparison to top-down approaches is the high level of detail which can be applied. The coefficient approach does not face restrictions on the definition of sectors / industries or product groups and thus allows very specific comparisons of material footprints to be performed, down to the level of single products or materials.

One key disadvantage of coefficient approaches is the high level of effort to construct solid

coefficients for a large number of especially highly processed products. The availability of coefficients for finished products is therefore limited. Further, double counting is possible, especially in cases where products are passing more than one border along processing stages, as these products are accounted for each time they pass a border. As a consequence, if applied on the global level, the sum of all footprints from bottom-up calculations will inevitably differ from the sum of global material extraction.

With regard to data availability for material coefficients, the Wuppertal Institute in Germany maintains a database for more than 200 products, with most coefficients being provided for one specific (mainly European) country or the world average (Wuppertal Institute 2014). The European Statistical Office also provides information about RME coefficients for imports and exports by 182 product groups and 51 raw material categories, adapted to the European case (Eurostat 2016a).

7.2.3 Hybrid approaches: complementing input-output analysis with coefficients

Hybrid approaches aim to exploit the advantages from IOA in combination with physical trade accounts and process-based coefficients. Depending on the processing stage, as well as the data quality and availability, a differentiated approach for the calculation of footprint indicators for different products is applied. Typically, material coefficients are used for raw materials and products with a low level of processing. Processed commodities and finished goods with more complex production chains are measured using IOA, which allows consideration of all indirect effects and thus all upstream material requirements.

Hybrid models are increasingly applied in all areas of resource flow accounting, acknowledging their respective strengths and capabilities. The combination of top-down and bottom-up methods is achieved in various ways. Hybrid approaches for the calculation of consumption-based material flow indicators integrate detailed statistics in mass units into monetary input-output tables, creating mixed-unit IO tables.

Hybrid calculation models have been set up for a range of European countries (see, for example, Kovanda and Weinzettel 2013; Schaffartzik *et al.* 2014a). Also, the European Statistical Office has developed a Hybrid calculation method to assess the material footprint of the EU-28 (Eurostat 2016b).

7.3 Outlook

Based on current international policy developments, for example in the context of the United Nations Sustainable Development Goals (SDGs; UN 2016), it is expected that demand for material footprint accounting and other demand-based accounts will increase soon, as the SDGs require countries to improve the resource productivity of both production and consumption, calling for both DMC and RMC to be applied.

However, no global reference method for calculating material footprints exists yet. Because of the global characteristics of supply chains and the differences in industry structure among countries, no national statistical office can run their own demand-based accounts reliably. Reporting requirements for the SDGs will therefore likely necessitate a global MRIO calculation system run by a trusted international organization to allow national statistical offices to use this capacity.

Once such a system is set up, the global, multi-regional IO tables could be made publicly available to national statistical offices, government agencies and research institutes. The utility of such a global harmonized framework would reach beyond material footprint accounting and could include

energy, emissions, waste, water and biodiversity satellite accounts as well as economic and social data (e.g. working hours, employment, and multiplier effects) to assess the various footprints of consumption.



Accounting for Stocks

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8 Accounting for stocks

8.1 Introduction

Since the seminal material flow study of the World Resources Institute (Adriaanse *et al.* 1997; Matthews *et al.* 2000), research on social metabolism and EW-MFA has mostly focused on flows, quantifying material extraction, trade flows and domestic material consumption. To a much lesser extent, research also investigated outflows of wastes and emissions. This research has greatly advanced the understanding of patterns and trends of global material flows and the underlying socio-economic and biogeographic drivers. The concept of social metabolism implies that the size and composition of material flows is closely related to in-use stocks of materials: Material inflows are required to build up and maintain stocks of artefacts, to provide services from them and to feed humans and livestock.

In particular, information about the historical development of in-use stocks of artefacts and their relation to input and end-of-life flows is of key importance for understanding material flow patterns and their development over time. Stocks of artefacts have a lifetime of often several decades and therefore a long-lasting impact.

