Technical annex for Global Material Flows Database

(Last revised 16/1/2018)

Introduction

This technical annex concentrates on cataloguing the primary data sets upon which the Global Material Flows Database is based, and on describing the transformations and further modelling used to transform, complete and/or extend the primary input data into the comprehensive time series data finally presented. A very brief outline of where this data set fits within the broader scheme of current and mooted future material flow accounting schemes is provided in the next section, for context.

Structure of current and planned future material flow accounts

This data set covers only a subset of the full, aspirational set of material flow accounts which would fill out a comprehensive material flows accounting framework. Details of this framework are 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, of which this data set only covers modules 1 and 2:

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 1). 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.

Indicator	Description / calculation if applicable
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}

Table 1. Material flows covered in the Global Material Flows Database

Possibly just cut and paste the “Main principles of Material flow accounts” section from the attached Technical annex correctionsJW.docx file. - Heinz/Stephan can decide what we want here.

Overview of compilation of Domestic extraction

The publically available online database presents direct material flows data for four main material categories, and also has a further disaggregation of these four main categories into 13 sub-categories. These shown in table 2, labelled MFA4 and MFA 13.

MFA4	MFA13
Biomass	Crops
Biomass	Crop Residues
Biomass	Grazed biomass and fodder crops
Biomass	Wood
Biomass	Wild catch and harvest
Metal ores	Ferrous ores
Metal ores	Non-ferrous ores
Non-metallic minerals	Non-metallic minerals - construction dominant
Non-metallic minerals	Non-metallic minerals - industrial or agricultural dominant
Fossil Fuels	Coal
Fossil Fuels	Petroleum
Fossil Fuels	Natural Gas
Fossil Fuels	Oil shale and tar sands

Table 2. Four category and 13 subcategory classifications of domestic extraction

The process of collating and /or modelling of data was actually performed at a much higher level of disaggregation, using a classification system with 62 different categories. This system, referred to as here as the Common Compilation Categories (CCC) was used for internal project purposes only, but was designed to conform as well as practicable with the system of categories used in (Eurostat 2013), and with minor alteration, forms the basis of the categories used in draft (new guide ref). How the CCC system relates to the MFA4 and MFA13 systems is shown in table 3.

CCC_Code	CCC_Name	MFA13	MFA4
A.1.1.1.1	Rice	Crops	Biomass

A.1.1.1.2	Wheat	Crops	Biomass
A.1.1.1.3	Cereals n.e.c.	Crops	Biomass
A.1.1.10	Other crops n.e.c	Crops	Biomass
A.1.1.11	Spice - beverage - pharmaceutical crops	Crops	Biomass
A.1.1.12	Tobacco	Crops	Biomass
A.1.1.2	Roots and tubers	Crops	Biomass
A.1.1.3	Sugar crops	Crops	Biomass
A.1.1.4	Pulses	Crops	Biomass
A.1.1.5	Nuts	Crops	Biomass
A.1.1.6	Oil bearing crops	Crops	Biomass
A.1.1.7	Vegetables	Crops	Biomass
A.1.1.8	Fruits	Crops	Biomass
A.1.1.9	Fibres	Crops	Biomass
A.1.2.1.1	Straw	Crop Residues	Biomass
A.1.2.1.2	Other crop residues (sugar and fodder beet leaves etc)	Crop Residues	Biomass
A.1.2.2.1	Fodder crops (including biomass harvest from grassland)	Grazed biomass and fodder crops	Biomass
A.1.2.2.2	Grazed biomass	Grazed biomass and fodder crops	Biomass
A.1.3.1	Timber (Industrial roundwood)	Wood	Biomass
A.1.3.2	Wood fuel and other extraction	Wood	Biomass
A.1.4.1	Wild fish catch	Wild catch and harvest	Biomass
A.1.4.2	All other aquatic animals	Wild catch and harvest	Biomass
A.1.4.3	Aquatic plants	Wild catch and harvest	Biomass
A.2.1.Fe	Iron ores	Ferrous ores	Metal ores
A.2.2.Ag	Silver ores	Non-ferrous ores	Metal ores
A.2.2.Al	Bauxite and other aluminium ores - gross ore	Non-ferrous ores	Metal ores
A.2.2.Au	Gold ores	Non-ferrous ores	Metal ores
A.2.2.Cr	Chromium ores	Non-ferrous ores	Metal ores
A.2.2.Cu	Copper ores	Non-ferrous ores	Metal ores
A.2.2.Mn	Manganese ores	Non-ferrous ores	Metal ores
A.2.2.nec	Other metal ores	Non-ferrous ores	Metal ores
A.2.2.Ni	Nickel ores	Non-ferrous ores	Metal ores
A.2.2.Pb	Lead ores	Non-ferrous ores	Metal ores
A.2.2.Pt	Platinum group metal ores	Non-ferrous ores	Metal ores
A.2.2.Sn	Tin ores	Non-ferrous ores	Metal ores
A.2.2.Ti	Titanium ores	Non-ferrous ores	Metal ores
A.2.2.U	Uranium ores	Non-ferrous ores	Metal ores
A.2.2.Zn	Zinc ores	Non-ferrous ores	Metal ores
A.3.1	Ornamental or building stone	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.2.1	Chalk	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.2.2	Dolomite	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.2.3	Limestone	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.4.1	Fertilizer minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.4.2	Chemical minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.4.3	Industrial minerals n.e.c	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.5	Salt	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.6	Gypsum	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.7.1	Structural clays	Non-metallic minerals - construction dominant	Non-metallic minerals

