Chair of Mining Engineering and Mineral Economics

Master's Thesis

Raw Material's Production Data: An Analysis of International Data Collections and Their Applications

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Declaration of Authorship

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Preface, Dedication, Acknowledgement

This thesis was completed as the final part of my Master's degree "Mining Engineering" at the Chair of Mining Engineering and Mineral Economics, at the Montanuniversitaet Leoben.

First of all, I thank Vice Rector Univ.-Prof. Peter Moser, from Montanuniversitaet Leoben, for his support and guidance during the preparation of this thesis.

The contributions of Dipl.-Ing. Christian Reichl, from the Austrian Federal Ministry of Sustainability and Tourism, Univ.-Prof. Fridolin Krausmann, Mrs Teresa J. Brown, Mineral Commodity Geologist, BGS, and Mr Michael Magyar, USGS, were of great help and I would like to thank them for their inputs.

Last but not least, I want to thank Mr Andreas Okorn, and my parents Marina and Johannes Kügerl, for their revisions and continuous support.

Abstract

This Master's Thesis is divided into three parts. First, three international data collections (World Mining Data, British Geological Survey, United States Geological Survey) of raw material's production data, and one collection on European level (Eurostat) are evaluated. The assessment includes commodities reported, countries covered, additional information on the commodity, as well as strengths and weaknesses of each report.
Secondly, applications using these reports are discussed, showing numerous studies and policy measurements relying on the figures by the data collections. This includes the criticality study of the European Union, Material Flow Analysis, and Sustainable Development Goals.
Thirdly, two power plants are compared in terms of material requirements for their construction – a combined heat and power plant and a wind farm. The amount of materials used per kilowatt hour of electricity production is assessed, as well as their recyclability and criticality for the EU.

Zusammenfassung

Diese Diplomarbeit ist in drei Teile gegliedert.
Zunächst werden drei internationale Datensammlungen (World Mining Data, British Geological Survey, United States Geological Survey) von Produktionsdaten von Rohstoffen und eine Sammlung auf europäischer Ebene (Eurostat) ausgewertet. Die Bewertung umfasst die erfassten Rohstoffe, die berücksichtigten Länder, zusätzliche Informationen über den jeweiligen Rohstoff, sowie die Stärken und Schwächen der einzelnen Berichte.
Zweitens werden Anwendungen, die diese Berichte nutzen, diskutiert, wobei zahlreiche Studien und politische Maßnahmen gezeigt werden, die sich auf die Zahlen der Datensammlungen stützen. Dazu gehören die Kritizitätsstudie der Europäischen Union, Materialflussanalysen und die nachhaltigen Entwicklungsziele.
Drittens werden zwei Kraftwerke in Bezug auf den Materialbedarf für ihre Konstruktion miteinander verglichen - ein Heizkraftwerk und ein Windpark. Die Menge der verwendeten Materialien pro Kilowattstunde Stromerzeugung wird ebenso bewertet, wie ihre Recyclingfähigkeit und ihre Kritizität für die EU.

Table of Contents

1 Introduction

Raw materials are an integral part of our everyday lives. They influence our living standards – starting at the "simple roof over our heads" to cars we drive and the smartphones we own. They influence the industry providing jobs and driving our economy, they affect our health and well-being by ensuring clean drinking water, and they are vital to our future and the future of our planet helping us to expand renewable energy systems, build electric cars, etc.

> *"Raw materials are not an exclusive concern of the mining industry, they are the concern of all of us."* (Pesonen, 2019)

In order to evaluate the amount of raw materials we need, recordings of the amounts of raw materials mined are of vital importance. Production of raw materials influences company planning, not only by companies involved in the mining sector, but also by downstream companies depending on those materials. Policy making also depends on availability and demand of raw materials, such as the Circular Economy Initiative by the European Union.

There are currently three major providers of data on raw materials production on an international level that are publicly available – the British Geological Survey, the United States Geological Survey, and the Austrian Federal Ministry on Tourism and Sustainability. The first step of this thesis is a comparison of these three providers evaluating what data they offer (raw materials and countries reported, metal content vs ore, additional information), how the data is collected, and if there are any differences. Moreover, an evaluation of strengths and weaknesses is conducted, and if possible, a guideline on how and when to use which provider shall be proposed. To focus more on the European level also Eurostat data is included which is not as expansive, in terms of raw materials and countries evaluated, but does also include different data sets such as import and export, or domestic consumption figures. Is this a valuable addition covering "blind spots" of the other providers, does it have different applications, where are the similarities?

