Australia's National
Science Agency

Technical annex for Global Material Flows Database - 2024 edition

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Foreword

This Technical annex was prepared for United Nations Environment Programme's International Resource Panel (UNEP IRP), as a deliverable under Activities 1 and 2 of Small-Scale Funding Agreement DTIE20-SC006 between UNEP IRP and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

It is an updated version of the technical annex which has accompanied the web-hosted interface of UNEP IRP's Global Material Flows Database hosted at Global Material Flows Database | Resource Panel, and is intended to replace the 2022 version of this document.

This is a final draft, for review by the IRP, edited by James West[1,]. Main contributing authors were James West, Mirko Lieber[2], Heming Wang[3].

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1 Introduction

This technical annex concentrates on cataloguing the primary data sets upon which the Global Material Flows Database (GMFD) - 2024 edition is based, and on describing the transformations and further modelling used to complete and/or extend the primary input data into the comprehensive time series data finally presented.

This update includes some changes in methodologies. Crucially, this means that some data series will change significantly and retrospectively for the same historical time series presented in earlier versions.

A brief outline of how this data set relates to earlier versions, and where it fits within the broader scheme of current and mooted future material flow accounting schemes is provided in Section 3, with more detail in specific sections where they were affected e.g. Section 16, on projection and combination of all materials time series for late years.

2 Background

The material flows accounting framework covered in UNEP (2016), outlines six modules for a comprehensive material flows accounting framework. These include:

1. Direct, gross physical domestic extraction (DE) of materials from the environment within a nation's territory, direct physical imports (IM) and direct physical exports (EX). These basic flows are further combined to produce further "territorial" metrics given in this data set (see **Table 2**). To be counted as DE, the extracted material must be used for some economic activity or at least further transformed. For example, all of a metal ore is counted, as it is generally all processed post-extraction.
2. Embodied material flows associated with imports and exports, i.e., the raw material equivalents of imports (RME_{IM}) and exports (RME_{EX}). These are then used to calculate material footprint (MF), which provides a view of a nation's material consumption that, unlike DMC, fully accounts for extraction in other countries used for local consumption, and for DE ultimately used for consumption in other countries.
3. The output side of the material flows account - domestic processed output (DPO), i.e. flows of waste and emissions and the gateways through which they leave the economy and return to the environment (landfill, soil, water and air).
4. Net additions to stocks (NAS). An account of in-use stock which allows for closing the material flow balance by linking inputs to outputs, when combined with set of balancing items.
5. Unused extraction that occurs in a country's territory, often associate with DE in module 1. Things such as waste rock / overburden in mining and unused crop residues would be accounted for here rather than module 1, as they do not enter into further economic activity / transformation.
6. This module would focus on the material flows of different economic sectors and would create a true material flow satellite account and is related to the creation of physical input output tables.

The data in the online data set only covers modules 1 and 2. Preliminary studies towards 3 and 4 were undertaken in parallel with the previous update.

Table 1 Material flows covered in the Global Material Flows Database

INDICATOR	
DE	Domestic extraction
IM	Physical imports (direct, territorial)
EX	Physical imports (direct, territorial)
DMI	Direct material input = DE + IM
PTB	Physical trade balance = IM - EX
DMC	Domestic material consumption = DE + IM - EX
RME_{IM}	Raw material equivalent of imports
RME_{EX}	Raw material equivalent of exports
MF	Material footprint = DE + RME_{IM} - RME_{EX}

3 Changes to this update relative to the preceding (2021) database

The 2024 version of the Global Material Flows Database (GMFD) largely retains the same set of material flow accounts covered compared to earlier versions. There has been no significant change in the scope or final categorization of either the territorial accounts, or of the consumption-based indicators.

The major expansion in scope of materials covered, first included in the previous (2021) version of the GMFD, were described in the previous version of this technical annex, UNEP International Resources Panel (2023). These were so significant that they are reiterated in full in Section 4 below, as background information which remains important for this version.

The main changes between the 2021 GMFD and this version, apart from extending the time series covered, are:

1. Major changes to the both the extent and methods of projection used for the latest years. For detail, see Section 16.
2. Updates to the “Engineering exclusions” settings used in the Multi-regional Input Output Table (MRIOT), which reallocates material for the raw materials equivalent (RME) or “consumption based” indicators. For detail, see Section 18.
3. Significant change to the financial input/output data underlying the MRIOT. For detail, see Section 18.
4. Increased resolution in the material categories at which domestic extraction (DE) is fed into to the MRIOT, for subsequent re-allocation. For detail, see Section 18.

The extensions to time series associated with 1. above mean that a longer section of each time series should not be used for statistical purposes such as regression analyses, for this update compared to the 2021 version. The method of projection discussed in Section 16 will build in a correlation with GDP growth. Some projected data begins to enter time series as early as 2020, and the last year which should be used to establish statistical correlations for analysis is 2019.

4 Reiteration of changes to 2021 database over the 2019 database

This section is simply a direct copy of section 2 of the final version of the Technical Annex to the 2021 version of the database. It is included here as it contains both important information of the extent of major changes then, and their practical effects on important indicators, notably DMC.

The 2021 version of the Global Material Flows Database (GMFD) marks a substantial expansion of the set of material flow accounts covered compared to earlier versions. A major change in the direct / territorial accounts is the expansion of the categories covered in Trade. The main change here is the inclusion of much more of the trade in complex and mixed materials manufactured goods. The scope has also been increased to include trade in waste.

These categories were largely excluded previously for a number of reasons, including poor data availability and quality, the fact that they cannot easily be linked back to one of the major primary materials officially covered by domestic extraction (DE), and because they also add mass which does not enter the system via DE. The latter two points are particularly important in that that the inclusion of these additional materials can cause problems for the expected material balances.

To minimize these potential negative impacts, the newly included materials are accommodated by simply adding additional categories to the previous classification systems. This preserves the DE-centric structure of earlier versions at the centre of the new system, allowing a user to quarantine the new categories. This separation begins at the highest level of detail at which the accounts are compiled and flows through to the aggregated categories presented on the public website.

This update of the GMFD marks substantial progress towards a more comprehensive material flows accounting framework, of the type covered in UNEP (2016), to which the reader is referred if further detail is desired. In brief, there are six modules mooted for a comprehensive material flows accounting framework, outline below:

1. Direct, gross physical domestic extraction (DE) of materials from the environment within a nation's territory, direct physical imports (IM) and direct physical exports (EX). These basic flows are further combined to produce further "territorial" metrics given in this data set (see Table 2). To be counted as DE, the extracted material must be used for some economic activity or at least further transformed. For example, all of a metal ore is counted, as it is generally all processed post-extraction.

2. Embodied material flows associated with imports and exports, i.e., the raw material equivalents of imports (RME_{IM}) and exports (RME_{EX}). These are then used to calculate material footprint (MF), which provides a view of a nation's material consumption that, unlike DMC, fully accounts for extraction in other countries used for local consumption, and for DE ultimately used for consumption in other countries.

3. Deals with the output side of the material flow account 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).
4. Measures net additions to stocks (NAS) and may contain a stock account of in-use stock (Stock) and allows for closing the material flow balance by linking inputs to outputs and by introducing a set of balancing items.
5. Deals with unused extraction that occurs in a country's territory, often associate with DE in module 1. Things such as waste rock / overburden in mining and unused crop residues would be accounted for here rather than module 1, as they do not enter into further economic activity / transformation.
6. This module would focus on the material flows of different economic sectors and would create a true material flow satellite account and is related to the creation of physical input output tables.

The data in the online data set only covers modules 1 and 2, although associated preliminary studies towards 3 and 4 were undertaken in parallel with this update.

Table 2 Material flows covered in the Global Material Flows Database

INDICATOR	
DE	Domestic extraction
IM	Physical imports (direct, territorial)
EX	Physical imports (direct, territorial)
DMI	Direct material input = DE + IM
PTB	Physical trade balance = IM - EX
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RME_{IM}	Raw material equivalent of imports
RME_{EX}	Raw material equivalent of exports
MF	Material footprint = DE + RME_{IM} - RME_{EX}

The second major area of change and improvement has been in the production of new material footprints using a totally new multi-regional input-output table (MRIOT) structure. In summary, there have been major improvements, most notably:

1. Increasing the sectoral resolution of the MRIOT (from xx economic sectors previously to 97 sectors in this version)
2. Introducing a series of "Engineering Exclusions" to preclude or reduce transactions between sectors which do not make sense analytically.

The new Global Resource Input Output Assessment (GLORIA) MRIO database used to produce the material footprints for this version of the database has its own separate, detailed technical documentation. The key methodological advances and changes it represents over earlier versions are extensive and complex, so the reader is referred to that document, Geschke (2021), rather than deal with it in depth in this annex.

A third major change is the much broader sourcing of data and higher level of detail used in compiling the metal ores DE accounts. This is the result of quite intensive and ongoing upgrade work undertaken by the WU. The result of this is that, rather than being simply an update or continuation of previous versions of this database in this category, large variations from the earlier historical time series will be quite common.

A fourth significant change from earlier versions of the GMFD relates to both the inclusion of more trade data, and preparation for more seriously addressing both stocks and DPO in the context of the circular economy going forward. In previous versions, DMC for any material was assumed to be zero to positive in any one year. While it was acknowledged that this is not strictly true, and that DMC could go negative e.g., after delayed release from stocks were taken into account, it was assumed (and generally true) that when a negative DMC was calculated from GMFD data for DE + PTB, a negative DMC was far more likely to be due to data inadequacies rather than a reflection of a genuine negative DMC situation. As a result, negative DMC values were simply set to zero, on the assumption that this was likely to reduce the size of the potential errors.

While this is quite likely still true, arbitrarily zeroing out negative DMC would seriously compromise the utility of the database for the type of mass-balancing and reconciliation functions that will be required of, if it is to serve in any DPO and circular economy role. Consequently, DMC values are now left as calculated. It is incumbent upon users to use their judgement and/or further research to determine whether individual instances of negative DMC are reasonable, or more likely to flag that the underlying DE and Trade data was inadequate to accurately calculate it.

5 Overview of compilation of Domestic extraction

The publicly available online database presents direct material flows data for four main material categories which are directly extracted from the environment. These are the same four high level categories used in previous versions of this database.

An additional seven categories to accommodate manufactured materials and waste are provided at the most aggregated level, but these will not have data for DE, as they generally make no sense in the context of DE, where they would involve double counting of materials. They are included mainly for international trade, where double counting is not a concern. Four of these categories accommodate "products mainly from…" manufactures for each of the main DE categories, and one covers complex/mixed manufactures, and one (internationally traded) waste.

One further additional category, "Excavated earthen materials (including soil) nec," is included as a placeholder, as it is already reportable for some jurisdictions material flows, notably the EU, but may in practice be used to record material flows which have not traditionally been included as DE. Notable examples include much "cut and fill" material in construction, and mining overburden. Introducing it as a separate category now enables it to be recorded, but also quarantined from DE estimates going forward.

There is also an intermediate detail system, where the four main DE categories are disaggregated further into 13 sub-categories, matching earlier versions of this database. There are also additional sub-categories for non-wild animals, while the "products mainly from fossil fuels" category is split into two sub-categories, one covering refined fuels, and the other all other fossil fuel derived products. This split was introduced to facilitate a level of backwards comparability with earlier versions, where refine fuels were included in the trade accounts (and so PTB and DMC calculation), while other fossil fuel-based products were mainly excluded.

This results in two systems of 11 and 22 categories respectively. These shown in table 2, labelled MFA4Plus and MFA13Plus, with the non-DE, trade related categories in blue.

Table 3 Augmented aggregate categories used for this update of GMFD (new, trade-related categories in blue)

MFA4Plus	MFA13Plus
Biomass	Crops
Biomass	Crop Residues
Biomass	Grazed biomass and fodder crops
Biomass	Wood
Biomass	Wild catch and harvest
Products from biomass	Non-wild animal products

MFA4Plus	MFA13Plus
Products from biomass	Products mainly from biomass nec.
Fossil Fuels	Coal
Fossil Fuels	Petroleum
Fossil Fuels	Natural Gas
Fossil Fuels	Oil shale and tar sands
Products from fossil fuels	Other products mainly from fossil fuels e.g., plastics
Products from fossil fuels	Refined fossil fuels mainly for fuel e.g., LPG gasoline diesel
Metal ores	Ferrous ores
Metal ores	Non-ferrous ores
Products from metals	Products mainly from metals nec.
Non-metallic minerals	Non-metallic minerals - construction dominant
Non-metallic minerals	Non-metallic minerals - industrial or agricultural dominant
Products from non-metallic minerals	Products mainly from non-metallic minerals
Excavated earthen materials (including soil) nec	Excavated earthen materials (including soil) nec
Mixed and complex products nec.	Mixed / complex products nec.
Waste for final treatment and disposal	Waste for final treatment and disposal

Collating and /or modelling of data was performed at a much higher level of disaggregation. Versions prior to 2021 were compiled used a 62 category "Common Compilation Categories" (CCC) system, and in 2021 this was expanded to a 90+ category system, referred to as the "Trade Common Compilation Categories' (TCCC). For this update, DE collation was further expanded to 367 categories, for reasons related to material footprinting, (see Section 18). This extra-detailed level is however, immediately mapped back to TCCC level for all other purposes, and never made available (for data copyright reasons among others).