A.3.7.2	Specialty clays	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.8.1	Industrial sand and gravel	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.3.8.2	Sand gravel and crushed rock for construction	Non-metallic minerals - construction dominant	Non-metallic minerals
A.3.9	Other non-metallic minerals n.e.c.	Non-metallic minerals - industrial or agricultural dominant	Non-metallic minerals
A.4.1.1.1	Lignite (brown coal)	Coal	Fossil Fuels
A.4.1.1.2	Other Sub-Bituminous Coal	Coal	Fossil Fuels
A.4.1.2.1	Anthracite	Coal	Fossil Fuels
A.4.1.2.2	Coking Coal	Coal	Fossil Fuels
A.4.1.2.3	Other Bituminous Coal	Coal	Fossil Fuels
A.4.1.3	Peat	Coal	Fossil Fuels
A.4.2.1	Crude oil	Petroleum	Fossil Fuels
A.4.2.2	Natural gas	Natural Gas	Fossil Fuels
A.4.2.3	Natural gas liquids	Petroleum	Fossil Fuels
A.4.3	Oil shale and tar sands	Oil shale and tar sands	Fossil Fuels

Table 3. Concordance between the MFA4 and MFA13 systems, and the detailed 62 category system used for initial compilation of data for domestic extraction

The main reason that data is not released at CCC 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 CCC 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 other limestone, quite possibly 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 MFA13 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 MFA13 crops category. At the other end of the spectrum, for categories where no such agency or mandate exists, e.g. for non-metallic minerals used construction, the domestic extraction figures given are usually the result of substantial modelling and indirect inference from statistics of related materials and products, which serve as proxies. Detail on the data sources used and estimation processes used is given in the appropriate material sections below.

A final point is that the time series base data sources upon which this data set is built start terminating, in some cases, as early as 2012. From that point on, as data series terminate, the missing years for each category to 2017 are infilled by projection, until by 2017 all data is pure projection. One implication of this is that data after 2012 should probably not be used for such statistical purposes as regression analyses.

Domestic extraction of biomass

Crops

The base data for crops was sourced directly from (FAO 2016a). The date that the data used for the Crops data here was accessed was August 2016, and at that time the final year for which data was generally available was 2014. 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.

The main process here simply involved aggregating the more than 180 crops given in the FAO data into the 13 crop categories available in the CCC 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 Crops estimation.

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 into 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 both 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 (Eurostat 2013) and (new guide ref), but not necessarily with all previous DE accounts.

Grazed biomass and fodder crops

Fodder crops can in the current data set is largely a legacy category, and place holder for the future, in case the FAO resumes collecting relevant data here. 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 the crops accounted for in the main crops category, which are subsequently used to feed animals. The FAO still accounts for the latter in its food balances[1].

[1] 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, it doesn't substitute easily into other important uses. Grasses, whole legume plants etc. where harvested from field, not grazed directly by animal, are also forage crops.

In contrast to fodder crops, grazed biomass has never been accounted in FAO statistics, but remains an active and substantial component of overall biomass for this data set. The method of calculation used here was detailed feed energy gap modelling[2]. The logic and data sources used in getting grazed biomass tonnages from feed gap modelling is as follows.

1. First, the total amount of animal products "grown" in a country was calculated, starting with animal products recorded in FAO (2016b), then subtracting/adding to this the animal product equivalent of live animals imported/ exported, derived via animal numbers and carcass weights from the same FAO source and FAO (2016c).
2. The feed energy required for each country's animal product output was then estimated by applying the feed energy requirements per kg of animal product to the (live trade corrected) output in each animal product. Regionally specific conversion coefficients for product -> feed energy from Wirsenius (2000) were used.
3. Tonnages for those primary crops recorded as going to animal feed in FAO (2016d) for each country were then converted into their equivalent in feed energy available to each class of animal. The conversion factors used here were also derived from Wirsenius (2000). To this available energy was added the energy available from fish used as feed, also sourced from FAO (2016d).
4. The figure derived for total available feed energy in each country was then hierarchically allocated to different classes of animal, i.e. first claim on any crops compatible with poultry was given to poultry, until their requirements were met. Pigs had second claim on any crops compatible with poultry and/ or pigs and/or ruminants. If any feed crops remained after the requirements for pigs were met, ruminants received the remainder.
5. If a feed energy gap remains for ruminant animal products output after step 4, the remainder is assumed to come from grazed biomass. Importantly, no role for crop residues is been considered[3]. This energy deficit filled from grazing is then converted to tonnes of grazed biomass required, using the energy content for "permanent pasture, over sown" for the relevant region for each country derived from Wirsenius (2000) as a conversion factor, and assuming a 15% moisture content.