The second part of this thesis is a literature review on applications of the data provided by the institutions evaluated in the first part. This includes studies on (global) material flows, and demand drivers, but also policies, such as the circular economy package by the EU, the critical raw materials list, or the Sustainable Development Goals are considered. The aim of this part is to show different applications of raw material's production data as well as its importance for policy makers, and to see whether there are any differences in data reported vs data required.

Thirdly, the data is used to conduct a comparison of two different electric energy production methods, wind power farms and thermal power plants. This comparison shall evaluate "new vs old technology" in terms of material input required to build such a power plant also looking into the type of materials used, e.g. materials considered critical by the European Union, or materials connected to issues such as conflicts, environmental problems, etc. This part has the purpose of showing that renewable energy sources still rely heavily on the input of primary raw materials, maybe even more than conventional energy production methods. It shall also show possible issues connected to the materials used for renewable energy production, such as availability of materials, dependency on certain countries, and recyclability.

Note: In this thesis figures are stated using "." as decimal points and "," as thousands separators.

2 Collections of Raw Material’s Production Data

In this thesis the three main publications of mineral raw material’s world production data are evaluated in detail regarding data provided, method of data collection and their advantages and disadvantages compared to each other. Only publications that are available for free were chosen and that cover the broadest selection of countries and mineral raw materials.
These publications are the World Mining Data (WMD) published by the Federal Ministry Republic of Austria Sustainability and Tourism, the World Mineral Production by the British Geological Survey (BGS) and the Minerals Yearbook by the United States Geological Survey (USGS).
Data provided by Eurostat in their material flow accounts for European production of raw materials is evaluated and compared to the other statistics as well in order to have a comparison to a slightly different type of data collection and evaluate its advantages and disadvantages.

2.1 World Mining Data

World Mining Data (WMD) is an annual publication by the Federal Ministry Republic of Austria Sustainability and Tourism which includes production figures of 63 mineral commodities from 168 countries. It is usually delayed two years, meaning the most current data in the publication of the year 2019 is from 2017. It is the “youngest” publication of the three global data providers, with 34 reports by 2019.

The commodity figures are grouped by:

- Continents
- World regions (according to IIASA)
- Development status (according to OECD definitions) of producer countries
- Per capita income of producer countries
- Country groups and economic blocks (e.g. EU or BRICS countries)
- Political stability using the Worldwide Governance Indicators of producer countries
- Groups of commodities
- Concentration of producer countries using the Herfindahl-Hirschman Index (HHI)

(Reichl *et al.*, 2019)

Moreover, the World Mining Data provides charts giving an overview on current production developments and visualising production data, such as the total production of minerals in the year 2017 by continents (Figure 1).

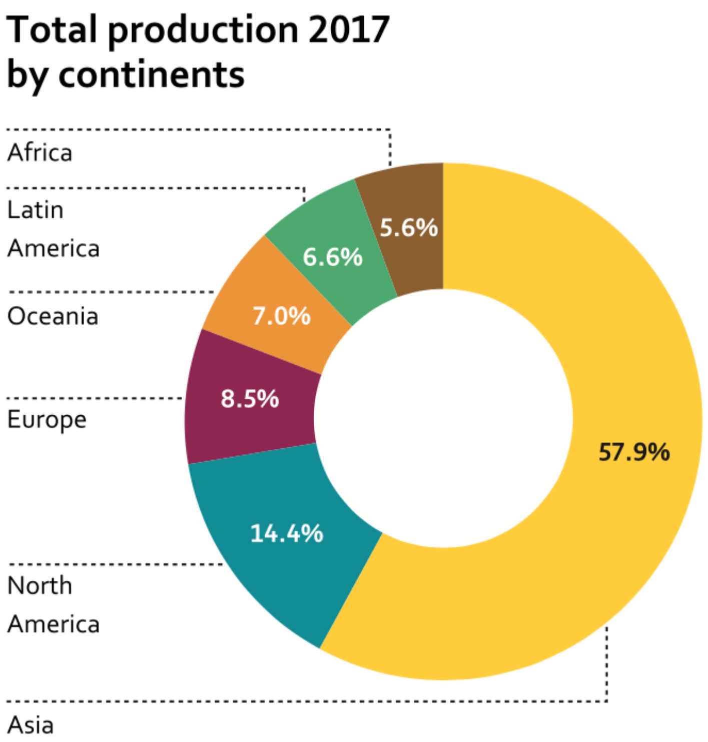

Figure 1: Distribution of mineral production per continent (Reichl *et al.*, 2019)

The 68 commodities are organised in five groups according to geological principles by Univ.Prof. Dr. Leopold Weber, former publisher of the World Mining data. The only exception to this is coal; here also the utilisation is considered (e.g. coking coal).