The TCCC level is also mainly used for internal project purposes, but was designed to conform as well as practicable with the system of categories used in (Eurostat, 2018) while incorporating some of the improvements suggested in (UNEP, 2020) with regard to metal ores[1]. How the TCCC system relates to the MFA4Plus and MFA13Plus systems is shown in table 3.

Table 4 Concordance between the MFA4Plus, MFA13Plus, and the detailed TCCC category system used for initial compilation of data for domestic extraction.

TCCC_Code	TCCC_Name	MFA13Plus	MFA4Plus
TCCC.1.1.1.1	Rice	Crops	Biomass
TCCC.1.1.1.2	Wheat	Crops	Biomass
TCCC.1.1.1.3	Cereals n.e.c.	Crops	Biomass
TCCC.1.1.10	Other crops n.e.c	Crops	Biomass
TCCC.1.1.11	Spice - beverage - pharmaceutical crops	Crops	Biomass
TCCC.1.1.12	Tobacco	Crops	Biomass
TCCC.1.1.2	Roots and tubers	Crops	Biomass
TCCC.1.1.3	Sugar crops	Crops	Biomass
TCCC.1.1.4	Pulses	Crops	Biomass
TCCC.1.1.5	Nuts	Crops	Biomass
TCCC.1.1.6	Oil bearing crops	Crops	Biomass
TCCC.1.1.7	Vegetables	Crops	Biomass
TCCC.1.1.8	Fruits	Crops	Biomass
TCCC.1.1.9	Fibres	Crops	Biomass
TCCC.1.2.1.1	Straw	Crop Residues	Biomass

[1] A significant change has been adapting the UNEP IRP manual's usage of element alpha-symbols for metals to create a logically and systematic means to extend the ores classified, as more elements become subject to mining. The extensibility of this system is one reason why "90+" is given as the number of categories for the TCCC system, rather than one definite number.

TCCC_Code	TCCC_Name	MFA13Plus	MFA4Plus
TCCC.1.2.1.2	Other crop residues (sugar and fodder beet leaves etc)	Crop Residues	Biomass
TCCC.1.2.2.1	Fodder crops (including biomass harvest from grassland)	Grazed biomass and fodder crops	Biomass
TCCC.1.2.2.2	Grazed biomass	Grazed biomass and fodder crops	Biomass
TCCC.1.3.1	Timber (Industrial roundwood)	Wood	Biomass
TCCC.1.3.2	Wood fuel and other extraction	Wood	Biomass
TCCC.1.4.1	Wild fish catch	Wild catch and harvest	Biomass
TCCC.1.4.2	All other aquatic animals	Wild catch and harvest	Biomass
TCCC.1.4.3	Aquatic plants	Wild catch and harvest	Biomass
TCCC.1.4.4	Hunting and gathering	Wild catch and harvest	Biomass
TCCC.1.5.1	Live animals other than in 1.4.	Non-wild animal products	Products from biomass
TCCC.1.5.2	Meat and meat preparations	Non-wild animal products	Products from biomass
TCCC.1.5.3	Dairy products birds eggs and honey	Non-wild animal products	Products from biomass
TCCC.1.5.4	Other products from animals (animal fibres skins furs leather etc.)	Non-wild animal products	Products from biomass
TCCC.1.6	Products mainly from biomass nec.	Products mainly from biomass nec.	Products from biomass
TCCC.2.1.Fe	Iron ores concentrates and compounds	Ferrous ores	Metal ores
TCCC.2.1.m.Fe	Iron metals alloys and manufactures	Ferrous ores	Metal ores
TCCC.2.2.Ag	Silver ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Al	Bauxite and other aluminium ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Au	Gold ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Cr	Chromium ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Cu	Copper ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.m.Ag	Silver metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Al	Aluminium metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Au	Gold metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Cr	Chromium metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Cu	Copper metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Mn	Manganese metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Mg	Magnesium metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.nec	Simple undefined or mixed processed metals nec	Non-ferrous ores	Metal ores
TCCC.2.2.m.Ni	Nickel metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Pb	Lead metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Pt	Platinum group metal metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Sn	Tin metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Ti	Titanium metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.U	Uranium metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.m.Zn	Zinc metals alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.2.Mn	Manganese ores concentrates and compounds	Non-ferrous ores	Metal ores

TCCC_Code	TCCC_Name	MFA13Plus	MFA4Plus
TCCC.2.2.nec	Other metal ores concentrates and compounds nec. including mixed	Non-ferrous ores	Metal ores
TCCC.2.2.Ni	Nickel ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Pb	Lead ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Pt	Platinum group metal ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Sn	Tin ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Ti	Titanium ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.U	Uranium ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.Zn	Zinc ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.3.m	Products mainly from metals nec.	Products mainly from metals nec.	Products from metals
TCCC.3.1	Ornamental or building stone	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.10	Excavated earthen materials (including soil) nec	Excavated earthen materials (including soil) nec	Excavated earthen materials (including soil) nec
TCCC.3.11	Products mainly from non-metallic minerals	Products mainly from non-metallic minerals	Products from non-metallic minerals
TCCC.3.2.1	Chalk	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.2.2	Dolomite	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.2.3	Limestone	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.4.1	Fertilizer minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.4.2	Chemical minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.4.3	Industrial minerals n.e.c	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.5	Salt	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.6	Gypsum	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.7.1	Structural clays	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.7.2	Specialty clays	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.8.1	Industrial sand and gravel	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.8.2	Sand gravel and crushed rock for construction	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.9	Other non-metallic minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.4.1.1.1	Lignite (brown coal)	Coal	Fossil Fuels
TCCC.4.1.1.2	Other Sub-Bituminous Coal	Coal	Fossil Fuels
TCCC.4.1.2.1	Anthracite	Coal	Fossil Fuels
TCCC.4.1.2.2	Coking Coal	Coal	Fossil Fuels
TCCC.4.1.2.3	Other Bituminous Coal	Coal	Fossil Fuels
TCCC.4.1.3	Peat	Coal	Fossil Fuels
TCCC.4.2.1	Crude oil	Petroleum	Fossil Fuels
TCCC.4.2.2	Natural gas	Natural Gas	Fossil Fuels
TCCC.4.2.3	Natural gas liquids	Petroleum	Fossil Fuels

TCCC_Code	TCCC_Name	MFA13Plus	MFA4Plus
TCCC.4.3	Oil shale and tar sands	Oil shale and tar sands	Fossil Fuels
TCCC.4.4.1	Refined fossil fuels mainly for fuel e.g., LPG gasoline diesel	Refined fossil fuels mainly for fuel e.g., LPG gasoline diesel	Products from fossil fuels
TCCC.4.4.2	Other products mainly from fossil fuels e.g., plastics	Other products mainly from fossil fuels e.g., plastics	Products from fossil fuels
TCCC.5	Mixed / complex products nec.	Mixed / complex products nec.	Mixed and complex products nec.
TCCC.6	Waste for final treatment and disposal	Waste for final treatment and disposal	Waste for final treatment and disposal

The main reason that data is not released at TCCC level is because, at such high levels of resolution, errors (or at least inconsistencies) in classification becomes a major problem in the base data sets. For example, at the TCCC level, the statistician compiling data at a National Statistical Office (NSO) could realistically have classified some limestone (the actual rock extracted from the environment) as “Ornamental or building stone” in one form (where cut or dressed for direct building use), other limestone as “Limestone” in another use (probably that being used as an input to cement production, or for soil conditioners), and still other limestone (quite likely the main bulk of it), as “Sand gravel and crushed rock for construction”. This is before we even take into account the poorly defined boundary in the real world between “Limestone” and “Dolomite”. At the MFA13Plus level, the inconsistencies in classification disappear in this case, with all of the above ending up in the “Non-metallic minerals - construction dominant” category. Similar effects are common for many other materials.

The degree to which different material categories are based directly on official statistics varies greatly between material categories. In the case of materials where there is a major international agency charged with compiling basic statistics, the domestic extraction figures here may be almost entirely based upon direct compilation from that data. A good example of this is the MFA13Plus crops category, which relies entirely on published FAO data. At the other end of the spectrum, for categories where no such agency or mandate exists, e.g., for Non-metallic minerals - construction dominant, the domestic extraction figures given are usually the result of substantial modelling and inference from statistics of related materials, products, and built infrastructure, which serve as proxies. Detail on the data sources used and estimation processes used is given in the appropriate material sections below.

6 Domestic extraction of biomass

6.1 Crops

The base data for crops was sourced directly from FAO (2023c)The date that the data used for the Crops was accessed was October 2020, and at that time the final year for which data was generally available was 2019. No further calculations were applied, so the tonnages in this data set are on the same basis (generally “as harvested”) as the tonnages in the FAO database. This means there is no standardization of crops to a common moisture content, which can be very different, for example, between for fresh fruit and vegetable crops and cereals.

The main process here simply involved aggregating the more than 180 crops given in the FAO data into the 14 crop categories available in the TCCC system.

Crop Residues

Crop residues are a by-product of the crop harvest, and so the first input to their calculation is the same FAO crop data used for the crop accounts.

From the crop data, the next stage in calculating crop residues is applying a harvest factor, which gives the non-harvested, above ground portion of the plant. A harvest factor of 1.2, for example, signifies that for each kg of crop harvested, 1.2 kg of crop residue is also produced.

As DE should only count materials which enter economic activity, only that portion of the available crop residues which are recovered from the field are counted. This requires the application of a second “recovery” factor.

Both harvest and recovery factors were sourced from Haberl et al. (2007). This source has eight different regionally specific harvest factors for 17 different crops, and eight different regionally specific recovery factors for 11 different crops. As the FAO data had over 180 crops, those crops which did not map directly to a recovery/harvest factor from Haberl et al. (2007) were allocated one from apparently similar crops which did have a factor. Note that for crop residues, no “dry matter basis” correction has been undertaken here, in keeping with the “as harvested” basis for the crops they are based on. This is in line with UNEP (2020) and Eurostat (2018), although no accompanying moisture content is recorded, unlike the Eurostat system.

6.2 Grazed biomass and fodder crops

Fodder crops in the current data set can be thought of as largely a legacy category, and also as a place holder for the future, in case the FAO resumes collecting relevant data here, and/or if data in these accounts begins to directly integrate data sourced from individual national accounts which include this detail. In earlier years, the FAO did collect and present data specifically on fodder crops (under FAO codes 636–655 and 857–859) however this no longer seems to be the case. Note that fodder crops should not be confused with any crops accounted for in the other crop categories which may subsequently be used to feed animals. The FAO still accounts for the latter in its food balances[2].

In contrast to fodder crops, grazed biomass has never been accounted for in FAO statistics, but remains an active and substantial component of overall biomass for this data set.

To calculate grazed biomass, a "roughage per head" requirement is simply applied to live animal herd numbers reported in (FAO, 2023e). These roughage requirements are differentiated by important classes of ruminant animals, and by World region. The factors applied are given in Table 5, with weights standardized to 15% moisture content.

This simple approach is now preferred to the feed energy gap model used prior to 2021. Even though the latter is theoretically superior, it relies on the availability of a lot of high-quality input data to get good results. Crucially, where such data is not available, applying it can lead to very large errors.

It became apparent that the data available from the central source used, the FAO, was not comprehensive enough to support feed gap modelling for most countries. This is especially with regard to the specification and standardization of non-grazed feed in puts to livestock raising. In this situation, the shortcomings of the simple roughage per head model were outweighed by the fact that it is very simple, very transparent, and much more limited in terms of the errors it can make compared to a feed gap modelling based on inadequate input data.

[2] A rule-of-thumb to distinguish the two is to consider whether a crop was grown specifically for animal feed and can’t readily be diverted to alternative use. To illustrate this point, maize grown and harvested conventionally as grain is just a crop, even if there is a 90% chance it will be used as animal feed. It could easily be diverted to human consumption, ethanol production, etc. In contrast, maize grown, harvested, and stored as silage is forage. Not only was this its intended use, but it also doesn’t substitute easily into other important uses. Grasses, whole legume plants etc. harvested from field, not grazed directly by animal, are also forage crops.

Table 5 Coefficients for roughage required per head in national animal herds. Source: Derived from (Krausmann et al., 2013)

Tonnes / head / year	South & Central Asia	Eastern Europe	North Africa & West Asia	North America & Oceania	Western Europe	Sub-Saharan Africa	Latin America & Caribbean	East Asia
Cattle, buffalo	1.2	4.5	2.8	5.9	5.9	2.0	3.6	4.1
Sheep, goats	0.3	0.6	0.3	0.6	0.6	0.3	0.3	0.4
Horses	2.8	4.0	3.4	4.1	4.2	3.0	3.5	4.3
Mules, asses	1.7	2.4	2.0	2.5	2.5	1.8	2.1	2.6

While fodder crops and grazed biomass continue as two distinct sub-categories at the TCCC level, and so ostensibly compiled separately, separating the two has always been very difficult in practical terms, even though conceptually simple. Ideally, fodder crops should be restricted to those crops specifically grown and harvested for ruminant forage and silage. Unfortunately, even when the FAO was still making data available for fodder crops, it suffers from two major problems. The first is the uncertain basis on which weight was determined regarding moisture content. This was a major problem, as crops in this class can have much higher than the 15% moisture assumed as a standard accounting basis, and upon which all feed energies are calculated. The second is that it appears unlikely that there was a clear separation between forage crops which are grazed directly in the field, and those which have been harvested and converted to silage or hay.