While fodder crops and grazed biomass are listed as two distinct categories, in reality 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 suffered from two major problems. The first is the uncertain basis on which weight was determined with regard to 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

[3] Substitution of crop residues for grazed biomass was not estimated due to the lack of sufficient data on the proportions of each specific crop residue going to feed. Good data on this would be required to make reasonable estimates of the remaining 'grazing gap' due to the highly non-linear response of ruminant productivity to feed energy density at lower values. The energy available for growth (i.e. beef production) can vary over eight-fold depending on whether the crop residue is a higher energy variety like sugar beet tops, or low energy variety like rice straw. Where a tonne of sugar beet tops would substitute for a tonne of the reference grazed pasture used in this study, over six tonnes of rice straw would be required to produce the same beef output as one grazed tonne.

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.

Wood

Data for production of forestry products is reported in the (FAO 2016e), 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 3. The conversion factors were source from Eurostat (2013)

FAO Code	FAO Name	Conversion factor
1623	Other Indust Roundwd(C)	0.52
1626	Other Indust Roundwd(NC)	0.68
1602	Pulpwood,Round&Split(C)	0.52
1603	Pulpwood,Round&Split(NC)	0.68
1601	Sawlogs+Veneer Logs (C)	0.52
1604	Sawlogs+Veneer Logs (NC)	0.68
1627	Wood Fuel(C)	0.52
1628	Wood Fuel(NC)	0.68

Table 3 FAO Forestry product categories included in domestic extraction, with corresponding factors used to convert from m3 to tonnes.

Wild catch and harvest

The only components actively compiled for this category were source from FAO (2017a). From this data source, the only categories considered were wild fish catch (aquaculture does not count as DE, in the same way livestock doesn't), and the harvest of aquatic plants. Wild catch of aquatic animals other than those specified in tonnes were not considered.

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 (2017b). 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. Wood trade data was sourced from (FAO 2016e), and trade in goods corresponding to Wild catch and harvest was compiled from (FAO 2017a).

The scope of individual products included for 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. This was especially pronounce for forestry products, where all 43 different products in FAO (2016e) were included for trade, compared to the eight used for DE. Most of these products in the base data were specified in tonnes. The conversion factors used for those products originally specified in M3 are given in table 4.

FAO Code	FAO Name	Conversion factor
1650	Insulating Board	0.3
1619	Chips and Particles	0.48
1620	Wood Residues	0.48
1648	MDF	0.52
1632	Sawnwood (C)	0.52
1627	Wood Fuel(C)	0.52
1623	Other Indust Roundwd(C)	0.52
1601	Sawlogs+Veneer Logs (C)	0.52
1602	Pulpwood,Round&Split(C)	0.52
1647	Hardboard	0.6
1634	Veneer Sheets	0.6
1646	Particle Board	0.68
1640	Plywood	0.68
1633	Sawnwood (NC)	0.68
1628	Wood Fuel(NC)	0.68
1626	Other Indust Roundwd(NC)	0.68
1604	Sawlogs+Veneer Logs (NC)	0.68
1603	Pulpwood,Round&Split(NC)	0.68

Table 4. FAO Forestry product categories included in trade, with corresponding factors used to convert from m^3 to tonnes

Domestic extraction of fossil fuels

Data on the extraction of fossil fuels have been taken from energy statistics of three international databases and integrated into one consistent dataset. The primary sources are the World Energy Statistics and Balances of the International Energy Agency (IEA 2016a), the United Nations Energy Statistics Database (UNSD 2016) and the International Energy Statistics of the U.S. Energy Information Administration (EIA 2016). From all three sources the most recent data available at the moment of compilation were used.

The IEA dataset is the most comprehensive currently available data set reporting on fossil fuel extraction and energy use of all countries world-wide. Data can be easily compiled and retrieved online (however, data of IEA are not free of charge).

Data from UNSD was retrieved in two different datasets. This is because years prior to 1990 are not available online at the UN data portal and have to be purchased additionally. Data from EIA is freely available online.

Integration of data

Data from all three sources have been integrated into one dataset. Highest priority was given to IEA data, which first were complemented with data from UNSD and after that with data from EIA. A rather strict approach was applied for the scope of complementation, i.e. data from UNSD were added only in those cases where IEA either did not provide any values for a time series at all or were used for replacement where its time coverage (for a single commodity of a single country) was at least more than half of that of IEA data. The same approach was used to complement that integrated dataset with data from EIA. The selection of time series to be included from each data source was based on an assessment of their coverage during the compilation of a previous version of the Global Material Flows Database which spanned the time period 1980-2010.

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

Table 5. Fossil fuel commodities derived from each primary data base and the applied concordance

For the purpose of consistency, data from the three different sources were not mixed for a single commodity of one country. However, within a single country different commodities can have different primary data sources.

Due to the different classification of coal between IEA and EIA there was a risk of double counting. In order to avoid any errors stemming from that issue, no data on coal from EIA were included, except for those countries where IEA did not provide any data for coal.

Data for coal extraction from UNSD was not included in the dataset because none of the coal commodities reported by UNSD exceeded the time coverage of data reported by IEA.

The integration of data has shown that data from IEA is comprehensive to such an extent that complementation from the other two sources occurred only in a few cases.

Database	Share
IEA	89.9%
UNSD	6.1%
EIA	4.0%

Table 6. Relative shares in total time series of primary data used in the dataset (by primary database)

Data adjustment and estimations

1. Conversion of data:

The Global Material Flows Database provides all values in tonnes. Therefore primary data which were reported in other units had to be converted using factors published by the same primary sources.