They constitute legacies for future material flows (Brunner and Rechberger 2002; Kapur and Graedel 2006) and can contribute to the creation of “lock-in” situations. Continuously growing stocks limit the possibilities to material loop closing by recycling (Circular Economy) and the age distribution of stocks determines when materials may become available as potential secondary resources as well as what their composition is likely to be (Haas *et al.* 2015; Krook and Baas 2013). Also the significance of stocks for greenhouse gas mitigation has been recognized, as building up and utilizing stocks of buildings and infrastructure is responsible for a large part of humanities energy consumption and GHG emissions (Müller *et al.* 2013; Pauliuk and Müller 2014). Although the interest in in-use stocks of materials has been growing in recent years, methods to estimate the size of stocks are still in their infancy and knowledge of the aggregate socio-economic stocks and their development over time is fragmentary at best. Comprehensive estimates for the different types of stocks, their material composition and their relation to flows at the global scale are lacking.

8.2 Methods to quantify stocks

8.2.1 Overview

As outlined in section 1.3.3 of this manual, in

EW-MFA three types of socioeconomic material stocks are distinguished: artefacts, livestock, and humans. Artefacts are mainly man-made

fixed assets as defined in the national accounts such as infrastructure, 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 also regarded as material stocks in EW-MFA. In use stocks of artefacts typically account for over 99 per cent of total stocks; the size of humans and livestock is comparatively small. The stock of livestock and humans can be estimated by using data on population and livestock numbers and assumptions on average live weight by age class, but in practical terms, it is often ignored in stock assessments.

A multitude of approaches to quantify the size of in-use stocks of artefacts and related material flows exist (Augiseau and Barles 2017; Tanikawa *et al.* 2015). On a very general level, two types of approaches can be distinguished: Accounting-based (bottom-up) “stock-driven” approaches and dynamic “inflow-driven” modelling (top-down). Accounting-based approaches estimate the mass of materials in stocks from quantitative information on the different types of stocks, such as buildings, infrastructure, or machinery and their material composition. Inflow-driven models use time series information on material inputs to in-use stocks, in combination with assumptions on lifetimes to infer the stock size over time and subsequently model end-of-life waste flows from stocks at each specific point in time. In practice, often hybrid approaches are used that mix different approaches, depending on the available data and research objectives.

8.2.2 Stock accounting

Accounting-based approaches to quantify stocks are mainly static bottom-up approaches. They use inventories or survey data about in-use artefacts

to estimate the mass and material composition of these specific stock types. This approach requires information on different in-use types of stocks (e.g. length of roads by road type, building statistics or the number of vehicles) and the mass and composition of the stocks (e.g. the mass of different materials contained in one km of different road types or different building types, or per vehicle). This is a very data-intensive method and it is usually applied only to specific stock types. Miatto *et al.* (2017) have, for example, quantified the long-term development of materials stocks in the road system of the USA. Only few attempts have been made to use this approach at the national scale for more comprehensive stock estimates. Examples include the study of Rubli *et al.* (2005) who have estimated the stocks of buildings and infrastructures in their analysis of the Swiss economy using such an approach; Wiedenhofer *et al.* (2015) have quantified stocks of residential buildings, roads and railways for the European Union, while Tanikawa *et al.* (2015) estimated the development of the stock of construction materials in Japan across all buildings and infrastructure. Ortlepp, Gruhler and Schiller (2015) disaggregated Germany's sum of floor space to various construction types. These stock-driven accounting approaches can produce high-resolution stock estimates for specific years, but they are less useful for comprehensive system wide estimates of all in-use stocks of materials, since this would require data for a huge variety of different stock types, and their changing material compositions over time. Statistical data, however, typically exist only for a few stocks (e.g. length of roads and railroads, number of buildings and floor space, number of cars) and are often of poor quality. The conversion of stock variables into mass units is prone to considerable uncertainty and the breakdown into specific materials, which is the key to link stock information to material flow

data from EW-MFA, requires detailed information on the material composition of different stocks. Due to these problems, results from stock-driven accounting are often not fully consistent with EW-MFA (Schiller, Müller and Ortlepp 2017) and currently often limited to recent years (Augiseau and Barles 2017).