6.3 Wood

Data for production of forestry products is reported in the FAO (2023b), in volumetric units. The subset of FAO products included as domestic extraction, and the factors applied to convert m^3 to tonnages (differentiating between coniferous and non-coniferous wood) are given in Table 6. The conversion factors were source from Eurostat (2013)

Table 6 FAO Forestry product categories included in domestic extraction, with corresponding factors used to convert from m3 to tonnes.

FAO Code	FAO Name	Conversion factor
1601	Sawlogs+Veneer Logs (C)	0.52
1602	Pulpwood,Round&Split(C)	0.52
1603	Pulpwood,Round&Split(NC)	0.68
1604	Sawlogs+Veneer Logs (NC)	0.68
1608	Pulpwood and particles, coniferous (production, 1961-1997)	0.52
1611	Pulpwood and particles, non-coniferous (production, 1961-1997)	0.68
1623	Other Indust Roundwd(C)	0.52
1626	Other Indust Roundwd(NC)	0.68
1627	Wood Fuel(C)	0.52
1628	Wood Fuel(NC)	0.68

6.4 Wild catch and harvest

The only components actively compiled for this category were source from FAO (2023a). From this data source, the only categories considered were wild fish and other marine animals catch (aquaculture does not count as DE, in the same way livestock doesn't), and the harvest of aquatic plants. No data on Hunting and gathering was sourced, and wild catch of aquatic animals other than those specified in tonnes were not considered.

7 Trade in biomass

As with domestic extraction, the main source of data for trade in biomass was online FAO sources. Unlike domestic extraction, there was very little modelling of data required, the main task being simple aggregation of tonnages given by the FAO, or in some cases conversion from other units to tonnes.

Trade data on crops, crop residues, and fodder crops was aggregated directly from FAO (2023d) Grazed biomass can't be traded by definition i.e., it enters into economic activity at the point it is extracted by the animal eating it. Data on traded processed crop products, and on animal and livestock products came from the same FAO bulk data file. Of the 396 individual product categories in the original FAO file (i.e., excluding aggregates), 263 were allocated to the crop type TCCC categories (TCCC.1.1 through TCCC.1.2), 83 to the animal related products under TCCC.1.5, 47 to TCCC.1.6 " Products mainly from biomass nec.", and three to TCCC.5 "Mixed / complex products nec.". Allocations were made with a view to quarantining the issue of inclusion of mass derived from non-DE derived materials e.g., added water, to the new TCCC.1.6 and TCCC.5 categories.

As with DE, data on trade under TCCC.1.4 was sourced only from (FAO, 2023a).

Wood trade data (i.e., under TCCC.1.3) was sourced from (FAO, 2023b), and trade in goods corresponding to TCCC.1.4 Wild catch and harvest was compiled from FAO (2022).

As in previous versions of this database, the scope of individual products included for Wood trade was broader than for DE, as risk of multiple counting the same material (e.g., first as extracted, then as a semi-processed commodity, then as a finished product) is not present when establishing trade balances. The explicit inclusion of separate categories for manufactured goods composed mainly of biomass, in this version, however, raised the question of whether some processed goods which had been allocated to primary production categories previously e.g., Sawnwood, plywood etc should now be allocated to "Products mainly from biomass nec" at the TCCC level, or continue to be allocated to "Timber (Industrial roundwood)" as in earlier versions.

The decision was made to continue allocating most of these products to TCCC1.3.1 "Timber (Industrial roundwood)" to preserve compatibility with earlier versions. Detailed allocation from the 61 relevant FAO categories (up from 43 included in the previous version), to the relevant TCCC category, along with the factors applied to convert FAO reported units to tonnes, is provided in Table 7.

Table 7 Allocation of FAO Forestry products included in trade to TCCC categories, with factors used to convert from FAO units to tonnes

FAO Code	FAO Item	Con. Factor	TCCC Code	TCCC Name
1600	Recovered post-consumer wood	1	TCCC.1.3.1	Timber (Industrial roundwood)
1601	Sawlogs and veneer logs, coniferous	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1602	Pulpwood, round and split, coniferous (production)	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1603	Pulpwood, round and split, non-coniferous (production)	0.68	TCCC.1.3.1	Timber (Industrial roundwood)
1604	Sawlogs and veneer logs, non-coniferous	0.68	TCCC.1.3.1	Timber (Industrial roundwood)

FAO Code	FAO Item	Con. Factor	TCCC Code	TCCC Name
1606	OSB	0.68	TCCC.1.6	Products mainly from biomass nec.
1608	Pulpwood and particles, coniferous (production, 1961-1997)	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1609	Recovered fibre pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1611	Pulpwood and particles, non-coniferous (production, 1961-1997)	0.68	TCCC.1.3.1	Timber (Industrial roundwood)
1612	Printing and writing papers, uncoated, mechanical	1	TCCC.1.3.1	Timber (Industrial roundwood)
1614	Pulpwood, round and split, all species (export/import, 1961-1989)	0.6	TCCC.1.3.1	Timber (Industrial roundwood)
1615	Printing and writing papers, uncoated, wood free	1	TCCC.1.3.1	Timber (Industrial roundwood)
1616	Printing and writing papers, coated	1	TCCC.1.6	Products mainly from biomass nec.
1617	Case materials	1	TCCC.1.6	Products mainly from biomass nec.
1618	Cartonboard	1	TCCC.1.6	Products mainly from biomass nec.
1619	Wood chips and particles	0.48	TCCC.1.3.1	Timber (Industrial roundwood)
1620	Wood residues	0.48	TCCC.1.3.1	Timber (Industrial roundwood)
1621	Wrapping papers	1	TCCC.1.3.1	Timber (Industrial roundwood)
1622	Other papers mainly for packaging	1	TCCC.1.3.1	Timber (Industrial roundwood)
1623	Other industrial roundwood, coniferous (production)	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1625	Other industrial roundwood, all species (export/import, 1961-1989)	0.6	TCCC.1.3.1	Timber (Industrial roundwood)
1626	Other industrial roundwood, non-coniferous (production)	0.68	TCCC.1.3.1	Timber (Industrial roundwood)
1627	Wood fuel, coniferous	0.52	TCCC.1.3.2	Wood fuel and other extraction
1628	Wood fuel, non-coniferous	0.68	TCCC.1.3.2	Wood fuel and other extraction
1629	Wood fuel, all species (export/import, 1961-2016)	0.6	TCCC.1.3.2	Wood fuel and other extraction
1630	Wood charcoal	1	TCCC.1.3.1	Timber (Industrial roundwood)
1632	Sawnwood, coniferous	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1633	Sawnwood, non-coniferous all	0.68	TCCC.1.3.1	Timber (Industrial roundwood)
1634	Veneer sheets	0.6	TCCC.1.3.1	Timber (Industrial roundwood)
1640	Plywood	0.68	TCCC.1.6	Products mainly from biomass nec.
1646	Particle board and OSB (1961-1994)	0.68	TCCC.1.6	Products mainly from biomass nec.
1647	Hardboard	0.6	TCCC.1.6	Products mainly from biomass nec.
1648	MDF/HDF	0.52	TCCC.1.6	Products mainly from biomass nec.
1649	Fibreboard, compressed (1961-1994)	0.6	TCCC.1.6	Products mainly from biomass nec.
1650	Other fibreboard	0.3	TCCC.1.6	Products mainly from biomass nec.
1651	Industrial roundwood, coniferous (export/import)	0.52	TCCC.1.3.1	Timber (Industrial roundwood)
1654	Mechanical wood pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1655	Semi-chemical wood pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1656	Chemical wood pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1657	Industrial roundwood, non-coniferous tropical (export/import)	0.68	TCCC.1.3.1	Timber (Industrial roundwood)
1660	Chemical wood pulp, sulphite, unbleached	1	TCCC.1.3.1	Timber (Industrial roundwood)
1661	Chemical wood pulp, sulphite, bleached	1	TCCC.1.3.1	Timber (Industrial roundwood)
1662	Chemical wood pulp, sulphate, unbleached	1	TCCC.1.3.1	Timber (Industrial roundwood)
1663	Chemical wood pulp, sulphate, bleached	1	TCCC.1.3.1	Timber (Industrial roundwood)
1667	Dissolving wood pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1668	Pulp from fibres other than wood	1	TCCC.1.3.1	Timber (Industrial roundwood)
1669	Recovered paper	1	TCCC.1.3.1	Timber (Industrial roundwood)
1670	Industrial roundwood, non-coniferous non-tropical (export/import)	0.6	TCCC.1.3.1	Timber (Industrial roundwood)
1671	Newsprint	1	TCCC.1.3.1	Timber (Industrial roundwood)

FAO Code	FAO Item	Con. Factor	TCCC Code	TCCC Name
1674	Printing and writing papers	1	TCCC.1.6	Products mainly from biomass nec.
1675	Other paper and paperboard	1	TCCC.1.3.1	Timber (Industrial roundwood)
1676	Household and sanitary papers	1	TCCC.1.3.1	Timber (Industrial roundwood)
1681	Wrapping and packaging paper and paperboard (1961-1997)	1	TCCC.1.3.1	Timber (Industrial roundwood)
1683	Other paper and paperboard n.e.s. (not elsewhere specified)	1	TCCC.1.3.1	Timber (Industrial roundwood)
1685	Mechanical and semi-chemical wood pulp	1	TCCC.1.3.1	Timber (Industrial roundwood)
1686	Chemical wood pulp, sulphite	1	TCCC.1.3.1	Timber (Industrial roundwood)
1693	Wood pellets	1	TCCC.1.3.1	Timber (Industrial roundwood)
1694	Other agglomerates	1	TCCC.1.3.1	Timber (Industrial roundwood)
1695	Wood chips, particles and residues	0.48	TCCC.1.3.1	Timber (Industrial roundwood)
1696	Wood pellets and other agglomerates	1	TCCC.1.3.1	Timber (Industrial roundwood)
1697	Particle board	0.6	TCCC.1.6	Products mainly from biomass nec.

8 Domestic extraction of metal ores

The dataset on extraction of metal ores was compiled in accordance with most standards on Material Flow Accounting (MFA) published by Eurostat and the OECD over the last two decades (EUROSTAT, 2001, 2007, 2012, 2018; OECD, 2004, 2008).

8.1 Data sources

Primary data on the extraction of metal ores was obtained from three major international data sources: the World Mining Data (WMD) database published by the Austrian Ministry of Agriculture, Regions and Tourism in Reichl (2021); the British Geological Survey's BGS (2021); and the United States Geological Survey's USGS (2021). Most of the data sets are available for free online or can be made available upon request. BGS provides an online download tool for all years starting from 1970, WMD and USGS provide Excel and pdf files (WMD for the most recent five years; USGS for all years, already starting before 1970). All data sources provide data annually, normally with a delay of 2-3 years.

The later accessed versions cited above were generally the same as in previous versions of these accounts for the years both had in common. However, due to a whole new underlying compilation structure, additional data was retrieved and included, to improve detail, total coverage, and quality. The various data sets included are as follows:

Table 8 Primary data sources for metals, metal ores, and metal compounds

Primary source	Data set	Time range
WMD	Data retrieved online	2014-2019
WMD	Database dump provided by WMD	1984-2017
WMD	Additional info on quality of data points (reported/estimated) provided by WMD	2015-2017
BGS	Data retrieved online	1970-2019
USGS	Data retrieved online (commodity-specific "Minerals Yearbooks")	2013-2018
USGS	Data from former metal ore accounts (collected from USGS in the past)	1970-2015

Data from the WMD is consistently reported for production of metals or for the production of the respective most common metal compounds (e.g., Niobium pentoxide instead of Niobium or Lithium oxide instead of Lithium). All data points for the respective metal or metal compounds are therefore already harmonized and converted to those materials. Exceptions include Bauxite, Beryllium concentrate, and Rare earth oxides. Almost all data refers directly or indirectly to extraction of primary raw materials rather than secondary materials.

Data from BGS and from USGS is provided for ores, concentrates, metals, and metal compounds. In some cases, the materials reported for the same metal vary across countries (e.g., Niobium content being reported for one country, but Columbite for another). In some cases, time series for a single country and element are reported with the basis varying over time (e.g., elemental Lithium content may be reported for several years, then Lithium carbonate). These peculiarities have been adjusted for.

Where data was available for mined as well as for refined products, only the former has been included, as it necessarily only includes primary raw material extraction, whereas the latter commonly includes secondary materials.

Data from USGS appeared to have unit errors in a few cases, which have been adjusted accordingly.

8.2 Integration of data

The data from these sources was integrated into one consistent dataset, using WMD as the main data source, then complementing it with data from BGS, then finally with data from USGS. An assessment of WMD data and communication with the WMD team indicates that its data is of comparatively high quality. Furthermore, as mentioned above, it provides very consistent time series, already harmonized for different metal compound bases.

To allow for a proper comparison of time series and to avoid any double counting, data series were concorded to one specific material ID for the key material / element under consideration. For example, leucoxene, rutile, ilmenite, titanium dioxide, and titanium concentrate all being associated with the material ID for titanium. This was done as a pre-processing step i.e., preceding the compilation to the TCCC level. The categories used for this detailed work for both metal ores, and later for non-metallic minerals, will be referred to as "Harmonized" categories.