The groups and contained minerals are:

- Iron and Ferro-Alloy Metals
    - Iron, Chromium, Cobalt, Manganese, Molybdenum, Nickel, Niobium, Tantalum, Titianium, Tungsten, Vanadium
- Non-Ferrous Metals
    - Aluminium, Antimony, Arsenic, Bauxite, Bismuth, Cadmium, Copper, Gallium, Germanium, Lead, Lithium, Mercury, Rare Earth Minerals, Rhenium, Selenium, Tellurium, Tin, Zinc
- Precious Metals
    - Gold, Platinum-Group Metals (Palladium, Platinum, Rhodium), Silver
- Industrial Minerals
    - Asbestos, Baryte, Bentonite, Boron Minerals, Diamond (Gem/Industrial), Diatomite, Feldspar, Fluorspar, Graphite, Gypsum and Anhydrite, Kaolin (China-Clay), Magnesite, Perlite, Phosphates (incl. Guano), Potash, Salt, Sulfur, Talc (incl. Steatite and Pyrophyllite), Vermiculite, Zircon
- Mineral Fuels
    - Steam Coal (incl. Anthracite and Sub-Bituminous Coal), Coking Coal, Lignite, Natural Gas, Crude Petroleum, Oil Sands, Oil Shales, Uranium

(Reichl *et al.*, 2019)

The metal figures usually indicate the contained metal content not the ore in order to ensure a global comparability of the amounts. Due to the widely varying metal contents a comparison of the mined ore would be pointless, e.g. iron ore in Carajás, Brazil (Vale) has an iron content of 67%, in Kiruna, Sweden (LKAB) approx. 48%. (Vale, 2017; LKAB, 2017)
As the output changes regularly due to changes in efficiency of the processing it is favourable to use the content of traded concentrate, or for example the content is calculated using the amount of mined ore multiplied by the metal content provided by mining companies.

The authors collect data using different methods. On the one hand questionnaires are sent out globally to Austrian embassies that distribute it among responsible authorities. The response rate is between 20 to 25%. Moreover, companies are consulted, especially in areas with a low number of producers (e.g. Latin America).
Other sources are the central bank, study groups and other data providers, such as BGS and USGS. The ministry also cooperates with World Mining Congress which is providing essential data of their members.

Unfortunately, there are some countries and commodities where little or no data is available. Lithium production, for example, is calculated from the products sold on the world market. Also, Cadmium is a problematic mineral where mainly export numbers are used to estimate the production.

A major strength of World Mining Data is the section on political stability, development status, etc. of producer countries, as well as the concentration of producer countries showing economic interdependencies.
World Mining Data is publicly available as PDF- and Excel-files that can be downloaded from the designated website. The Excel-files include all data available between 1984 and 2017.

(Information on data collection and reporting kindly provided by Dipl.-Ing. Christian Reichl, Federal Ministry of Sustainability and Tourism)

2.2 World Mineral Production

British Geological Survey, BGS, annually publish the World Mineral Production a collection of production figures of 75 commodities in total, 73 reported globally and 2 for Europe only. BGS have a long-standing history of providing data on raw materials, the predecessors of the World Mineral Production - World Mineral Statistics and Statistical Summary of the Mineral industry - date back to 1913.

Commodities reported are:

A. Alumina, Aluminium, Antimony, Arsenic, Asbestos, Aggregates (Europe only)
B. Barytes, Bauxite, Bentonite, Beryl, Bismuth, Borates, Bromine
C. Cadmium, Chromium, Coal, Cobalt, Copper, Cement (Europe only)
D. Diamond, Diatomite
F. Feldspar, Ferro alloys, Fluorspar, Fuller's earth
G. Gallium, Germanium, Gold, Graphite, Gypsum
I. Indium, Iodine, Iron ore, Iron and steel
K. Kaolin
L. Lead, Lithium
M. Magnesite, Magnesium, Manganese, Mercury, Mica, Molybdenum
N. Natural gas, Natural sodium carbonate, Nepheline syenite, Nickel, Niobium
P. Perlite, Petroleum, Phosphates, Platinum, Potash, Pyrites
R. Rare earths, Rhenium
S. Salt, Selenium, Silicon, Sillimanite, Silver, Strontium, Sulphur
T. Talc, Tantalum, Tellurium, Tin, Titanium, Tungsten
U. Uranium
V. Vanadium, Vermiculite
W. Wollastonite
Z. Zinc, Zirconium

(Brown *et al.*, 2019)

The metals are often reported as metal content, for aluminium, cobalt, copper, iron, lead, nickel, tin, and zinc both ore and metal production are indicated separately. This can either be the calculated metal content of a concentrate, or in other cases the content is calculated using gross weight of ore and a grade estimate according to commodity, deposit and/or country. As an example, the table for mine production of antimony reported as metal content is shown in Figure 2.