8.2.3 Dynamic stock modelling

Inflow-driven dynamic stock models, which use average service lifetimes of stock-building material inputs to quantify the size of stocks, are easier to link consistently with EW-MFA. Physical stock-building inflows can be derived from material flow accounts in combination with additional information on the fraction of materials that is used to build up stocks, sourced e.g. from production statistics. Such a modelling then treats each year's inflow of a specific stock building material as a separate vintage with a certain lifetime distribution, similar to a demographic population approach. In this method, the stock is an endogenously calculated output of the model; it is the sum of all materials remaining in use in the vintages of past inflows. The method is quite flexible concerning the types of material flows and stocks that can be modelled, from fabricated products in various end-uses and scales; inflow data can be materials or substances (e.g. steel, timber, cement) but also stock units such as car sales, which are converted into mass of materials. Dynamic stock-modelling can be linked consistently with material flow accounts, not only to quantify the size of stocks but also to model the outflow of end-of-life waste from discarded stocks and estimate potential recycling and down-cycling flows of materials. This approach further enables a what-if scenario design, where the size and dynamics of in-use stocks are the consequences of scenario assumptions about stock-building material inflows, service lifetimes and recycling

rates. Inflow-driven dynamic models have been widely used to estimate the long-term development of stocks of specific substances such as metals (Glöser, Soulier and Tercero Espinoza 2013; Liu and Müller 2013; Pauliuk, Wang and Müller 2013), and cement (Cao *et al.* 2017a; Cao *et al.* 2017b) for national economies and at the global scale, and more recently also for comprehensive EW-MFA-based stock estimates. Fishman *et al.* (2014) have used this approach to estimate the development of the mass of materials in the stock of artefacts in Japan and the USA based on time series data from material flow accounts. Krausmann *et al.* (2017) developed a model that uses data on domestic material consumption (DMC) from a global material flow database, various production statistics and information on stocking rates (the fraction of the DMC of these materials that becomes stocked) to determine the amount of materials which are used to build up or maintain stocks globally for the entire 20th century. Inflows of different materials are then allocated to different stock types with different lifetimes. The model quantifies all in-use stocks of artefacts, distinguishing 15 major stock types (e.g. paper, timber, bricks, concrete, glass, metals). The modelling also yields estimates of global outflows of solid waste from discarded stocks and flows of secondary recycled resources, which is useful information to complement the domestic processed output (DPO) indicator in EW-MFA and to inform assessments of the circular economy. While inflow-driven dynamic stock models can be linked consistently with EW-MFA, their resolution with respect to different stock types is currently limited by available data. It is also challenging to provide estimates about different functional types of stocks (e.g. commercial or residential buildings, cars, and airplanes), due to limited information on the allocation of inflows to specific stock types, lifetimes of different stocks and their changes over time.



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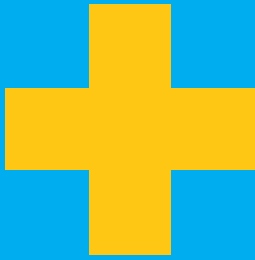
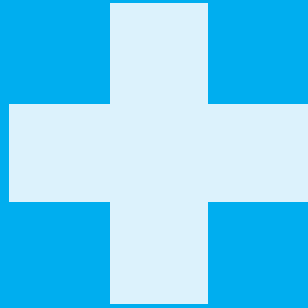
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Annex 1



Annex 1

Annex 1 is an online annex that contains UNEP's EW-MFA Compiler, which supports countries to build EW-MFA. As well as providing the basic structure required for these accounts, a number of simple

tools are also included for the calculation of some material categories, where they are not the result of simple summation. The table of contents of the EW-MFA Compiler is shown below:

Table 6.3 Table of contents EW-MFA Compiler.