Similarly, as part of this pre-processing for compilation, conversion to elemental metals equivalent based on atomic weights was generally conducted. For example, Chromium (III) oxide, Tantalum pentoxide, and Tungsten trioxide were converted to Chromium, Tantalum, and Tungsten, respectively.

The primary source data did not always support full elemental disaggregation. In those cases, aggregated or mixed material categories were reported. The most prominent examples are rare earth elements and platinum-group metals.

Data for the metal accounts was overwhelmingly sourced from WMD and BGS, and so involved relatively few processing steps for integration.

As the accounts are for material extraction, direct data on ores reported by BGS was given priority over estimated ores back-calculated from WMD data. For example, BGS reports production of iron ore, whereas WMD reports production of iron, from which original ore extraction needs to be determined by applying factors.

An additional factor involved footnotes the WMD and BGS provide, which specified whether a value was reported (e.g., from national statistical accounts, surveys, etc.), or estimated by WMD/BGS. This information is available for all data from BGS, but only explicitly for the years 2015-2017 and 2019 for the WMD. Subsequent communication with the WMD team revealed that whatever applied for the latter years could be assumed for the whole time series. Where BGS data incorporated more reported data points for these years, for a specific material and country, it was given priority for the whole time series.

Where WMD did not report values for the extraction of a commodity in a country, BGS data was used. This combined (WMD plus BGS) data was then complemented with data from USGS in the same way.

As data from WMD was not available for the years before 1984, all time series were based on BGS and / or USGS data for the period 1970 to 1983.

Reported zeros in the highest priority data source (e.g., where WMD reported 0, but BGS or USGS reported something non-zero, the GMFD reports 0) were retained, whereas blank / NA values were filled with data from the lower priority source.

Nearly 56% of the final data for the metal accounts originates from WMD data, with 42% based on BGS data.

Table 9 Shares of data points for metal ores in the final dataset, by primary data source.

Primary source	Nr. of data points	Share
WMD	5237	12.58%
Own estimation based on WMD	18050	43.34%
BGS	9232	22.17%
Own estimation based on BGS	8257	19.83%
USGS	447	1.07%
Own estimation based on USGS	419	1.01%

8.3 Aggregation of data

A table specifying the aggregation of materials can be found in Appendix table A.1. It details the concordance between the metal commodities derived from the primary sources and the raw material categories used in the Global Material Flows Database. Data for 54 categories of metals were aggregated into 15 metal ore groups. For metals or metal compounds where no estimation was conducted (for whatever reason), the materials involved were included as reported (e.g., lithium oxide, also see "Exceptions for estimation of gross ore" below).

8.4 Estimation of gross ore from data on net-metal contents

Data on metal production compiled by geological or statistical agencies is often reported in terms of net-metal contents, i.e., metal quantity after the processing and concentration of crude ores. MFA standards however require that metal extraction should be accounted for on a run-of-mine ore basis, i.e., total ore extracted for further processing and concentration. Therefore, in cases where only data on net metal content are reported, the application of factors to compensate for lose in recovery, as well as basic ore grades (metal concentration in ore), are required in order to transform reported net metal content values into gross ore equivalents. An added complication here is that many ores are polymetallic e.g., combined copper-gold ores.

The concentration of metal in primary ores can vary widely between countries and mines. Applying (at a minimum) country-specific information on average metal concentrations is necessary to obtain reasonable estimates of crude ore tonnages extracted for a given level of primary metal production.

For this purpose, a comprehensive set of estimation factors was compiled. These factors represent the “associated ore” for each metal, based on a price-allocation approach. This was chosen to avoid overestimation or “false inflation” of metal ore tonnages when they are back-calculated from metals obtained from polymetallic ores.

Data for the compilation of estimation factors included mining data from the FINEPRINT project, FINEPRINT (2021) as well as from the “Metals and Mining” section in S&P Global’s Capital IQ Pro platform S&P Global (2021), formerly S&P Global Market Intelligence. Data on metals prices came from four sources, World Bank (2020), Metalary (2020), Bloomberg (2020), and USGS (2013).

Estimation factors were calculated from each of the two individual mining data sets individually. The coverage of these two sources is shown in the following table.

Table 10 Coverage of mining data used for compilation of ore estimation factors

Source	No. of metals	No. of countries	Mines included	Max. time range	No. of metal intensities	Derived factors
FINEPRINT	19	46	555	2000-2020	5552	1705
S&P Global	25	105	2509	1992-2020	35301	6687

Data on metal prices was integrated in the order shown in the table below. For the nine materials reported in all four sources, World Bank data showed the smallest variations, followed by Metalary, then Bloomberg, then USGS. Data from World Bank and USGS has a consistent time range across all materials, while time coverage varies for each material in the other two sources (see Table 11).

Table 11 Coverage of metal price data used for compilation of ore estimation factors

Source	Number of materials	Maximum time range
World Bank	11	1971-2019
Metalary.com	24	1970-2018
Bloomberg	70	1971-2020
USGS	54	1970-2010

Combining the data on metal prices resulted in time series for 79 individual metals and metal compounds. This total count includes compounds associated with specific metals e.g., Tantalum and Tantalum pentoxide, and metalloids.

After the integration step, price data gaps were filled with linear interpolation. After that, forward and backward extrapolation was applied using two different methods. Firstly, by applying the trend of an associated material (e.g., Ta vs. Ta_2O_5) if the latter one’s coverage was sufficient. If the first option was not possible, a second option was used: applying an index compiled from other time series. This index was created by calculating indices of all materials with sufficient time coverage (back to 1986 or earlier), then creating a median index based on those (to avoid distortion due to strong volatility across some time series). This index was smoothed by applying a LOESS method, a form of local regression, to give a general trend over the whole time range, less affected by short-duration fluctuations.

For the estimation of metal ores, Eurostat (2018) recommends using long-term average prices. This reduces short-term fluctuations, but more importantly reduces misleading results. An example of the latter is where a short-term, large relative decrease/increase in price will change allocation of ore to one metal relative to another. This in turn will lead to proportional change in estimation factor(s), which can flow through to major apparent changes in production of a metal ore even where underlying metal production remained unchanged. For the GMFD, averages for the 1990-2020 were calculated and applied (for comparison, the Eurostat guide provides averages for 1990-2010). This seemed suitable, as it covers more of the total time range of the current dataset, including more recent data.

The metal prices were combined with metal production to allocate a mine's ore extraction to each metal produced, proportional to the total value of each metal it produces. Where practicable, different types of ore produced within an individual mine were taken into consideration.

This approach to allocation was preferred over the estimation of “dominant ores”, i.e., allocating all ore to the dominant (i.e., the most valuable) metal included in the ore. Thereafter, tonnes of ore per ton of each individual metal were calculated per mine. Based on that, a weighted average (by production) was determined across all mines for each country. This gives country-specific, annual estimation factors, based on real production data.

Estimation factors derived from both mining data sets were combined, giving priority to data from S&P Global, which had better coverage, resulting in more consistent time series. This data was extrapolated for each time series back to 1970 and up to 2020 (using the earliest and latest values to avoid making assumptions on changes in metal concentrations).

Due to different coverage in the underlying mining data, many time series showed strong apparent fluctuations. Therefore, all time series were smoothed, again using the LOESS method.

As the two mining data sets did not cover all required estimations factors, the data were complemented using the following additional steps (integrated sequentially to avoid double counting):

- Creation of global averages derived from mining data, for application where no country-specific estimation factors were available. Geographical associations were not considered (e.g., global averages were applied to the Soviet Union rather than factors for Russia).
- Inclusion of country-specific, but non-annual metal concentrations collected from literature. This included numerous publications by various geological surveys, ministries, and other institutions, already collected for previous compilations of the database. Correspondence with experts from relevant agencies (e.g., USGS) and cross-checking within the project team was also used to review and revise, where necessary, factors used in earlier versions of the GMFD. An overview of the sources used for these ore grades are listed in the Appendix table A.3.
- Creation of global averages from the factors derived from literature. Application to data points where no country-specific estimation factors were available.
- Calculation of country-specific factors based on ore production reported by BGS and metal production reported by WMD (where mining data was not specific regarding the type of content)

The above compilation resulted in a set of 22522 distinct estimation factors across all years, countries, and metals. Of these, 16185 factors were applied to the dataset.

8.5 Exceptions for estimation of gross ore

Table 12 Exceptions for estimation of gross ore

Ore	Notes
Aluminium	Bauxite was only included if reported by the primary sources. This means that no back-calculation of bauxite was conducted from aluminium. Primary aluminium is overwhelmingly sourced from bauxite, from a limited number of countries. Therefore, all data on the production of aluminium and alumina was removed entirely, in order to not create false estimations.

Arsenic, Cadmium, Gallium, Germanium, Indium, Rhenium, Selenium	No estimation attempted, due to lack of suitable factors.
Lithium ore	Was not estimated in most cases, as it was assumed, that if no ore was reported by BGS, the respective lithium was sourced from brines. In such cases, no conversion to elemental lithium was conducted, in order to retain at least the amount of Li2O reported by WMD. Estimation was only conducted if it could be assumed that Lithium was produced from ore.
Magnesium	Only reported magnesite was included. Data on Magnesium was included as reported, without estimation.
Platinum-group metals	Estimations were only conducted if the specific metals were reported (e.g., platinum, palladium, osmium, etc.). If a mixed or aggregated categorization was reported (e.g., “PGM” or “Other PGM”), no estimation was conducted.

8.6 Adjustment of geographical scope and of outliers

The Global Material Flows Database reports data for the Soviet Union and former Yugoslavia until 1991 and for its successor states from 1992 on. Data for Czechoslovakia are reported until 1992 and for its successor states from 1993 on. Therefore, data from BGS was adjusted accordingly, as for some time series, it provided a different geographical structure for these transition years and the mentioned regions. Such adjustments were not necessary for data from the other two sources.

A relatively small number of time series had extreme outliers, which were judged highly improbable, and so assumed to be incorrect. To identify and deal with such cases, the following procedure was applied: Values were compared to their 5-year moving average, with any falling outside +3 standard deviations being flagged. This resulted in 149 cases being identified across all abiotic materials. These values were subsequently replaced using a linearly interpolated value.

9 Trade in metal ores

Data for trade in metal ores was one of several material trade categories provided by Northeastern University of Shenyang, China (NEU). This data can be thought of as primarily aggregated UN Comtrade data sourced from UNSD (2020a), but with substantial additional processing, some data synthesis, and cross-checking applied. The derivation of the NEU data set, where (for which categories), and why it is used, is the subject of Section 16.

The NEU data was used for both trade in those categories which have matching accounts in DE, and for the new "products mainly from metal ores" category. The decision on whether categories like "TCCC 2.1.m.Fe Iron metals alloys and manufactures" should be allocated to the relevant "Ores" category, or to the corresponding "Products mainly from…." was less straightforward than for most other categories, as in previous versions of the GMFD, basic manufactured items composed of one identifiable metal were included in the trade accounts together with ores and concentrates, to enable the inclusion of more of the total materials involved in international trade rather than leave out anything which did not meet the strict definition of domestic extraction. Again, only more mixed metals products and manufactures have been allocated to "Products mainly from metals nec.". This will preserve better continuity and comparability of this update with previous versions of the GMFD, but could change in subsequent updates, subject to review.

10 Domestic extraction of non-metallic minerals

10.1 Reported and estimated data accounts

Non-metallic minerals can be grouped into those used mainly for construction purposes (construction-dominant), and those which are mainly used for other industrial or agricultural purposes. The former (e.g., sand, gravel, limestone, gypsum, clay) makes up by far the largest quantity of all minerals extracted each year, however the reported statistics on these are usually of poor quality, and very limited coverage. This necessitates estimation of most of this category. The following section deals with directly reported data on all non-metallic minerals reported from statistical accounts, with the subsequent section dealing with the estimation methods used for construction-dominant.

10.2 Data sources for non-metallic minerals

Primary data on the extraction of non-metallic minerals were obtained from three comprehensive international data sources: the World Mining Data (WMD) published by the Austrian Ministry of Agriculture, Regions and Tourism in Reichl (2021), the British Geological Survey BGS (2021), and the United States Geological Survey USGS (2021). All data sets are available for free online. The BGS provides an online download tool, while the WMD and USGS provide Excel and PDF files. All data sources provide data annually, normally with a delay of 2-3 years (t-2, t-3).

In addition to web-scraping data from the Excel files of USGS (specifically the Mineral Yearbooks for commodities), several large manual collection exercises were conducted. These made use of data from the Mineral Yearbooks for individual countries, which contained country-specific information on commodities not listed under the global USGS “Commodity Statistics”. For the most part, these were stone-like materials, e.g., limestone, dolomite, basalt, granite, sandstone, quartzite, among others.

Unpublished information from statistical surveys provided by WMD was also manually compiled. Again, these documents mainly contained information on construction-dominant or stone-like materials.