The IEA and UNSD report all categories relevant for the Global Material Flows Database in primary units of 1000 tons, except for natural gas which had to be converted from terajoule into tonnes, using a conversion factor provided by IEA (18 t/TJ), as well as other hydrocarbons, which had to be converted to oil sand based on the amount of produced synthetic oil.

Primary data	Commodity	Unit (primary data)	Factor used	Source (of factor)
IEA	Natural gas	Terajoule	18	IEA
IEA	Other hydrocarbons (reflecting oil production from oil sands)	tonnes	14.663	(NASA Earth Observatory 2016)
EIA	Natural gas	Billion cubic feet	19522.8	IEA (t/TJ) EIA (TJ/cubic feet)
EIA	Coal	Short ton	0.9072	EIA
EIA	Oil	Barrel / day	49.79	EIA
EIA	Natural gas liquids	Barrel / day	35.1	EIA

Table 7. Factors used to convert reported physical units to metric tons

2. Estimations:

At the time of data retrieval IEA provided data for the years 1971 to 2015 (only covering previous years for some OECD countries). Therefore values for the year 1970 were 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 aggregate category 'Crude/NGL/feedstocks' and therefore the latter was split up based on the ratio of production of the former two during the following three years.

IEA does not report disaggregated data on coal extraction for years prior to 1978. Instead the two categories 'Hard Coal' and 'Brown Coal' are used. These two categories were disaggregated into their respective sub-categories using the average relative shares of the years 1978 to 1987. According to (IEA 2016b) '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'. However, documentation provided by IEA does not specify how 'Sub-bituminous coal' is allocated for different countries. Therefore an approach was applied which compared aggregated values for the year 1977 and disaggregated values for the year 1978, determining where 'Sub-bituminous coal' had to be allocated to.

EIA provided data for the years 1980-2014; hence, for the time range 1970-1979 data points had to be estimated. This was done by calculating average fuel intensities (fossil fuel per GDP) for the years 1980-1984 and applying those to the GDP data of the missing years (GDP data for this was taken from UNSD (2017)).

3. Adjustment of geographical scope:

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 IEA and UNSD were adjusted accordingly, as these two sources provided a different geographical structure for these transition years and the mentioned regions.

4. Different allocations

After repeated communication with IEA, the data reported on 'Other hydrocarbons' were only included for two countries, Canada and Venezuela, as in case of all other countries the included production did either not refer to primary extraction of raw materials or it was not possible to certainly say that it would only refer to primary extraction. Data for Canada was therefore allocated to A.4.3 – Oil shale and tar sands, data for Venezuela to A.4.2.1 – Crude oil.

Trade in fossil fuels

Unlike for Domestic extraction (DE), data for trade in fossil fuels was only taken from IEA (IEA 2016a). While for DE the number of material categories is straightforward and hardly poses any issues with integration, for trade the number of processed fossil fuels has exceeded a number for which the effort necessary for a robust integration of another data set would not justify the possibly relatively small improvement of detail which any additional data would have provided over the already existing data from IEA. Such an additional data integration would have unnecessarily increased the risk of potential double counting.

A range of specifications explained for domestic extraction of fossil fuels above also apply for data on trade:

1. The number of detail in covered materials is the same as for domestic extraction.
2. Missing values for the year 1970 were estimated by applying a linear extrapolation based on the trend of the following four years. 'Crude/NGL/feedstocks' was split up based on the ratio of production of the underlying materials during the following three years.
3. The two categories 'Hard Coal' and 'Brown Coal' were disaggregated into their respective sub-categories using the average relative shares of the years 1978 to 1987.
4. Data adjusted in their geographical structure for the Soviet Union, former Yugoslavia and Czechoslovakia during the period 1989-1993, as IEA provided a different geographical structure for these transition years and the mentioned regions.

Domestic extraction of metal ores

The dataset on extraction of metal ores was composed following the standards on Material Flow Accounting (MFA) published by Eurostat and the OECD over the last decade (EUROSTAT 2012, 2007, 2001; OECD 2004, 2008).

Data sources

Primary data on the extraction of metal ores were obtained from three comprehensive international data sources: the British Geological Survey (BGS 2017), the United States Geological Survey (USGS 2017) and the World Mining Data published by the Austrian Ministry for Science, Research and Economy (Reichl et al. 2016). All data sets are available for free online. BGS provides an online download tool, USGS and WMD provide Excel and pdf files. All data sources provide data annually, normally with a delay of 2-3 years (t-2, t-3).

Integration of data

Data from these sources were integrated into one consistent dataset, using the BGS database as main data source and complementing with the other two data sources. Hence, data from the other two sources were used in those cases where BGS does not report values for the extraction of a commodity in a country. In most cases, the time series of each commodity in a specific country is based on one main data source. Only in a small number of cases an additional data source was used, mainly to extend time series starting later than 1970 while production existed already back then.

Aggregation of data

The following table provides the concordance between the commodities derived from the primary sources and their aggregation into the raw material groups used in the Global Material Flows Database. Data for 32 types of metals were collected and aggregated into 10 metal ore groups.