Mine production of antimony tonnes (metal content)

Country	2013	2014	2015	2016	2017
Russia	* 6 520	* 6 400	7 420	6 620	6 120
Turkey	4 512	3 013	1 917	2 700	4 750
South Africa	2 332	816	400	* —	* —
Canada	177	5	1	0	0
Guatemala	159	—	—	25	—
Honduras	—	13	14	—	—
Mexico	294	266	90	166	240
Bolivia	5 053	4 186	3 843	2 669	2 844
Ecuador	—	—	—	—	579
Burma (a)	* 7 000	4 234	5 777	2 780	3 060
China	152 104	140 389	120 732	107 535	* 101 000
Iran	400	432	1 020	1 765	* 1 800
Kazakhstan	* 900	* 800	* 700	* 900	* 200
Kyrgyzstan	* 900	* 1 450	* 1 200	* 1 880	* 1 100
Laos	804	620	1 166	242	320
Pakistan (b)	89	127	114	21	15
Tajikistan	7 307	* 7 000	* 6 800	* 12 700	* 12 500
Thailand	488	706	* 700	32	—
Vietnam	990	1 098	219	229	243
Australia (b)	3 062	3 680	3 926	5 004	4 294
World total	193 000	175 000	156 000	145 000	139 000

Note(s)
(1) This table includes antimony content of antimonial lead alloys.

(a) Years ended 31 March following that stated
(b) Years ended 30 June of that stated

Figure 2: Mine production of antimony in tonnes (metal content) (Brown *et al.*, 2019)

BGS also provides regional publications, for example for Europe, Africa, China and South East Asia. The European Mineral Statistics include additional statistics on import and export, and information on European mineral production as percentage of world production. For some minerals, for example Coal and Lithium, Mineral Profiles are published, including information on mineralogy, deposits, extraction, processing methods, and uses.

All publications can be downloaded from BGS homepage as PDF-files and additionally production, export and import data from 1970-2017 can be downloaded as Excel-files in steps of 10 years maximum.

Considering data collection, BGS uses various methods. As a first step questionnaires are sent out individualised for each country contacted. Moreover, internet research is conducted, consulting websites of government organisations and companies and also other publications are consulted. Previously, BGS was supported by UK Embassies providing data of their country, but this is not very common anymore.

(Information on data collection and reporting kindly provided by Mrs Teresa J. Brown, Mineral Commodity Geologist, BGS)

2.3 Minerals Yearbook

The Minerals Yearbook is a publication by United States Geological Survey (USGS). It consists of three volumes:

- Volume I: Metals and Minerals
- Volume II: Area Reports, Domestic
- Volume III: Area Reports, International

Volume I on metals and minerals includes individual reports for 90 commodities that are published annually. These reports include an extensive review of consumption, prices and trade with focus on the United States. They also include a world review analysing industry and world market structure, as well as an outlook considering future demand and applications.
Statistics given in Volume I again focus on the USA, providing imported and exported amounts, apparent consumption, and price development. Production figures document global production. (U.S. Geological Survey, 2019e)

Commodities reported in Volume I are:

A. Manufactured Abrasives (incl. Fused Aluminium Oxide, Corundum, Silicon), Aggregates (Construction Sand and Gravel, Crushed Stone), Bauxite and Alumina, Aluminium, Antimony, Arsenic, Asbestos
B. Barite, Bentonite (Clay Minerals) Beryllium, Bismuth, Boron, Bromine
C. Cadmium, Cement, Chromium, Clay Minerals (incl. Bentonite, Fuller's Earth, Kaolin), Cobalt, Niobium (Columbium), Copper, Crushed Stone (incl. Calcium Carbonate, Granite, Limestone, Marble, Sandstone, Slate, Traprock)
D. Diamond (industrial), Diatomite, Dimension Stone (incl. Granite, Limestone, Marble, Sandstone, Slate)
F. Feldspar (incl. Nepheline Syenite), Ferro-alloys, Fluorspar
G. Gallium, Garnet (industrial), Gemstones (incl. Shell), Germanium, Gold, Graphite, Gypsum
H. Hafnium Helium
I. Iodine, Iron Ore, Iron and Steel, Iron and Steel Scrap, Iron and Steel Slag, Iron Oxide Pigments
K. Kyanite and Related Minerals (incl. Synthetic Mullite)
L. Lead, Lime, Lithium
M. Magnesium, Magnesium Compounds, Manganese, Mercury, Mica, Molybdenum
N. Nickel, Niobium, Nitrogen
P. Peat, Perlite, Phosphate Rock, Platinum-Group-Metals (Iridium, Osmium, Palladium, Rhodium, Ruthenium), Potash, Pumice and Pummicite
R. Rare Earths (incl. Yttrium), Rhenium
S. Salt, Construction Sand and Gravel, Selenium, Silica (incl. Quartz Crystal, Industrial Sand and Gravel, Tripoli), Silicon, Silver, Soda Ash, Strontium, Sulfur
T. Talc (incl. Pyrophyllite), Tantalum, Tellurium, Thorium, Tin, Titanium (incl. Ilmenite, Rutil), Tungsten
V. Vanadium, Vermiculite
W. Wollastonite
Z. Zeolites, Zinc, Zirconium

(U.S. Geological Survey, 2019a)

However, there are exceptions; some of the 90 commodities are only reported for the USA:
Manufactured Abrasives, Construction Sand and Gravel, Crushed Stone, Dimension Stone, Industrial Garnet, Helium, Iron and Steel Scrap, Iron and Steel Slag, Wollastonite (no production or trade figures at all), Zeolites

USGS usually reports metal content to enable a comparison between mines, plants, and facilities at various stages of the supply chain. The value reported is adapted to industry standards.
The main method of data collection is via survey forms, a Mineral Questionnaire, developed for each country according to its current mineral industry.

Volume II focuses on statistical data and information for the United States on a State-by-State basis and is therefore not relevant for this analysis.

Volume III indicates mineral production, trade, policy and industry developments for 175 countries. It is possible that Volume I and Volume III provide different production figures for one commodity. This depends on the different methods of data collection and different sources used by the respective specialist. However, lately USGS is trying to reconcile the numbers internally and agree on one value in order to avoid discrepancies (this is not valid for historical data).

The Minerals Yearbook is published with a delay of three to four years. At the time of this assessment the most current data available was from 2015 or 2016 depending on the commodity. It has a longstanding history with the first volume published in 1932. There is also historic data available for some commodities dating back until 1900.

More recent data is published in the so-called Mineral Commodity Summaries that are already available for 2018. This publication focuses on the US industry and market and is not as extensive as the Minerals Yearbook. It covers 90 minerals and materials providing domestic production and use, imports and exports, prices, stocks, recycling and substitutes, notable events, trends, and issues, as well as some details on world production, resources, and reserves.
(U.S. Geological Survey, 2019a, 2019b, 2019c, 2019d, 2019e)

All publications are available online, on the USGS website.

(Information on data collection and reporting kindly provided by Mr Michael Magyar, USGS)

2.4 Eurostat

Eurostat records economy-wide material flow accounts (EW-MFA) with the purpose of providing information on the interaction of national economy with the natural environment and with global economy. Data collection for these accounts started in 2017 including material inputs to national economies (domestic extraction, physical imports, balancing items), and material output from national economies (domestic processed output, physical exports, balancing items).

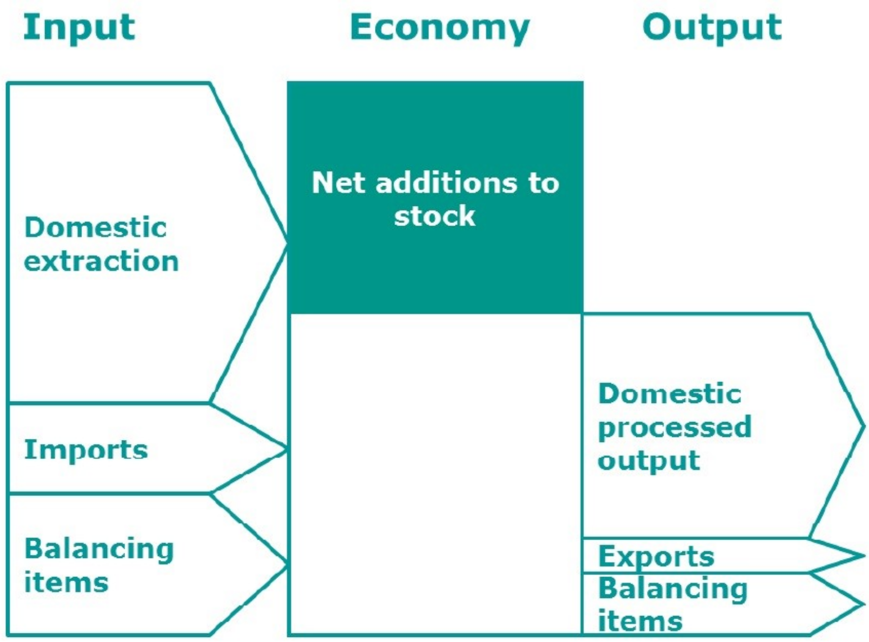

Figure 3: Main material flows of an economy (Eurostat, 2018)