Table 13 Primary data sources for non-metallic minerals

Primary source	Data set	Time range
WMD	Data retrieved online	2014-2019
WMD	Database dump provided by WMD	1984-2017
WMD	Additional info on quality of data points (reported/estimated) provided by WMD	2015-2017
WMD	Unpublished information from statistical surveys	1971-2019
BGS	Data retrieved online	1970-2019
USGS	Data retrieved online (commodity-specific “Minerals Yearbooks”)	2013-2018
USGS	Data from former metal ore accounts (collected from USGS in the past)	1970-2015
USGS	Additional time series collected from USGS files (country-specific “Minerals Yearbooks”)	1970-2015
USGS	Additional data points collected from USGS files (country-specific “Minerals Yearbooks”)	2012-2018

10.3 Integration of data for non-metallic minerals

Data from the sources listed in Table 13 was integrated into one consistent dataset. WMD data was judged to be the most consistent quality, and so as main data source. The WMD data was then complemented with data from the other sources where necessary, generally where the respective higher-ranking source did not report values for a given commodity - country - year data point. While many individual time series are based entirely on one main data source, there are also a lot of composite time series, mixing values based on data from the different sources.

To permit meaningful comparison of coverage, and to avoid double counting, the disparate data was first concorded to specific harmonized material IDs (as earlier discussed for metal ores). As the number of existing minerals is large, and the classifications thereof diverse, non-standardized, and often poorly specified, more than 1280 distinct allocations of different materials from the primary sources to these harmonized material categories had to be made.

All stone-like materials were allocated according to their lithology (e.g., “crushed limestone”, “limestone for cement”, “powdered limestone”, “limestone for lime” were all allocated to “limestone”). The only exception here was where values were specifically reported as dimension or ornamental stone. These were all allocated to other specific material IDs, then aggregated under “A.3.1 - Ornamental or building stone”.

The data set from the first stage of integration, based on directly reported data from the primary sources, was subsequently combined with estimates of non-metallic minerals based on requirements for construction (further described below) in a second stage. In this stage of data integration, the higher value for each material - country - year data point had precedence.

A slightly adjusted approach was applied for the integration of data for “TCCC.3.8.2: Sand gravel and crushed rock for construction”. The quantities reported by the BGS and the USGS for sand, gravel, and crushed rock/stone were aggregated before integrating them with the respective estimations for sand and gravel. A comparison of these various accounts, conducted beforehand, led to the conclusion that in a significant number of cases the gravel was likely being reported as crushed rock/stone.

The largest individual share of data in the final data set for non-metallic minerals came from the USGS (more than 34% of the total, and about 50% of directly reported data in this category). The corresponding figures for the WMD were 17% and 25%, while for the BGS they were 17% and 25%. More than 32% of the data came from estimation construction-based estimates of the construction-dominant minerals.

Table 14 Relative shares in of all data points for non-metallic minerals by primary data source in the final dataset

Source	Count	Share
WMD	15763	14.76%
Own estimation based on WMD	2087	1.95%
BGS	17975	16.83%
Own estimation based on BGS	289	0.27%
USGS	34810	32.60%
Own estimation based on USGS	1134	1.06%
Unpublished information from statistical surveys of WMD	1231	1.15%
Estimation based on consumption of cement	14580	13.65%
Estimation based on consumption of cement and bitumen	7158	6.70%
Estimation based on consumption of cement and production of bricks and tiles	8919	8.35%
Own estimation - gap filled by values of preceding or consecutive years	2832	2.65%

10.4 Conversion of units for non-metallic minerals

In many cases, non-metallic minerals are not reported in metric tonnes, but in other mass units or as volumes. As the GMFD reports all in metric tons, these values are converted accordingly. Material-specific unit conversion factors were applied to this end. In addition to the 32 mass-to-mass unit conversions applied, a further 234 of such material-specific volume to mass conversion factors were compiled. These were mainly based on the factors provided by Eurostat (2018) and UNEP (2019), with bespoke derivations for certain materials. Additional factors synthesized from online research were applied for a few unconventional cases, e.g., for area units like square meters (often being the unit for reported numbers on the production of stone tiles).

10.5 Aggregation and gap filling of data for non-metallic minerals

A table specifying the concordance between commodities derived from the primary sources, and their allocation to categories used in the GMFD, is provided in Appendix table A.2. Primary data for 69 categories of non-metallic minerals were aggregated into 14 non-metallic mineral groups.

Many time series of certain non-metallic minerals can be considered fragmented or patchy. After aggregation (to respective TCCC or MFA13 or MFA4 categories), this would lead to misleading results. To be more precise, different coverage across years for the underlying materials of an aggregated category would lead to the impression of a change in production, whereas the actual reason would just be the lack of coverage of certain data points. To avoid this, particularly for differing late years in each time series, selective gap filling was applied. This was conducted where an underlying material of a TCCC was lacking coverage, while other underlying materials of the same TCCC had data coverage for a year. This approach was only applied to years after 2011 (being the latest year for which former estimations on construction-dominant materials were integrated), to avoid creating unnecessary false data for earlier years.

10.6 Estimation of gross mine production of for non-metallic minerals from data on reported net production

In contrast to the necessary conversion of reported metal extraction, most industrial minerals are mined in the form which is either used economically or initially enters processing (i.e., already representing Domestic Extraction), and as such do not have to be estimated. Exceptions to this include diamonds, phosphate rock, potash, and sulphur. Diamonds are usually reported in the unit “carat” in their already processed form. Therefore, mine-specific ore grades for the largest mines and main diamond-producing countries were researched, using company reports and scientific publications, to estimate the mined ore. The same logic as for metals was applied, using national averages where possible, otherwise using global averages. In the case of potash, only the K_2O content in potash ores is reported by the primary sources. For sulphur, usually only the sulphur content of sulphur ores and pyrite. Estimation factors were therefore again required to approximate the mined of potash and sulphur ores.

Average factors were applied for nepheline concentrate, petroleum from oil sands, phosphorus oxides (in particular P_2O_5), sulphur, and potassium oxide (K_2O). Even though potassium is accounted as a metal, the resulting estimated amount of potash is included in A.3.4.1, due to being a major fertilizer mineral. Average factors by country were applied for diamonds (gem and industrial).

10.7 Estimations of non-metallic minerals used for construction.

For many countries no data is reported on the extraction of non-metallic minerals primarily used for construction (i.e., sand, gravel, and clay, limestone, and gypsum). When they are available, they are often unreliable, partial, and under-reported. Sand, gravel, and clay have a fundamental role in load-bearing structural components, yet these materials can be locally sourced in most world areas, and they economic value is extremely low. For this reason, a lot of extraction tend to end up unreported, and national statistical offices, especially in developing countries, tend to not require their reporting.

This lack of data requires estimations, which were conducted starting from the year 2012. Everything up to 2011 was included from similar estimations of former compilations of the Material Flow Database.

For this purpose, either the apparent consumption / DMC (domestic extraction + imports – exports) or production of several materials/items was calculated or made use of (namely cement used for concrete, bitumen used for road construction, and production of bricks and tiles). Based on those, the necessary quantities of non-metallic minerals related to these materials/items were estimated.

The respective data was sourced from UNSD, USGS, UN Comtrade, and the IEA.

Table 15 Data sources used for estimations of construction-dominant materials

Primary source	Data	Used for estimation of
UNSD	Production of cement	Limestone, Sand, gravel, clay, gypsum
USGS	Production of cement	
UN Comtrade	Imports/Exports of cement	
UN Comtrade	Imports/Exports of sand	
UN Comtrade	Imports/Exports of gravel	
IEA	Production/Imports/Exports of bitumen	Sand, gravel
UNSD	Production of bricks	Clay
UNSD	Production of clay tiles	Clay

Please note: Estimations up to the year 2011 furthermore included calculations on the net extension of railways. These which were neglected in current estimations, as the contribution of railways to the total consumption of non-metallic minerals is negligible and would not significantly affect the accounts. These data points made use of data from the World Bank Transport Division World Bank (2015), i.e., on the total length of countries' railway networks for the years 1980-2014.

Data on production of cement from USGS was only used where it was not available from UNSD. Based on the data for cement and bitumen, the apparent consumption for each was calculated.

The applied estimation factors are based on Miatto, Schandl, Fishman, and Tanikawa (2017).

Table 16 Factors applied for estimations on construction-dominant materials

Estimation of	Based on	Applied factor
Limestone	DMC of cement	1.216
Sand and gravel		5.26
Clay		0.304
Gypsum		0.05
Sand and gravel	DMC of bitumen	51.12
Clay	Production of bricks	1.349 (per ton) 0.998 (per m³) 1796.4 (per mio. units)
Clay	Production of clay tiles	1.349 (per ton) 3197 (per mio. units)

The resulting numbers were combined for those materials where more than one estimation was conducted (i.e., for clay as well as for sand and gravel). The various datasets to be combined had a different data coverage for some years. This would lead to misleading numbers, giving the impression of a change in production, while the reason would actually be a lacking coverage of one of the underlying data points. In order to avoid this, a selected gap filling was applied, for those cases, where the respective other dataset(s) contained a data point for a given country in a given year.

Final numbers for sand and gravel were then corrected with trade data from UN Comtrade. This is especially relevant for countries which import most of these materials (for example like Singapore) and would otherwise be subject to considerable overestimations. The same was done for all data on sand and gravel included from previous estimations (i.e., up until year 2011) as it seemed to not have been undertaken for these numbers yet.

Estimations for clay were discarded for two countries, as data on the production of bricks was not available for the latest years. These countries are China and India. In these cases, instead, the former estimations (up to 2011) were extended for the whole time series up to the latest year of all estimations. These former estimations were based on data from national sources: China Construction Association (2009), Ministry of Economy Trade and Industry (2013).

As mentioned above, these estimations were integrated with reported data, checked against each other, and for each data point, preference given to the higher one. The respective common compilation categories are the following:

Table 17 Integration of estimations for construction-dominant minerals

TCCC Code	TCCC Name	MFA13
TCCC.3.2.3	Limestone	Non-metallic minerals - construction dominant
TCCC.3.6	Gypsum	Non-metallic minerals - construction dominant
TCCC.3.7.1	Structural clays	Non-metallic minerals - construction dominant
TCCC.3.8.2	Sand gravel and crushed rock for construction	Non-metallic minerals - construction dominant

10.8 Adjustment of outliers

A relatively small number of time series had extreme outliers, which were judged highly improbable, and so assumed to be incorrect. To identify and deal with such cases, the following procedure was applied: Values were compared to their 5-year moving average, with any falling outside +3 standard deviations being flagged. This resulted in 149 cases being identified across all abiotic materials. These values were subsequently replaced using a linearly interpolated value.

11Trade in non-metallic minerals

As with trade in metal ores, the data for trade in non-metallic minerals provided by Northeastern University of Shenyang, China (NEU). This data can be thought of as primarily aggregated UN Comtrade data, UNSD (2020a), but with substantial additional processing, data synthesis, and cross-checking applied. The derivation of the NEU data set, where (for which categories), and why it is used, is the subject of Section 16.

The NEU data set was used for all trade in non-metallic minerals categories i.e., those with matching DE counterparts, and the new "products mainly from non-metallic minerals".

12 Domestic extraction of fossil fuels

Data on the extraction of fossil fuels were sourced from three international energy databases and integrated into one consistent dataset. The primary sources used were the United Nations Energy Statistics Database UNSD (2020b), the World Energy Statistics and Balances of the International Energy Agency IEA (2020), and the International Energy Statistics of the U.S. Energy Information Administration EIA (2021). The most recent data available at the time of compilation were used for the most recent years, however, older (historical) sections of the database reused previously compiled data from the Material Flow Database, as there was no point in recompiling them (an example here is the disaggregation of accounts for coal for 1970-1978 based on IEA data).

Data from UNSD was provided directly by its Energy Statistics Section, for the full time period. Years prior to 1990 are not available online at the UN data portal (and have to be purchased additionally).

The IEA dataset is likely the most comprehensive available data set on fossil fuel extraction and energy use for most countries, although it reports data for fewer individual countries than the UNSD. Data can be easily compiled and retrieved online, which was done via OECD's iLibrary (IEA data itself not being free of charge).

Data from EIA is freely available online and was retrieved via an API.

The time coverage for each of these base data sources is given in Table 18

Table 18 Primary data sources used for domestic extraction oof fossil fuels

Primary source	Data set	Time range
UNSD	Data provided by UNSD	1970-2019
IEA	Data retrieved online from OECD iLibrary	1971-2019
EIA	Data retrieved online via API	1980-2020

12.1 Integration of fossil fuel data

Data from all three sources in Table 18 were integrated into one dataset. Highest priority was given to UNSD data, which was complemented first with data from the IEA, and after that with data from EIA.

Rigid rules were applied for complementation i.e., data from IEA was added only in those cases where the UNSD either did not provide any values for a time series at all or used to replace a whole time series (i.e., for an individual commodity and country) where its coverage over time was at least 50% higher than that of UNSD data. This selection process involved the whole time series starting from 1970, except for coal, where the comparison was only conducted from 1990 on. All data on coal prior 1991 came from the IEA, due to the higher level of disaggregation being available.

The same approach was subsequently used to complement the resulting dataset (UNSD plus IEA) with data from EIA. It should be noted that EIA only reported data starting from 1980 (except for crude oil, which starts in 1973).