Primary database	Commodity	CCC Code	CCC Name
BGS	Iron ore	A.2.1.Fe	Iron ores
	Silver, mine	A.2.2.Ag	Silver ores
	Bauxite	A.2.2.Al	Bauxite and other aluminium ores - gross ore
	Gold, mine	A.2.2.Au	Gold ores
	Chromium ores and concentrates	A.2.2.Cr	Chromium ores
	Copper, mine	A.2.2.Cu	Copper ores
	Manganese ore	A.2.2.Mn	Manganese ores
	Antimony, mine	A.2.2.nec	Other metal ores
	Arsenic, white		
	Beryl		
	Bismuth, mine		
	Cadmium		
	Cobalt, mine		
	Germanium metal		
	Lithium minerals		
	Magnesium metal, primary		
	Mercury		
	Molybdenum, mine		
	Rare earth minerals		
	Selenium metal		
	Tantalum and niobium minerals		
	Tellurium metal		
	Tungsten, mine		
	Vanadium, mine		
	Zirconium minerals		
	Nickel, mine	A.2.2.Ni	Nickel ores
	Lead, mine	A.2.2.Pb	Lead ores
	Platinum group metals, mine	A.2.2.Pt	Platinum group metal ores
	Tin, mine	A.2.2.Sn	Tin ores
	Titanium minerals	A.2.2.Ti	Titanium ores
	Uranium	A.2.2.U	Uranium ores
	Zinc, mine	A.2.2.Zn	Zinc ores
USGS	Iron ore	A.2.1.Fe	Iron ores
	Cadmium	A.2.2.nec	Other metal ores

	Cobalt		
	Magnesium		
	Mercury		
	Niobium and tantalum		
	Rare earths		
	Vanadium		
	Indium and thallium		
	Bauxite	A.2.2.Al	Bauxite and other aluminium ores - gross ore
	Chromite	A.2.2.Cr	Chromium ores
	Gold	A.2.2.Au	Gold ores
	Lead	A.2.2.Pb	Lead ores
	Nickel	A.2.2.Ni	Nickel ores
	Silver	A.2.2.Ag	Silver ores
	Titanium	A.2.2.Ti	Titanium ores
	Uranium	A.2.2.U	Uranium ores
WMD	Iron	A.2.1.Fe	Iron ores
	Aluminium	A.2.2.Al	Bauxite and other aluminium ores - gross ore
	Gold	A.2.2.Au	Gold ores
	Cadmium	A.2.2.nec	Other metal ores
	Rare Earths Metals		

Table 8. Concordance between primary metal ores data and the compiled data set

Estimation of gross ore from data on net-metal contents

Data on metal production compiled by geological institutes or statistical agencies is often reported in terms of net-metal contents, i.e. metal quantity after the processing and concentration of crude ores. However, according to MFA standards, metal extraction should be accounted as crude ores, i.e. the overall amounts of extracted metal ores before processing and concentration. Therefore, in cases where no data on gross ore extraction but only data on net metal content are reported, an application of estimations is required, in order to transform all reported net metal content values into equivalents of gross ores.

The concentrations in which metals occur in primary ores in nature can differ considerably between countries and mines. This requires applying (at least) country-specific information on average metal concentrations in order to obtain robust estimates of the corresponding amounts of extracted crude ore. Information on metal concentrations was obtained from a large number of publications by different geological surveys, ministries, and other institutions, collected already during the compilation of a former version of the data set in 2015 and subsequently furthermore extended. Suggestions for data sources and publications to be used were taken from a literature list available in the technical report of the database at www.materialflows.net WU Vienna (2015). In addition, correspondence was conducted with experts from relevant agencies (e.g. USGS) and all factors were revised and cross-checked within the project team. An overview of the used sources for ore grades are listed in Table 9 below.

In those cases where data on extraction of a metal in a country was available, but no respective factor to estimate the gross weight could be found, different types of proxy values were applied. Depending on the specific case, either an available factor for a neighbouring country or regional (i.e. country group / continent) or global average factors were applied. In case none of these were available, the regional or global average factors were calculated based on existing information.

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 (Inputside) 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)

Table 9. Sources used for the compilation of metal ore grades applied in the data compilation

Adjustment of geographical scope

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 were adjusted accordingly, as for some time series it provided a different geographical structure for these transition years and the mentioned regions.

Trade in metal ores

Base data for the trade in metal ores (and products which could be traced in origin to metal ores) was sourced from the UN Comtrade database, UN Statistics Division (2016). The only products taken into consideration were those recorded on a clear mass unit basis in the original data. This means that complex manufactured items are largely excluded, however comparison with other physical trade data sets, indicate that the total tonnage excluded is likely to be less than 15%, and the total global tonnage calculated for this data set was in fact intermediate between the two data sets it was compared to[4].

The sets of commodities aggregated over the full time period of the database varied for different periods, as the product categorization systems employed by Comtrade has changed multiple times over time. In all, four different generations of Comtrade's HS system and three of the SITC system are used.