Flows inside one economy (that do not cross borders) are not recorded in MFA.

The EW-MFA reports a number of different material groups:

- Biomass
    - Crops
        - Cereals; Roots, tubers; Sugar crops; Pulses; Nuts; Oil-bearing crops; Vegetables; Fruits; Fibres; Other crops (excluding fodder crops n.e.c.)
        - Crop residues (used), fodder crops and grazed biomass
    - Wood
    - Wild fish catch, aquatic plants and animals, hunting and gathering
    - Live animals and animal products (excluding wild fish, aquatic plants and animals, hunted and gathered animals)
    - Products mainly from biomass
- Metal ores (gross ores)
    - Iron
    - Non-ferrous metal: Copper; Nickel; Lead; Zinc; Tin; Gold, silver, platinum and other precious metals; Bauxite and other aluminium; Uranium and thorium; Other non-ferrous metals
    - Products mainly from metals
- Non-metallic minerals
    - Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)
    - Chalk and dolomite
    - Slate
    - Chemical and fertiliser minerals
    - Salt
    - Limestone and gypsum
    - Clays and kaolin
    - Sand and gravel
    - Other non-metallic minerals n.e.c.
    - Excavated earthen materials (including soil), only if used (optional reporting)
    - Products mainly from non-metallic minerals

- Fossil energy materials/carriers
    - Coal and other solid energy materials/carriers
    - Liquid and gaseous energy materials/carriers
    - Products mainly from fossil energy products
- Other products
- Waste for final treatment and disposal
- Domestic processed output
    - Emissions to air
    - Waste disposal to the environment
    - Emissions to water
    - Dissipative use of products
    - Dissipative losses
- Balancing items: net output (= Balancing item: output side – Balancing item: input side)

(Eurostat, 2019a)

Relevant for this assessment is the domestic extraction of metals and minerals. Here the "run-of-mine" concept is applied, reporting extraction of ores rather than metal content. It is measured before any separation or concentration excluding any materials not containing wanted metals or minerals. If available, gross ores reported by the mine operator are used. Otherwise run-of-mine amounts have to be calculated using conversion factors. National and international statistics tend to report metal content or concentrates, and these values are converted to gross ores by multiplying them with a factor determined according to commodity and mine, country, and year. In case specific data is not available a general conversion factor has to be used. These general factors are based on annual business reports of mines calculated for each metal individually. An issue requiring special attention is ore containing more than one metal in order to avoid double counting. (Eurostat, 2018)

Eurostat collects data from three different sources: 1) National statistical institutes using digital questionnaires which are mandatory since 2013. 2) EU-wide harmonised sources of statistical data, and 3) data provided by international sources such as UN Food and Agricultural Organisation (FAO), BGS, and USGS. (Eurostat, 2018)

Figure 4 shows all tables covered in the questionnaires.

Questionnaire's tables	2000	2001	...	2016	2017
Table A* MF.1 Biomass MF.2 Metal ores MF.3 Non-metallic minerals MF.4 Fossil energy materials/carriers	**Domestic extraction**				
Tables B* and D* MF.1 Biomass (with additional material classes for animal and biomass products) MF.2 Metal ores (with additional material class for metal products) MF.3 Non-metallic minerals (with additional material class for products mainly from non-metallic minerals) MF.4 Fossil energy materials/carriers (with additional material class for products mainly from fossil energy material) MF.5 Other products MF.6 Waste traded for final treatment and disposal	**Physical imports and exports**				
Table F MF.7.1 Emissions to air MF.7.2 Waste disposal MF.7.3 Emissions to water MF.7.4 Dissipative use of products MF.7.5 Dissipative losses	**Domestic processed output**				
Table G MF.8.1 Balancing items: input side MF.8.2 Balancing items: output side	**Balancing items**				
Table H DE - Domestic extraction IMP - Imports EXP - Exports DMI - Direct material input DMC - Domestic material consumption PTB - Physical trade balance DPO - Domestic processed output NAS - Net additions to stock	**EW-MFA derived indicators**				
Table I DE - Domestic extraction IMP_RME - Imports in RME RMI - Raw material input EXP_RME - Exports in RME RMC - Raw material consumption	**MFA in raw material equivalents**				

** These tables record mandatory data according to Regulation (EU) No 691/2011*

Figure 4: Exemple questionnaire used by Eurostat (Eurostat, 2018)

Table A is viewed in more detail in Figure 5.