Table 19 Fossil fuel commodities derived from each primary data base and the allocation applied for GMFD

UNSD	IEA	EIA	Allocation in GMFD
	Hard coal (if no detail)	Hard Coal	➔ Disaggregated into different types of coal

	Brown coal (if no detail)		➔ Disaggregated into different types of coal
Anthracite	Anthracite	Anthracite	Anthracite
Coking coal	Coking coal	Metallurgical coal	Coking Coal
Other bituminous coal	Other bituminous coal	Bituminous Coal	Other Bituminous Coal
Sub-bituminous coal	Sub-bituminous coal	Sub-bituminous coal	Other Sub-Bituminous Coal
Lignite	Lignite	Lignite	Lignite (brown coal)
Peat	Peat		Peat
	Crude/NGL/feedstocks (if no detail)		➔ Disaggregated into different types (crude/NGL)
Conventional crude oil	Crude oil	Crude Oil including Lease Condensate	Crude oil
Natural gas liquids	Natural gas liquids	Natural Gas Plant Liquids	Natural gas liquids
Natural gas (including LNG)	Natural gas	Dry Natural Gas	Natural gas
Oil shale and tar sands	Oil shale and tar sands		Oil shale and tar sands
Other Hydrocarbons	Other Hydrocarbons		➔ Only for Canada (allocated to tar sands) and Venezuela (allocated to crude oil)

For the sake of consistency, data from the three sources were not mixed within the individual time series for a single commodity, for any individual country (this is different to the accounts established for metal ores and non-metallic minerals). However, individual countries can use different primary data sources for different commodities.

As the same production of coal may be classified differently in the different surveys conducted by UNSD, IEA, and EIA, there is a risk of double counting. To prevent this, coal for each individual country was sourced from only one of the three data sets. The selection process used the same criteria described above.

Data from UNSD and IEA makes up nearly 94% of all data points for fossil fuels in the final dataset (see Table 20). Note that the data sourced from the USGS mentioned there is “Peat for agricultural use”, which was compiled separately as part of the accounts for non-metallic minerals, and so not part of the process described above. It is allocated to fossil fuels, in category “A.4.1.3 – Peat” in the final data, as the database categorises by material rather than function as far as practicable.

Table 20 Relative shares of all data points for fossil fuels in the final dataset, by primary data source

Primary source	Nr. of data points	Share
UNSD	13711	66.60%
Own estimation based on UNSD	50	0.24%
IEA	5561	27.01%
EIA	546	2.65%
USGS	717	3.48%
WMD	2	0.01%

12.2 Data adjustment and estimations for fossil fuels

12.2.1 Conversions

The GMFD provides all values in metric tons. Primary data reported in other units therefore had to be converted. Preference was given to using conversion factors published by the same primary source.

The UNSD and IEA reported all categories relevant for the Global Material Flows Database in primary units of 1000 tonnes, except for natural gas which had to be converted from terajoule into tonnes. This was done by using a conversion factor provided by IEA.

The only real estimation from a performed for fossil fuels proxy (as distinct from the interpolations / extrapolations and splits described in the next section), was for extraction of oil sands. This was estimated based on production of other hydrocarbons (i.e., based on the amount of synthetic oil produced)[3]. This has been included in the Table 21 along with the simple conversion factors, for simplicity.

Table 21 Factors applied to reported physical units of fossil fuels to convert to metric tons.

Primary data	Commodity	Unit (primary data)	Factor used	Source (of factor)
IEA/UNSD	Natural gas	Terajoule	18	IEA (OECD & IEA, 2005) [4]
IEA	Other hydrocarbons (reflecting oil production from oil sands)	tonnes	14.663	Oil sand per barrel: (NASA Earth Observatory, 2016); Barrel to metric tons: (BP, 2017)[5]
EIA	Natural gas	Billion cubic feet	19522.8	TJ to metric tonnes: (OECD & IEA, 2005); Cubic feet to TJ: (EIA, 2015) [6]
EIA	Coal	Short ton	0.9072	(OECD & IEA, 2005)
EIA	Oil	Thousand barrel / day	49786	(BP, 2017)[7]
EIA	Natural gas liquids	Thousand barrel / day	35096	EIA [8]

12.2.2 Estimates

At the time the data was accessed, IEA provided data for the years 1971 to 2019 (covering earlier years for some OECD countries only). Most values for the year 1970 were therefore estimated by applying a linear extrapolation based on the trend of the following four years.
‘Crude oil’ and ‘Natural gas liquids’ were only reported within the aggregated category 'Crude / NGL /

[3] Documentation by IEA reveals that for Canada „Production of other hydrocarbons represents synthetic crude oil produced from tar sands.” (IEA, 2016) As data points from UNSD were similar, the same case was assumed.

[4] *55.52 MJ/kg (gross) -> 0.018 kg/MJ = 18 t/TJ*. Values have been rounded accurate to a tenth. Not taking into account gases other than methane content of natural gas. Gross Calorific Value has been used, in accordance with Eurostat MFA Handbook.

[5] *0.1364 t/bbl -> 7.3314 bbl/t * 2 t/bbl = 14.663.* Derived from a factor of 2 tonnes of oil sand per barrel of synthetic oil.

[6] *1.0846 MJ/cf = 1084.6 TJ/billion cf -> 1084.6 TJ/billion cf * 18 t/TJ = 19522.8 t/billion cf*

[7] *0.1364 t/bbl -> 0.1364 t/(bbl per day) * 365 days = 49.786 t/(bbl per year) = 49786 t/(thousand bbl per year)*. Based on the worldwide average gravity of crude oil. In line with conversion factors of EIA International Energy Statistics (EIA, 2016).

[8] *10.4 bbl/t -> 0.0962 t/(bbl per day) * 365 days = 35.096 t/(bbl per year) = 35096 t/(thousand bbl per year)*

feedstocks' before 1970 so they were calculated individually for 1970 by splitting this aggregated category by their individual shares for 1971-1973.

As mentioned above, UNSD does not report coal earlier than 1990, so data from IEA was used for that time period. The IEA does not however report disaggregated data on coal extraction for years prior to 1978, only the two categories 'Hard Coal' and 'Brown Coal'. These two categories were disaggregated into their respective sub-categories using the average shares for the years 1978 to 1987. According to IEA (2016) 'Hard Coal' comprises 'Anthracite', 'Coking coal' and 'Other bituminous coal' and in some cases 'Sub-bituminous coal', while 'Brown Coal' comprises 'Lignite' and in some cases 'Sub-bituminous coal'. The documentation provided by IEA does not specify how 'Sub-bituminous coal' is allocated for different countries. Aggregated values for 1977 were therefore compared to disaggregated values for 1978 to determine where 'Sub-bituminous coal' should be allocated.

12.2.3 Adjustments of geographical scope and of outliers

The GMFD reports data for the Soviet Union and former Yugoslavia until 1991, thence for their successor states from 1992 on. Data for Czechoslovakia are reported until 1992 and for its successor states from 1993 on. Data was aggregated or split accordingly where necessary (i.e., where the primary sources provided a different geographical structure for these transition years and regions).

As with metal ores and non-metallic minerals, values were compared to their 5-year moving average, with any points departing by +3 standard deviations or more being replaced with an interpolated value.

12.2.4 Reallocations to different material sub-categories

After repeated communication with IEA during earlier compilations of the Material Flow Database, data reported for 'Other hydrocarbons' by the UNSD and IEA was included for only two countries - Canada, and Venezuela. For all other countries, either the reported production did not refer to primary extraction at all, or it was not possible to say for certain that it referred to primary extraction exclusively. Data for Canada was allocated to A.4.3 – Oil shale and tar sands, while that for Venezuela was allocated to A.4.2.1 – Crude oil, in accordance with information from IEA's documentation IEA (2016).

13 Trade in fossil fuels

In contrast to DE, trade data on fossil fuels was sourced entirely from the UN's Energy Statistics Database UNSD (2023a), with the exception of TCCC.4.4.2 "Other products mainly from fossil fuels e.g., plastics".

Further processing was limited to applying a conversion factor (to tonnes) where necessary, then extracting only those a relevant (fossil fuel) UNSD items (33 in total) and allocating them to the relevant TCCC category prior to subsequent aggregation and reporting. Allocation and conversion factors used are shown in Table 22.

Table 22 Allocation of UNSD traded fossil fuel items to relevant TCCC fossil fuel categories, with conversion factors

UNSD Name	Conversion Factor	TCCC Code
Brown Coal Briquettes	1000	TCCC.4.1.1.1
Brown Coal	1000	TCCC.4.1.1.1
Lignite	1000	TCCC.4.1.1.1
Anthracite	1000	TCCC.4.1.2.1
Coking coal	1000	TCCC.4.1.2.2
Patent fuel	1000	TCCC.4.1.2.3
Hard Coal	1000	TCCC.4.1.2.3
Coal Tar	1000	TCCC.4.1.2.3
Peat Products	1000	TCCC.4.1.3
Conventional crude oil	1000	TCCC.4.2.1
Refinery Feedstocks	1000	TCCC.4.2.1
Gas Coke	1000	TCCC.4.2.1
Ethane	1000	TCCC.4.2.2
Natural Gas (including LNG)	17.63	TCCC.4.2.2
Natural Gas Liquids	1000	TCCC.4.2.3
Aviation Gasoline	1000	TCCC.4.4.1
Bio jet kerosene	1000	TCCC.4.4.1
Gas Oil/ Diesel Oil	1000	TCCC.4.4.1
Gasoline-type jet fuel	1000	TCCC.4.4.1
Kerosene-type Jet Fuel	1000	TCCC.4.4.1
Other kerosene	1000	TCCC.4.4.1
Liquified Petroleum Gas	1000	TCCC.4.4.1
Lubricants	1000	TCCC.4.4.1
Motor Gasoline	1000	TCCC.4.4.1
Naphtha	1000	TCCC.4.4.1
Other hydrocarbons	1000	TCCC.4.4.1
Other oil products n.e.c.	1000	TCCC.4.4.1
Paraffin waxes	1000	TCCC.4.4.1
Fuel Oil	1000	TCCC.4.4.1
Refinery Gas	1000	TCCC.4.4.1
Additives and Oxygenates	1000	TCCC.4.4.2
Bitumen	1000	TCCC.4.4.2
Other coal products	1000	TCCC.4.4.2

Most of the new TCCC.4.4.2 "Other products mainly from fossil fuels e.g., plastics" category was sourced from data provided by Northeastern University of Shenyang, China (NEU). This data set is discussed in detail in Section 15. A minor component in this category was also included from the UNSD data (see the last three rows in Table 22).

14 Trade in Mixed and complex products nec.

Data provided by NEU, discussed in Section 16, was the only source used for this new category, which has no DE equivalent. This category was used as the default category for products which were thought to be of too mixed an origin in their DE to be confidently placed in a "products mainly from…" category, and which were also not clearly a traded waste product which better fit the new "Waste for final treatment and disposal" category.

15 Trade in Waste for final treatment and disposal

Data provided by NEU, discussed in Section 5, was the only source used for this new category, which has no DE equivalent.

16 Notes on trade data set provided by Northeastern University

Data on trade in metal ores, non-metallic minerals, and categories including more complex / mixed manufactured items, along with waste, was provided by Northeastern University of Shenyang, China (NEU). from an in-house dataset they have produced, based on UNSD (2020a). This dataset takes a starting point UN Comtrade data (UNSD, 2020a), but subsequently applies a battery of data cleaning, interpolation, and balancing procedures. As a result, it cannot be directly compared back to a simple aggregate of the detailed UN Comtrade base data. Journal articles describing the methodologies used include (Chen et al., 2022) and (Jiang et al., 2022).

Note that the dataset from NEU actually has data for all of the categories covered in the GMFD but has only been used where there is no specialized agency for the class of commodities concerned, which assemble their own trade accounts. During preparation of the GMFD it was found that the trade data prepared by such specialized agencies such as the FAO for most biomass categories, and the IEA and/or UNSD's energy accounts, were more continuous, coherent, and comprehensive. As with earlier versions, the GMFD thus continued to use those sources were possible.

In addition to covering the material categories previously covered by Comtrade data in the GMFD, the NEU data is also used for the expanded range of processed products covered in this update. The full range of TCCC for which NEU trade data was used is given in Table 2, along with subsequent allocation to the final MFA13Plus and MFA4Plus categories.

An salient point regarding allocation to the MFA13Plus and MFA4Plus categories is that a decision had to be made regarding whether categories like "TCCC 2.1.m.Fe Iron metals alloys and manufactures" should be allocated to the relevant "Ores" category, or to the corresponding "Products mainly from…." category. On the one hand, the TCCC category is clearly comprised of refined through to manufactured goods, and so most logically belongs in the new "Products mainly from metals nec." category at MFA13Plus level rather than with the primary ores. However, in early versions of the GMFD, basic manufactured items composed of one identifiable metal were included in the trade accounts together with ores and concentrates, to enable the inclusion of more of the total materials involved in international trade rather than leave out anything which did not meet the strict definition of domestic extraction. This practice has again been used for this update, with only more mixed metals products and manufactures being allocated to "Products mainly from metals nec

Table 23 TCCC categories for which NEU data was used. Note: Individual non-ferrous metals' periodic table symbol substituted by 'x' for table only.