To deal with this, aggregating the Comtrade data from its original categories to the CCC categories took place in two stages. The first involved separately capturing major tonnage metal ores based commodities in three broad categories: metal ores and concentrates, near primary metal products, and metal salts. The allocation of Comtrade SITC categories to "near primary metals products" for example, used 21 different SITC code stems to which a computational algorithm was then applied to find the highest total value for each country under that stem, and then add that tonnage to the total under the appropriate metal category in the CCC system. For example, a SITC stem of "67" was used to extract the highest tonnage total at that level or below for the entire family of Iron and steel products e.g. S1-67 Iron and steel, S1-671 Pig iron spiegeleisen sponge iron etc, S1-6712Pig iron including cast iron.......S1-672 Ingots & other primary forms of iron or steel, etc. This total was then added to the "A.2.1.Fe Iron ores" CCC category for the appropriate country.

A similar process was undertaken for the broad metal ores and concentrates category, and for the metal salts (compounds) category, and then repeated for all three broad categories using that input

[4] The 13 category trade data assembled for input to UNEP (2016) showed greater tonnages of physical trade, while an unpublished dataset compiled by the Potsdam Institute for Climate Impact Research, which reconciles international import flows against export flows, showed consistently lower total tonnages. Both use Comtrade data as the base input data source.

trade data which was classified using the HS system, changing to the appropriate set of stems for that system. To capture the relevant HS products for the broad metals near primary group, for example, 91 individual stems were used.

Domestic extraction of non-metallic minerals

Reported data accounts

The bulk of non-metallic minerals can be clustered into those used for construction purposes and those which are not. While the former (e.g. sand, gravel, limestone, gypsum, clay) makes up the largest quantity of all minerals extracted each year, the reported statistics on these are usually not of high quality and coverage, wherefore estimations are necessary. The following section therefore takes into account those data on all non-metallic minerals reported in statistical accounts, followed by information on the respective estimations for construction minerals.

Data sources

Primary data on the extraction of non-metallic minerals were obtained from three comprehensive international data sources: the British Geological Survey (BGS 2017), the United States Geological Survey (USGS 2017) and the World Mining Data published by the Austrian Ministry for Science, Research and Economy (Reichl et al. 2016). All data sets are available for free online. BGS provides an online download tool, USGS provides Excel files and pdf country sheets and the WMD are published in pdf format. All data sources provide data annually, normally with a delay of 2-3 years (t-2, t-3).

Integration of data

Data from these sources were integrated into one consistent dataset, using the BGS database as main data source and complementing with the other two data sources. Hence, data from the other two sources were used in those cases where BGS does not report values for the extraction of a commodity in a country. In most cases, the time series of each commodity in a specific country is based on one main data source. Only in a small number of cases an additional data source was used, mainly to extend time series starting later than 1970 while production existed already back then.

Aggregation of data

The following table provides the concordance between the commodities derived from the primary sources and their aggregation into the raw material groups used in the Global Material Flows Database.

Primary database	Commodity	CCC Code	CCC Name
BGS	Phosphate rock	A.3.4.1	Fertilizer minerals n.e.c.
	Potash		
	Frasch	A.3.4.2	Chemical minerals n.e.c.
	Barytes		
	Borates		
	Fluorspar		
	Pyrites		
	Sulphur ore		
	Asbestos	A.3.4.3	Industrial minerals n.e.c
	Bromine		

	Diatomite		
	Feldspar		
	Graphite		
	Iodine		
	Magnesite		
	Mica		
	Nepheline syenite		
	Perlite		
	Sodium carbonate, natural		
	Strontium minerals		
	Talc		
	Vermiculite		
	Wollastonite		
	Brine salt	A.3.5	Salt
	Brine salt & sea salt		
	Evaporated salt		
	Other salt		
	Rock salt		
	Rock salt & brine salt		
	Salt in brine		
	Sea salt		
	Gypsum and plaster	A.3.6	Gypsum
	Attapulgite	A.3.7.2	Specialty clays
	Bentonite		
	Fuller's earth		
	Kaolin		
	Sillimanite minerals		
	Sepiolite		
	Crushed rock	A.3.8.2	Sand gravel and crushed rock for construction
	Sand and gravel		
USGS	Igneous rock	A.3.1	Ornamental or building stone
	Marble		
	Sandstone		
	Slate		
	Chalk	A.3.2.1	Chalk
	Dolomite	A.3.2.2	Dolomite
	Calcite	A.3.2.3	Limestone
	Limestone		
	Marketable potash	A.3.4.1	Fertilizer minerals n.e.c.
	Barite	A.3.4.2	Chemical minerals n.e.c.
	Fluorspar		
	Sulphur		
	Bromine	A.3.4.3	Industrial minerals n.e.c
	Diatomite		
	Feldspar		
	Gemstones		
	Industrial diamonds		
	Magnesite		
	Mica		
	Natural iron oxide pigments		
	Perlite		
	Pumice and related materials		
	Qartz and quartzite		
	Sodium carbonate, natural		
	Talc and pyrophyllite		
	Salt nec	A.3.5	Salt
	Gypsum	A.3.6	Gypsum
	Common clay	A.3.7.1	Structural clays
	Ball clay	A.3.7.2	Specialty clays
	Bentonite		
	Kaolin		
	Kyanite and related minerals		
	Potter clay		
	Special clay		
	Industrial sand and gravel (silica)	A.3.8.1	Industrial sand and gravel
	Crushed stone	A.3.8.2	Sand gravel and crushed rock for construction
	Sand and gravel		