Figure 5: Table A - Domestic Extraction (Eurostat, 2019b)

So-called MEMO items visible in Figure 5 are items that can be reported voluntarily for information purposes only.

Eurostat provides an online data explorer, where the required material, the environmental indicator (domestic extraction, imports, exports, domestic material consumption, direct material inputs, physical trade balance), year, unit of measure, and country can be selected. Countries reported include all EU member states, as well as Norway, Switzerland, North Macedonia, Albania, Serbia, Turkey, and Bosnia and Herzegovina.
(Eurostat, 2018, 2019b)

2.5 Comparison

This chapter will provide a comparison and an overview of advantages and possible disadvantages of the different data providers.

Table 1: Comparison advantages & disadvantages of WMD, BGS, USGS

World Mining Data (Austrian Ministry)	**World Mineral Production (BGS)**	**Minerals Yearbook (USGS)**	**MFA (Eurostat)**
Advantages	***Advantages***	***Advantages***	***Advantages***
	Long history, data from 1913 onward	Long history, yearbook from 1932 onward (additional historical data from 1900)	
Groupings according to development status, regional groups, economic blocks, and political stability	(Some additional information in European Mineral Statistics and Mineral Profiles, not in World Mineral Production)	A lot of additional information on commodities (use, consumption, etc.)	Different data then other providers (ores rather than content)
Share of world mineral production by countries, incl. Herfindahl-Hirschman Index (HHI)		(Commodity Summaries are only provider of information on global resources/reserves)	Data on consumption, imports, exports

World Mining Data (Austrian Ministry)	World Mineral Production (BGS)	Minerals Yearbook (USGS)	MFA (Eurostat)
Advantages	***Advantages***	***Advantages***	***Advantages***
Graphs providing an overview on distribution of RM production, key commodities (e.g. battery RM)			Easy to use database with a lot of different settings
Pdf and Excel-files publicly available	Pdf and Excel-files publicly available	Pdf and Excel-files publicly available	Data publicly available, can be downloaded as Excel-files
	Provide information on form of raw material production (e.g. sulphur from pyrites, by-product, etc.)	Provide information on form of raw material production (e.g. sulphur from pyrites, by-product, etc.)	Very current data (one-year delay, newest data from 2018)
Supported by World Mining Congress		Most manpower employed	
Clear indication of estimated figures	Clear indication of estimated figures	Clear indication of estimated figures	Clear indication of estimated figures
Sources of data are clearly stated			

World Mining Data (Austrian Ministry)	**World Mineral Production (BGS)**	**Minerals Yearbook (USGS)**	**MFA (Eurostat)**
Disadvantages	***Disadvantages***	***Disadvantages***	***Disadvantages***
Shortest period of available data (compared to BGS and USGS)	No additional information on global level	Separate Pdf/Excel-file for every commodity	Very aggregated
No additional information on raw materials	Pdf-files are highly protected (e.g. copying not possible), makes it hard to work with	Published with a long delay	Only for Europe
		Additional information focused on USA	No additional information on raw materials
			Metal production data not comparable to international data (ores)
			Many figures are not reported because they are marked as confidential

The global data providers, World Mining Data (Federal Ministry Republic of Austria Sustainability and Tourism), World Mineral Production (British Geological Survey), and Minerals Yearbook (United States Geological Survey) are very similar considering the actual figures they report. For many metals they have established an annual meeting to discuss sources and numbers together with different study groups. Usually, all three report metal content and only in some cases ores. For instance, WMD, BGS, and USGS report both Aluminium and Bauxite. BGS and USGS additionally provide information on alumina (Al_2O_3).

In the following two tables the commodities reported are compared in more detail. Table 2 lists all commodities reported by the four data providers (WMD, BGS, USGS, and Eurostat) allowing a comparison of commodities reported and the unit (metal content, ore) this is done in. Table 3 shows a detailed comparison of actual production figures reported by all four data providers for the European Union (EU-28) only, in order to allow a comparison with Eurostat data. However, it must not be forgotten that Eurostat reports ores rather than metal content.