TCCC_Code	TCCC_Name	MFA13Plus	MFA4Plus
TCCC.1.6	Products mainly from biomass nec.	Products mainly from biomass nec.	Products from biomass
TCCC.2.1.Fe	Iron ores concentrates and compounds	Ferrous ores	Metal ores
TCCC.2.1.m.Fe	Iron metals alloys and manufactures	Ferrous ores	Metal ores
TCCC.2.2.x	(x = non-ferrous metal chemical symbol) ores concentrates and compounds	Non-ferrous ores	Metal ores
TCCC.2.2.m.x	(x = non-ferrous metal chemical symbol) metal, alloys and manufactures	Non-ferrous ores	Metal ores
TCCC.2.3.m	Products mainly from metals nec.	Products mainly from metals nec.	Products from metals
TCCC.3.1	Ornamental or building stone	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.10	Excavated earthen materials (including soil) nec	Excavated earthen materials (including soil) nec	Excavated earthen materials (including soil) nec
TCCC.3.11	Products mainly from non-metallic minerals	Products mainly from non-metallic minerals	Products from non-metallic minerals
TCCC.3.2.1	Chalk	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.2.2	Dolomite	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.2.3	Limestone	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.4.1	Fertilizer minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.4.2	Chemical minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.4.3	Industrial minerals n.e.c	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.5	Salt	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.6	Gypsum	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.7.1	Structural clays	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.7.2	Specialty clays	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.8.1	Industrial sand and gravel	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.3.8.2	Sand gravel and crushed rock for construction	Non-metallic minerals - construction dominant	Non-metallic minerals
TCCC.3.9	Other non-metallic minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
TCCC.4.4.2	Other products mainly from fossil fuels e.g., plastics	Other products mainly from fossil fuels e.g., plastics	Products from fossil fuels
TCCC.5	Mixed / complex products nec.	Mixed / complex products nec.	Mixed and complex products nec.
TCCC.6	Waste for final treatment and disposal	Waste for final treatment and disposal	Waste for final treatment and disposal

17 Projection and combination of all materials time series for late years

As in earlier version of the GMFD, the final years of data are an amalgam of real data from base sources (e.g. the FAO, UN Statistics division etc) augmented by projected data where such real date was not yet available.

Unlike earlier versions, which typically ended two years earlier than their year of release, to reduce the need for projected data, this version holds data up to and including 2024. This requires the inclusion of much more projected data than previous versions.

Furthermore, two methods of projection have been used. In earlier versions, projection was done from the existing materials time series. . These methods were detailed in full in the preceding (30th August 2022) version of this annex, UNEP International Resources Panel (2023). Key points on that methodology have been copied into the text box below.

For DE, projection was done at the TCCC level. The projections were based on simple linear trends established from subsets of prior years' data, however a number of filters and conditional settings were required to avoid the common situations where such projection was likely to give a misleading result. These are detailed below:

1. There had to be a minimum of 5 data points available. Even this number can give very volatile trends, but to set the number much higher risked excluding too many newly established industries entirely e.g., copper mining in Laos.
2. At least one of these data points needed to occur after 2014. Absence of data after this point was taken to indicate that the extractive industry had genuinely shut down e.g., the mines all closed.
3. If more than 15 data points were available, only the most recent 15 were used, to be more reflective of recent trends.
4. If there were any recent (post 2014) data points, but < 5 data points overall to establish a trend, the time series was filled out to 2019 with repeats of the last data point.
5. If a projection from a negative trend goes negative in later years, these years are set to NA (as negative DE makes no sense).

The same general process was used to extend physical trade data, with some modifications. The operation was performed at the same TCCC level as for DE, rather than on the more aggregated MFA13(Plus) level as done in earlier versions. Unlike DE, the data for 2019 was not zeroed then projected, as the Comtrade data was no pronounced major cut-off in many time series in 2018 in the NEU data.

In contrast, there were more "ragged" time series which, with much wider variation in the date at which latest data appeared to have been reported for different countries. The trade data were also more volatile than for DE. This led to a decision to change the cut-off year for earliest most-recent data year from 2014 used for DE to 2012 for trade, and use all available datapoints to project the trend rather than just most recent 15.

In this update, the above projection method applies until 2019. Data so constructed for 2019 then provides the base year level from which further projection is performed using the second method described below.

External modelling of economic growth in a Computable General Equilibrium (CGE) model provides annual indexed change coefficients to apply to these base levels to create the projections. The factors used come from a "baseline" (most expected) economic growth scenario, modelled in early 2023. Detail on the specific CGE model used, the Global Trade and Environment Model (GTEM-C) is in Cai, Newth, Finnigan, and Gunasekera (2015). Detail on the baseline scenario settings will be available with the release of the next update to the UNEPs Global Resources Outlook report, later in 2024.

The base/index year is set at 2019, the latest year for which all materials data is fully based on "real" (observed or calculated from real) data. The CGE model provided factors for 62 primary material categories, for 34 individual countries or multi-country regions. Separate factors where available for production, imports, and exports for 2020 through 2024.

These CGE derived factors were subsequently mapped on to the most detailed set of country and materials used in the compilation processes for DE, physical imports, and physical exports. This is in many cases a one-to-many operation. Major countries and commodities generally had their own specific coefficients for each year, but this was not the case for minor commodities and smaller countries. For example, while projected domestic extraction of rice for China in 2022 gets its own unique coefficient from the CGE model, domestic extraction of quinoa for Bhutan will get a common multiplier applied to all "Rest of Asia" countries for all minor cereals for that year.

Once these projections are in place, they are subsequently overwritten wherever quality observed data could be sourced. Most data for 2020 is thus actually observed / historical data (from sources such as the FAO, IEA etc). The proportion of projected data in the GMFD increases progressively for later years until all of 2023 and 2024 is pure projection.

18 Other Data used for Ratios

The base data used to establish GDP and for Population was sourced from UNSD (2023b) and UNSD (2023c) respectively. The GDP basis selected from those available was Constant 2015 prices in US Dollars. This is the same currency basis used for the preceding GMFD update.

19 Material footprint

Material footprinting is a complex process and does not lend itself to adequate description in a short technical annex. It involves apportioning physical domestic extraction accounts like those established in this data set, according to financial transactions, to attribute the extracted materials on a consumption rather than production basis. This is achieved via a series of interlinked national financial input - output tables. This system of input-output table is known as a multi-regional input-output table (MIOT), and the particular MIOT used for this work is Global Resource Input Output Assessment (GLORIA) ran by Sydney University. This supersedes the EORA MIOT used for versions earlier than 2021.

The Material Footprint accounts established for this version of the GMFD do not have major structural changes over the 2021 version, unlike the major structural change the 2021 version embodied over the 2018 version. There have, however, been changes to settings and inputs which have significant and retrospect effects on the RME based indicators.

The most important of these include:

1. Updating the settings for the “Engineering Exclusions”, which use expert judgement to constrain or preclude intersectoral flows which make little logical sense.
2. The Domestic Extraction data enters the MRIOT for reallocation at a much higher level of resolution than previously, particularly for biomass. Additionally, updated splits for allocation to different economic sectors have been applied to some DE streams.
3. One of the major input data sets to the MRIO process, the OECD’s Inter-Country Input-Output (ICIO) Tables, have now had smoothing applied to them prior to input.

Regarding 2. above, DE is now disaggregated into 367 different material categories before being fed-in to the MRIOT reallocation process, rather than the 61 categories previously used. Nearly all of these extra categories are in biomass, and come from using the original, highly detailed FAO system of categories. These crops now also have an individual “crop residue” categories attached to them. This change was implemented mainly to prepare for future land and water footprinting exercises, where there is great variability between individual crops. They

Furthermore, naïve equal splitting where one material is allocated to multiple sectors has been replaced with more asymmetric splitting, where additional information has justified this.

Regarding 3. above, the original OECD ICIO data input has large inter-year variability. Given its importance in the material reallocation process, this variability flowed through to the RME accounts, leading to unrealistic discontinuities in RME indicators. Smoothing this data helped reduce the inter-year variability to reflect the considerable inertia we expect to see for measures of RME.

Detailing the current methodology has requires its own extensive standalone technical documentation. The best source for information on changes to successive releases on the supporting documents page for the GLORIA MRIOT, Industrial ecology virtual laboratory (2024).

It should be noted that the definitions of different components of materials (or emissions) embodiment in trade vary according to the principles applied. The raw material equivalents of exports and imports (RME_{exp}, RME_{imp}) used in for the GMFD are defined in Lenzen et al. (2022), and adhere to MRIO principles. These differ from Emissions embodied in bilateral trade (EEBT) approaches. For a detailed comparison between the two approaches, see Kanemoto, Lenzen, Peters, Moran, and Geschke (2012).

As with previous versions of the GMFD, the country / region sets for the MRIO work behind the material footprints, and the corresponding country set for the direct accounts like DE and physical trade, are not identical. Most notably, there are more countries with at least some individual country direct DE and/or trade data over time (220), compared to the set available for material footprint (164 plus 4 "rest of…." global regions).

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21 Appendices

A.1. Aggregation of data for metal ores – Overview by primary source to TCCC Code and classification

Please note: Due to the excessive size of source material names, only harmonized material names are shown in the following table.

Primary database	TCCC Code	TCCC Name	Harmonized material name
WMD / own estimation based on WMD	TCCC.2.1.Fe	Iron ores concentrates and compounds	Iron - associated ore
	TCCC.2.2.Ag	Silver ores concentrates and compounds	Silver - associated ore
	TCCC.2.2.Al	Bauxite and other aluminium ores - gross ore	Aluminium
			Bauxite
	TCCC.2.2.Au	Gold ores concentrates and compounds	Gold - associated ore
	TCCC.2.2.Cr	Chromium ores concentrates and compounds	Chromium - associated ore
	TCCC.2.2.Cu	Copper ores concentrates and compounds	Copper - associated ore
	TCCC.2.2.Mn	Manganese ores concentrates and compounds	Manganese - associated ore
	TCCC.2.2.nec	Other metal ores concentrates and compounds	Antimony - associated ore
			Arsenic
			Bismuth - associated ore
			Cadmium
			Cobalt - associated ore
			Gallium
			Germanium
			Indium
			Lithium ore
			Lithium oxide
			Mercury - associated ore
			Molybdenum - associated ore
			Niobium - associated ore
			Rare-earth oxides
			Rhenium
			Selenium
			Tantalum - associated ore
			Tellurium - associated ore
			Tungsten - associated ore
			Vanadium - associated ore
			Zircon
	TCCC.2.2.Ni	Nickel ores concentrates and compounds	Nickel - associated ore
	TCCC.2.2.Pb	Lead ores concentrates and compounds	Lead - associated ore
	TCCC.2.2.Pt	Platinum ores concentrates and compounds	Palladium - associated ore
			Platinum - associated ore
			Rhodium - associated ore
	TCCC.2.2.Sn	Tin ores concentrates and compounds	Tin - associated ore
	TCCC.2.2.Ti	Titanium ores concentrates and compounds	Titanium - associated ore
	TCCC.2.2.U	Uranium ores concentrates and compounds	Uranium - associated ore
	TCCC.2.2.Zn	Zinc ores concentrates and compounds	Zinc - associated ore
BGS / own estimation based on BGS	TCCC.2.1.Fe	Iron ores concentrates and compounds	Ferrous ore
	TCCC.2.2.Ag	Silver ores concentrates and compounds	Silver - associated ore
	TCCC.2.2.Al	Bauxite and other aluminium ores - gross ore	Aluminium
			Bauxite
	TCCC.2.2.Au	Gold ores concentrates and compounds	Gold - associated ore
	TCCC.2.2.Cr	Chromium ores concentrates and compounds	Chromium ore
	TCCC.2.2.Cu	Copper ores concentrates and compounds	Copper - associated ore

	TCCC.2.2.Mn	Manganese ores concentrates and compounds	Manganese ore
	TCCC.2.2.nec	Other metal ores concentrates and compounds	Antimony - associated ore
			Arsenic
			Beryl
			Bismuth - associated ore
			Cadmium
			Cobalt - associated ore
			Gallium
			Germanium
			Indium
			Lithium compound n.e.c.
			Lithium ore
			Magnesium
			Mercury - associated ore
			Molybdenum - associated ore
			Rare-earth oxides
			Rhenium
			Strontium mineral
			Tantalum - associated ore
			Tungsten - associated ore
			Vanadium - associated ore
			Zircon
	TCCC.2.2.Ni	Nickel ores concentrates and compounds	Nickel - associated ore
	TCCC.2.2.Pb	Lead ores concentrates and compounds	Lead - associated ore
	TCCC.2.2.Pt	Platinum ores concentrates and compounds	Iridium - associated ore
			Osmium - associated ore
			Palladium - associated ore
			PGM
			Platinum - associated ore
			Rhodium - associated ore
	TCCC.2.2.Sn	Tin ores concentrates and compounds	Tin - associated ore
	TCCC.2.2.Ti	Titanium ores concentrates and compounds	Ilmenite
			Leucoxene
			Rutile
			Titanium ore
	TCCC.2.2.U	Uranium ores concentrates and compounds	Uranium - associated ore
	TCCC.2.2.Zn	Zinc ores concentrates and compounds	Zinc - associated ore
USGS / own estimation based on USGS	TCCC.2.1.Fe	Iron ores concentrates and compounds	Ferrous ore
	TCCC.2.2.Ag	Silver ores concentrates and compounds	Silver - associated ore
	TCCC.2.2.Al	Bauxite and other aluminium ores - gross ore	Aluminium
			Bauxite
	TCCC.2.2.Au	Gold ores concentrates and compounds	Gold - associated ore
	TCCC.2.2.Cr	Chromium ores concentrates and compounds	Chromium ore
	TCCC.2.2.nec	Other metal ores concentrates and compounds	Beryl
			Cadmium
			Cobalt - associated ore
			Coltan
			Columbite, niobium ore
			Gallium
			Indium
			Lithium ore
			Magnesium
			Mercury - associated ore
			Niobium - associated ore
			Rare-earth oxides
			Strontium mineral
			Tantalum - associated ore
			Vanadium - associated ore
			Zircon
	TCCC.2.2.Ni	Nickel ores concentrates and compounds	Nickel - associated ore
	TCCC.2.2.Pb	Lead ores concentrates and compounds	Lead - associated ore
	TCCC.2.2.Ti	Titanium ores concentrates and compounds	Titanium - associated ore

	TCCC.2.2.U	Uranium ores concentrates and compounds	Uranium - associated ore
	TCCC.2.2.Zn	Zinc ores concentrates and compounds	Zinc - associated ore

A.2. Aggregation of data for non-metallic minerals – Overview by primary source, TCCC, material names

Please note: Due to the excessive size of source material names, only harmonized material names are shown in the following table.