	Asphalt	A.3.9	Other non-metallic minerals n.e.c.
	Peat	A.4.1.3	Peat
WMD	Fluorspar	A.3.4.2	Chemical minerals n.e.c.
	Sulfur		
	Diamonds (gem/industrial)	A.3.4.3	Industrial minerals n.e.c
	Diatomite		
	Feldspar		
	Talc (incl. steatite and pyrophyllite)		

Table 10. Concordance between primary non-metallic minerals data and the compiled data set

Estimation of gross mine production 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 first enters processing, and as such do not have to be converted. Exceptions to this include diamonds, potash, and sulphur. Diamonds are reported in the unit “carat” in their already processed form. Therefore, mine-specific ore grades were researched for the largest mines and diamond-producing countries from company reports and scientific publications in order to estimate the mined ore. The same logic as for metals is applied, by using national averages as far as possible, otherwise regional or global averages. As with all other commodities this extraction is reported in kt. In case of potash only the production of the K2O content in potash ores is reported by the primary source, for sulphur only the sulphur content in sulphur ores and pyrites. Therefore estimation factors are applied to report the actually mined potash and sulphur ores as well as pyrites.

Non-metallic minerals used for construction

Many countries have no data on 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.

To overcome this limitation, we calculate the apparent consumption (apparent consumption = import + domestic extraction – exports) of four materials/items, and find the relation that stands between these materials/items and the necessary quantity of non-metallic minerals that are related to those. We firstly calculate the apparent consumption of:

1. Cement;
2. Bitumen;
3. Bricks;
4. Net extension of railways.

We then relate the amount of non-metallic minerals that are used in the production/construction of:

1. Concrete;
2. Roads;
3. Bricks (raw materials);
4. Railways ballast;
5. Building sublayers;

6. Cement (raw materials).

Primary data for cement production has been sourced from the United States Geological Survey which reports for the years 1970-2013 in USGS (2014). This was cross-checked with reports from Cembureau for years 2001-2011 (Cembureau 2014). We then used data on trade from UN Statistics Division (2016) for the years 1970-2011, to determine national net trade balance in cement, and applied that to production figures to determine national level cement consumption. While the Comtrade database has data on some products to 2016, its data on the trade of cement currently ends in 2011.

Data for bitumen was sourced from the International Energy Agency (IEA), which had data on extraction and trade for bitumen from 1970 to 2014 in (IEA 2017).

Brick production data was sourced from UN Statistics Division (2011). Some data had to be discarded as deemed implausible (e.g. for China and Japan), while other notable brick producing countries were completely missing (e.g. India and Italy). This data was retrieved from national sources: China Construction Association (2009), Ministry of Economy Trade and Industry (2013), CGIL Fillea (2015).

To measure the extension of railway networks the dataset compiled by the World Bank Transport Division was used (Bank 2015). This database reports the total length of countries' railway networks for years 1980-2014. While the first 10 years are missing, the contribution of railways to the total consumption of non-metallic minerals is negligible and does not sensibly alter the account.

To these proxy accounts we applied the following conversion factors, which have been calculated in Miatto et al. (2017).

1. Cement consumption to non-metallic minerals used in concrete: 5.26 x cement
2. Bitumen consumption to non-metallic minerals used in roads: 51.12 x bitumen
3. Fired bricks to raw materials: 1.16 x bricks
4. Railway length extension to gravel ballast: (2119.3 x gauge – 581.2) x length
5. Cement consumption to gravel in building sublayers: 0.42 x cement
6. Cement to raw materials: 1.57 x cement

The results of these estimations are then integrated into the following common compilation categories:

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

For each time series data point, the reported data are checked against the estimations and if found higher, are given preference.

Trade in non-metallic minerals

As with metal ores, the base data for trade in non-metallic minerals was sourced from UN Statistics Division (2016). The only products taken into consideration were those recorded on a clear mass unit basis in the original data. The same process described for metal ores, of using “stems” from the different SITC and HS categorization systems used by Comtrade, in conjunction with a computational algorithm, to capture products and allocate them to the appropriate CCC category was used. Here the process was considerably simpler, as only eight different stems were required to capture the relevant HS system materials from the four different generations of HS, while 30 were needed to cover the different generations of the SITC system.

Projection and combination of data for late years

As some of the base data time series for some materials began to terminate as early as 2012, to construct a time series which extended to 2017, it was necessary to begin projecting some of the data components from 2013 onwards. The projected components constitute an increasing proportion of the total dataset for each year after 2012, until by 2017 all data for all materials comes from projection.

For DE, projection was done on data series at the CCC level. The projections were made 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 2010. Absence of data after this point was taken to indicate that the extractive industry had genuinely shut down e.g. mine 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 2010) data points, but < 5 data points overall to establish a trend, the time series was filled out to 2017 with repeats of the last data point.
5. If a projection from a negative trends goes negative in later years, these years are set to NA (as negative DE makes no sense).

The same process was used to extend physical trade data, except that as the trade data is generally very volatile data at high disaggregation levels, the projections were not performed at CCC level, but rather on the data after it had already been aggregated up to the maximum 13 subcategory resolution released in this data set.

Other Data used for Ratios

The base data used to establish GDP and for Population was sourced from UNSD (2017). The GDP basis selected from those available was Constant 2005 prices in US Dollars.

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 the EORA MRIO ran by Sydney University. For a technical understanding of EORA, the interested reader will need to go to http://www.worldmrio.com/ and follow the links to literature, FAQs, and other information there.