SHEET	TITLE	STATUS
Contents	Table of contents	<i>for information</i>
Intro	Introduction and methodology	<i>for information</i>
Description & Definitions	Description of tables and Definitions	<i>for information</i>
Table_A	Domestic Extraction	to fill in
Table_B	Imports of Materials	to fill in
Table_C	Exports of Materials	to fill in
Table_D	Material Outflows	to fill in
Table_E	Balancing Items	to fill in
Table_F	Headline Indicators	to be filled in automatically
Corresp SDMX Codes	Correspondence EW-MFA Codes to SDMX Codes	<i>can be used for estimation of selected items</i>
Corresp FAO Crop Codes_DE	Correspondence FAO Crop Codes to EW-MFA Codes_Domestic Extraction	<i>can be used for estimation of selected items</i>
Crop Residues Tool_DE	Calculated totals for Crop Residues - Domestic Extraction	<i>can be used for estimation of selected items</i>
Grazed Biomass Tool_DE	Calculated totals for Grazed Biomass - Domestic Extraction	<i>can be used for estimation of selected items</i>
ConvFact Wood_DE	Conversion Factors Wood - Domestic Extraction	<i>can be used for estimation of selected items</i>
Metal Ores Tool 1_DE	Calculated totals for Metal Ores - Mined Ores	<i>can be used for estimation of selected items</i>

Table 6.3 Table of contents EW-MFA Compiler. (Cont.)

SHEET	TITLE	STATUS
Metal Ores Tool 2_DE	Calculated totals for Metal Ores - Processed/ Shipped Ores	<i>can be used for estimation of selected items</i>
Metal Ores Tool 3_DE	Calculated totals for Metal Ores - SMS Back Calculation	<i>can be used for estimation of selected items</i>
ConvFact Non-Met Minerals	Conversion Factors Non-Metallic Minerals	<i>can be used for estimation of selected items</i>
Chalk, Dol and Limest Tool_DE	Calculated totals for Chalk, Dolomite and Limestone_Domestic Extraction	<i>can be used for estimation of selected items</i>
ConvFact Clays_DE	Conversion Factors Clays - Domestic Extraction	<i>can be used for estimation of selected items</i>
Sand and Gravel Tool_DE	Calculated totals for Sand and Gravel for Construction_Domestic Extraction	<i>can be used for estimation of selected items</i>
Fossil Fuels Tool_DE	Calculated totals for Fossil Fuels - Domestic Extraction	<i>can be used for estimation of selected items</i>
Fossil Fuels Tool_Imp	Calculated totals for Fossil Fuels - Imports	<i>can be used for estimation of selected items</i>
Fossil Fuels Tool_Exp	Calculated totals for Fossil Fuels - Exports	<i>can be used for estimation of selected items</i>
ConvFact Peat	Conversion Factor Peat	<i>can be used for estimation of selected items</i>
ConvFact Crude Oil and NGL	Conversion Factors Crude Oil and Natural Gas Liquids_Domestic Extraction	<i>can be used for estimation of selected items</i>
ConvFact Natural Gas	Conversion Factors Natural Gas	<i>can be used for estimation of selected items</i>
Corresp HS2017_Trade	Correspondence Table HS 2017 Codes to EW- MFA Codes	<i>can be used for estimation of selected items</i>
Corresp SITC Rev.4_Trade	Correspondence Table SITC Rev. 4 Codes to EW-MFA Codes	<i>can be used for estimation of selected items</i>
The full EW-MFA Compiler is available from: https://wedocs.unep.org/20.500.11822/41948		



United Nations Environment Programme
P.O. Box 30552-00100, Nairobi, KENYA
E-mail: unenvironment-publications@un.org