Primary database	**TCCC Code**	**TCCC Name**	**Harmonized material name**
WMD / own estimation based on WMD	TCCC.3.1	Ornamental or building stone	Dimension stone n.e.c.
			Igneous rock (basalt, basaltic lava, diabase, granite, porphyry, etc.)
			Marble, travertines etc.
			Ornamental stone
			Sandstone
			Slate including fill (incl. roof slate)
	TCCC.3.2.1	Chalk	Chalk
	TCCC.3.2.2	Dolomite	Dolomite
	TCCC.3.2.3	Limestone	Calcite
			Calcium carbonate
			Limestone
			Marl and shell
	TCCC.3.4.1	Fertilizer minerals n.e.c.	Phosphate rock
			Potash
	TCCC.3.4.2	Chemical minerals n.e.c.	Barite
			Borate minerals
			Fluorspar
			Pyrite
			Sulphur ore
	TCCC.3.4.3	Industrial minerals n.e.c	Abrasives, natural (puzzolan, pumice, volcanic cinder etc.)
			Asbestos
			Diamond ore, gems
			Diamond ore, industrial
			Diatomite
			Feldspar
			Gemstone-bearing mineral ore
			Gemstones n.e.c.
			Graphite, natural
			Magnesite
			Mica
			Nepheline syenite
			Ochre and pigment earths
			Perlite
			Qartz and quartzite
			Sodium carbonate, natural
			Talc (steatite, soapstone, pyrophyllite)
			Vermiculite
	TCCC.3.5	Salt	Rock salt
			Salt nec
			Sea salt
	TCCC.3.6	Gypsum	Gypsum and anhydrite
	TCCC.3.7.1	Structural clays	Common clay, clay for bricks etc.
			Loam
	TCCC.3.7.2	Specialty clays	Ball clay
			Bentonite, sepiolite and attapulgite
			Fire, refactory and flint clay, Andalusite, kyanite and sillimanite
			Fuller's earth
			Kaolin

			Laterite
			Potter clay
			Special clay
	TCCC.3.8.1	Industrial sand and gravel	Industrial sand
			Silica
			Silica Sand
	TCCC.3.8.2	Sand gravel and crushed rock for construction	Crushed stone
			Sand and gravel
	TCCC.3.9	Other non-metallic minerals n.e.c.	Asphalt
			Chert and flint
			Other non-metallic minerals n.e.c.
			Silicate minerals n.e.c.
			Stone, n.e.c.
BGS / own estimation based on BGS	TCCC.3.4.1	Fertilizer minerals n.e.c.	Phosphate rock
			Potash
	TCCC.3.4.2	Chemical minerals n.e.c.	Barite
			Borate minerals
			Fluorspar
	TCCC.3.4.3	Industrial minerals n.e.c	Asbestos
			Bromine
			Diatomite
			Feldspar
			Graphite, natural
			Iodine
			Magnesite
			Mica
			Nepheline syenite
			Perlite
			Sodium carbonate, natural
			Talc (steatite, soapstone, pyrophyllite)
			Vermiculite
			Wollastonite
	TCCC.3.5	Salt	Brine salt
			Evaporated salt
			Rock salt
			Salt nec
			Sea salt
	TCCC.3.6	Gypsum	Gypsum and anhydrite
	TCCC.3.7.2	Specialty clays	Bentonite, sepiolite and attapulgite
			Fire, refactory and flint clay, Andalusite, kyanite and sillimanite
			Fuller's earth
			Kaolin
	TCCC.3.8.2	Sand gravel and crushed rock for construction	Crushed stone
			Sand and gravel
USGS / own estimation based on USGS	TCCC.3.1	Ornamental or building stone	Dimension stone n.e.c.
			Igneous rock (basalt, basaltic lava, diabase, granite, porphyry, etc.)
			Marble, travertines etc.
			Ornamental stone
			Sandstone
			Slate including fill (incl. roof slate)
	TCCC.3.2.1	Chalk	Chalk
	TCCC.3.2.2	Dolomite	Dolomite
	TCCC.3.2.3	Limestone	Calcite
			Calcium carbonate
			Limestone
			Marl and shell
	TCCC.3.4.1	Fertilizer minerals n.e.c.	Phosphate rock
			Potash
	TCCC.3.4.2	Chemical minerals n.e.c.	Barite

			Borate minerals
			Fluorspar
			Pyrite
			Sulphur ore
	TCCC.3.4.3	Industrial minerals n.e.c	Abrasives, natural (puzzolan, pumice, volcanic cinder etc.)
			Asbestos
			Bromine
			Diamond ore, gems
			Diamond ore, industrial
			Diamonds (unspecified)
			Diatomite
			Feldspar
			Gemstone-bearing mineral ore
			Gemstones n.e.c.
			Graphite, natural
			Iron ore for pigments
			Magnesite
			Mica
			Nepheline syenite
			Ochre and pigment earths
			Perlite
			Qartz and quartzite
			Sodium carbonate, natural
			Talc (steatite, soapstone, pyrophyllite)
			Vermiculite
			Wollastonite
	TCCC.3.5	Salt	Salt nec
	TCCC.3.6	Gypsum	Gypsum and anhydrite
	TCCC.3.7.1	Structural clays	Common clay, clay for bricks etc.
			Loam
	TCCC.3.7.2	Specialty clays	Ball clay
			Bentonite, sepiolite and attapulgite
			Fire, refactory and flint clay, Andalusite, kyanite and sillimanite
			Fuller's earth
			Illite
			Kaolin
			Laterite
			Potter clay
			Special clay
	TCCC.3.8.1	Industrial sand and gravel	Industrial sand
			Silica
			Silica Sand
	TCCC.3.8.2	Sand gravel and crushed rock for construction	Crushed stone
			Sand and gravel
	TCCC.3.9	Other non-metallic minerals n.e.c.	Asphalt
			Chert and flint
			Other non-metallic minerals n.e.c.
			Silicate minerals n.e.c.
			Stone, n.e.c.
Estimation based on consumption of cement	TCCC.3.2.3	Limestone	Limestone
	TCCC.3.6	Gypsum	Gypsum and anhydrite
Estimation based on consumption of cement and bitumen	TCCC.3.8.2	Sand gravel and crushed rock for construction	Sand and gravel
Estimation based on consumption of cement and production of bricks and tiles	TCCC.3.7.1	Structural clays	Common clay, clay for bricks etc.

Own estimation - gap filled by values of preceding or consecutive years	TCCC.3.1	Ornamental or building stone	Dimension stone n.e.c.
			Igneous rock (basalt, basaltic lava, diabase, granite, porphyry, etc.)
			Marble, travertines etc.
			Ornamental stone
			Sandstone
			Slate including fill (incl. roof slate)
	TCCC.3.2.1	Chalk	Chalk
	TCCC.3.2.2	Dolomite	Dolomite
	TCCC.3.2.3	Limestone	Calcite
			Calcium carbonate
			Limestone
			Marl and shell
	TCCC.3.4.1	Fertilizer minerals n.e.c.	Phosphate rock
			Potash
	TCCC.3.4.2	Chemical minerals n.e.c.	Barite
			Fluorspar
			Pyrite
			Sulphur ore
	TCCC.3.4.3	Industrial minerals n.e.c	Abrasives, natural (puzzolan, pumice, volcanic cinder etc.)
			Asbestos
			Diamond ore, gems
			Diamond ore, industrial
			Diamonds (unspecified)
			Diatomite
			Feldspar
			Gemstone-bearing mineral ore
			Gemstones n.e.c.
			Graphite, natural
			Iron ore for pigments
			Magnesite
			Mica
			Nepheline syenite
			Ochre and pigment earths
			Perlite
			Qartz and quartzite
			Sodium carbonate, natural
			Talc (steatite, soapstone, pyrophyllite)
			Vermiculite
			Wollastonite
	TCCC.3.5	Salt	Salt nec
			Sea salt
	TCCC.3.6	Gypsum	Gypsum and anhydrite
	TCCC.3.7.1	Structural clays	Common clay, clay for bricks etc.
			Loam
	TCCC.3.7.2	Specialty clays	Ball clay
			Bentonite, sepiolite and attapulgite
			Fire, refactory and flint clay, Andalusite, kyanite and sillimanite
			Fuller's earth
			Illite
			Kaolin
			Laterite
			Potter clay
			Special clay
	TCCC.3.8.1	Industrial sand and gravel	Industrial sand
			Silica Sand
	TCCC.3.8.2	Sand gravel and crushed rock for construction	Crushed stone
			Sand and gravel
	TCCC.3.9	Other non-metallic minerals n.e.c.	Asphalt
			Chert and flint

			Other non-metallic minerals n.e.c.
			Silicate minerals n.e.c.
			Stone, n.e.c.

A.3. Literature sources used for the compilation of additional ore estimation factors

Metal	Institution/Author	Publications
Antimony	**US Geological Survey**	USGS - Country Reports
		Personal Communication
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Bauxite	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook, SH 2, Aluminium
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
		Studies on supply and demand of mineral raw materials
	US Geological Survey	USGS - Country Reports
Beryllium	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished manuscript.
Chromium	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook, Chromium
		Studies on supply and demand of mineral raw materials
Cobalt	**US Geological Survey**	Personal Communication
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Copper	**Bureau of Mines**	The availability of primary copper in market economy countries. United States Department of the Interior. IC 9310.
	Federal Institute for Geosciences and Natural Resources, Germany	Geological yearbooks
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
		Studies on supply and demand of mineral raw materials XI
	Mudd, G.	The sustainability of mining in Australia: key production trends and their environmental implications. Melbourne, Department of Civil Engineering, Monash University and Mineral Policy Institute.
	US Geological Survey	USGS - Country Reports
		Personal Communication
	Wuppertal Institute	Database of Wuppertal Institute (WI)
Gold	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbooks
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	Mudd, G.	The sustainability of mining in Australia: key production trends and their environmental implications. Melbourne, Department of Civil Engineering, Monash University and Mineral Policy Institute.
	US Geological Survey	USGS - Country Reports
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
	Wuppertal Institute	Database of Wuppertal Institute (WI)
Iron ores	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	US Geological Survey	Iron ore statistical compendium
		USGS - Country Reports
		Personal Communication

Lead	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	Mudd, G.	The sustainability of mining in Australia: key production trends and their environmental implications. Melbourne, Department of Civil Engineering, Monash University and Mineral Policy Institute.
	US Geological Survey	USGS - Country Reports
	Wuppertal Institute	Database of Wuppertal Institute (WI)
Lithium	**Federal Institute for Geosciences and Natural Resources, Germany**	Studies on supply and demand of mineral raw materials XXI
	US Geological Survey	USGS - Country Reports
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Manganese	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	US Geological Survey	USGS - Country Reports
		Minerals Yearbook, Manganese
		Manganese ore statistical compendium
Mercury	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	US Geological Survey	USGS - Country Reports
		Personal Communication
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Nickel	**Federal Institute for Geosciences and Natural Resources, Germany**	Geological yearbook
		Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	US Geological Survey	USGS - Country Reports
		Personal Communication
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Platinum-group (PGM)	**US Geological Survey**	USGS - Country Reports
		Personal Communication
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Rare Earths Metals	**Schütz, H.**	Technical Details of NMFA (Inputside) for Germany (Imports to Germany). Wuppertal Institute, Wuppertal.
Silver	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
		Studies on supply and demand of mineral raw materials XI
	US Geological Survey	USGS - Country Reports
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Tin	**Bureau of Mines**	Tin availability - market economy countries. United States Department of the Interior. IC 9086.
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Titanium (incl/ Ilmenite and Rutile)	**Wagner, H., Weber, L.**	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.

Tungsten	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	Schütz, H.	Technical Details of NMFA (Input side) for Germany (Imports to Germany). Wuppertal Institute, Wuppertal.
	US Geological Survey	Personal Communication
Uranium	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	US Geological Survey	USGS - Country Reports
Vanadium	**Wagner, H., Weber, L.**	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
Zinc	**Federal Institute for Geosciences and Natural Resources, Germany**	Rohstoffwirtschaftliche Länderstudien (Raw material country studies – in German)
	Mudd, G.	The sustainability of mining in Australia: key production trends and their environmental implications. Melbourne, Department of Civil Engineering, Monash University and Mineral Policy Institute.
	US Geological Survey	USGS - Country Reports
	Wagner, H., Weber, L.	Gesichtspunkte für die bergtechnische und bergwirtschaftliche Beurteilung von Vorkommen mineralischer Rohstoffe. Unpublished German manuscript.
	Wuppertal Institute	Database of Wuppertal Institute (WI)