One point to note here is that the scopes of the MRIO behind EORA, and that of the direct physical accounts such as DE covered in this data set, are different. The direct physical accounts began with a pool of over 220 countries which had existed at some point between 1970 and 2017. This set was reduced to 192 by removing countries for which the base data was too poor to justify trying to establish accounts. The material footprint account only covers countries which have existed after 1990, and usually supports only one version of a country, e.g. one Ethiopia or Sudan, not pre and post-split versions. From the EORA MRIO's widest possible scope of 187 countries, after other conditions are met there is only currently material footprint data for 170 countries included here. This means that while in theory the global total of DE should be equal to the global total of MF, the differing scopes mean that here it isn't.

Bank, W. 2015. Rail Lines (Total Route-Km).

BGS. 2017. World Mineral Statistics. London: BGS - British Geological Survey.

Cembureau. 2014. *World Statistical Review 2001 - 2011*. Brussels: Cembureau - European Cement Association.

CGIL Fillea. 2015. *Statistiche degli indicatori del settore laterizi e manifatti cementizi per la contrattazione sindacale*. Italy: CGIL Fillea.

China Construction Association. 2009. *China Building and Industrial Materials Yearbook*: China Construction Association.

EIA. 2016. International Energy Statistics. Washington: U.S. Energy Information Administration.

EUROSTAT. 2001. *Economy-wide material flow accounts and derived indicators. A methodological guide*. Luxembourg: Statistical Office of the European Union.

EUROSTAT. 2007. *Economy-wide Material Flow Accounting - "A compilation guide". By Weisz, H., Krausmann, F., Eisenmenger, N., Schütz, H., Haas, W. and A. Schaffartzik*. ENV/MFA/06 (2007). Luxembourg: EUROSTAT.

EUROSTAT. 2012. *Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2012*. Luxembourg: Statistical Office of the European Communities.

Eurostat. 2013. *Economy-wide Material Flow Accounting (EW-MFA) - Compilation Guide 2013*.

FAO. 2016a. FAOSTAT - Production - Crops - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.

FAO. 2016b. FAOSTAT - Production - Livestock Primary - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.

FAO. 2016c. FAOSTAT - Trade - Live animals - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.

FAO. 2016d. FAOSTAT - Food Balance - Food balance sheets - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.

FAO. 2016e. FAOSTAT - Forestry - Forestry production and trade - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.
FAO. 2017a. Fishstat database.
FAO. 2017b. FAOSTAT - Trade - Crops and livestock products - Bulk downloads - All Data Normalized. : Food and agriculture organization of the United Nations.
Haberl, H., K. H. Erb, F. Krausmann, V. Gaube, A. Bondeau, C. Plutzar, S. Gingrich, W. Lucht, and M. Fischer-Kowalski. 2007. Supporting Information - Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. In *PNAS*.
IEA. 2016a. World energy statistics, IEA World Energy Statistics and Balances (database).
IEA. 2016b. *World Energy Statistics - 2016 EDITION DATABASE DOCUMENTATION*.
IEA. 2017. World energy statistics, IEA World Energy Statistics and Balances (database).
Miatto, A., H. Schandl, T. Fishman, and H. Tanikawa. 2017. Global Patterns and Trends for Non-Metallic Minerals used for Construction. *Journal of Industrial Ecology* 21(4): 924-937.
Ministry of Economy Trade and Industry. 2013. *Yearbook of Current Production Statistics, Mineral Resources and Petroleum Products, Ceramics and Building Materials*: Ministry of Economy Trade and Industry,.
NASA Earth Observatory. 2016. Athabasca Oil Sands. https://earthobservatory.nasa.gov/Features/WorldOfChange/athabasca.php. Accessed.
OECD. 2004. *Recommendation on material flows and resource productivity*. Paris: OECD.
OECD. 2008. *Measuring Material Flows and Resource Productivity. The OECD guide* ENV/EPOC/SE(2006)1/REV3. Paris: Environment Directorate. Organisation for Economic Co-operation and Development.
Reichl, C., M. Schatz, and G. Zsak. 2016. *World Mining Data*. Vienna: Federal Ministry for Science, Research and Economy.
UN Statistics Division. 2016. Commodity Trade Statistics Database United Nations.
UN Statistics Division. 2011. Industrial Commodity Production Statistics Database 1950 - 2008, edited by U. Nations. New York.
UNEP. 2016. *Global Material Flows and Resource Productivity - An Assessment Study of the UNEP International Resource Panel*.
UNSD. 2016. Energy Statistics Database: United Nations Statistics Division.
UNSD. 2017. National Accounts Main Aggregates Database: UN Statistics Division.
USGS. 2017. International Minerals Statistics and Information. Washington D.C.: US Geological Survey.
USGS. 2014. *2013 Mining and quarrying trends*. U.S. Geological Survey.
Wirsenius, S. 2000. Human Use of Land and Organic Materials: Modeling the Turnover of Biomass in the Global Food Systemthesis, Department of Physical Resource Theory, Chalmers University of Technology, Göteborg.
WU Vienna. 2015. *Technical Report on the compilation of the material flow database for www.materialflows.net*. Vienna: Vienna University of Economics and Business.