Table 2: Comparison of reported commodities for WMD, BGS, USGS, Eurostat

WMD			BGS			USGS			Eurostat		
Commodity		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**
Iron	Fe	metr.t	Iron ore		metr.t	Iron ore	gross and iron ore content	metr.t	Iron	ore	metr.t
			Iron and steel	pig iron	metr.t	Iron and Steel	pig iron	metr.t			
				crude steel	metr.t		direct-reduced iron	metr.t			
							raw steel	metr.t			
			Ferro alloys	ferro-chrome, -molybdenum, -nickel, -vanadium, -manganese, -silico-manganese, -silicon, Silicon metal, -silico-chrome, -titanium, other ferro-alloys	metr.t	Ferroalloys	ferro-chromium, -molybdenum, -nickel, -vanadium, -manganese, -silicomanganese, -silicon, -niobium, Silicomanganese, -chromium silicon, -titanium, Spiegeleisen, other (Blast furnace, electric furnace)	metr.t			
			Silicon			Silicon metal		metr.t			
						Iron oxide pigments	w/o USA	metr.t			
Chromium	Cr2O3	metr.t	Chromium	ores and concentrates	metr.t	Chromite		metr.t			
						Ferrochromium		metr.t			
Cobalt	Co	metr.t	Cobalt	metal content	metr.t	Cobalt	cobalt content, mine	metr.t			
				refined	metr.t		cobalt content, refined	metr.t			
Manganese	Mn	metr.t	Mangan	ore	metr.t	Manganese	ore and Mn content	metr.t			
Molybdenum	Mo	metr.t	Molybdenum	metal content	metr.t	Molybdenum	mine, Molybdenum content	metr.t			
Nickel	Ni	metr.t	Nickel	metal content	metr.t	Nickel	mine, Ni content		Nickel		
				smelter/refinery	metr.t						
Niobium	Nb2O5	metr.t	Niobium	Tantalum and Niobium minerals	metr.t	Niobium	concentrate, Nb content	kg			
						Ferroniobium	Nb content	metr.t			
Tantalum	Ta2O5	metr.t	Tantalum			Tantalum	concentrate, Ta content	metr.t			
Titanium	TiO2	metr.t	Titanium	Titanium minerals	metr.t	Ilmenite and leucoxene		metr.t			
						Rutile		metr.t			
						Titaniferous slag		metr.t			
Tungsten	W	metr.t	Tungsten	metal content	metr.t	Tungsten	concentrate, tungsten content	metr.t			
Vanadium	V2O5	metr.t	Vanadium	metal content	metr.t	Vanadium	ore, concentrate, slag; Vanadium content	metr.t			
Aluminium	Al, smelter prod.	metr.t	Aluminium	primary	metr.t	Aluminum		metr.t	Bauxite and other aluminium		
			Alumina	Al2O3	metr.t	Alumina		metr.t			
Antimony	Sb	metr.t	Antimony	metal content	metr.t	Antimony	metal content	metr.t			
Arsenic	As2O3	metr.t	Arsenic	white arsenic	metr.t	Arsenic	Arsenic Trioxide	metr.t			
Bauxite	crude ore	metr.t	Bauxite		metr.t	Bauxite		metr.t			
Bismuth	Bi	metr.t	Bismuth	metal content	metr.t	Bismuth	refined	metr.t			
Cadmium	Cd, smelter prod.	metr.t	Cadmium	primary (and secondary for some countries)	metr.t	Cadmium	refined	metr.t			

WMD			BGS			USGS			Eurostat		
Commodity		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**
Copper	Cu	metr.t	Copper	metal content	metr.t	Copper	mine production, copper content	metr.t	Copper		
				smelter	metr.t		smelter, primary and secondary	metr.t			
				refined	metr.t		refined, primary and secondary	metr.t			
Gallium	Ga	metr.t	Gallium	primary	metr.t	Gallium	low-grade primary world production	kg			
Germanium	Ge	metr.t	Germanium	primary (and secondary for some countries)	metr.t	Germanium		kg			
Lead	Pb	metr.t	Lead	metal content	metr.t	Lead	mine, lead content	metr.t	Lead		
				refined	metr.t		refinery, primary and secondary, lead content	metr.t			
Lithium	Li2O	metr.t	Lithium	Li content	metr.t	Lithium	Li content; mineral concentrate, li carbonate, li chloride, li hydroxide	metr.t			
Mercury	Hg	metr.t	Mercury		kg	Mercury	mine	metr.t			
Rare Earths	REO	metr.t	Rare Earths	REO	metr.t	Rare Earths	rare-earth osice equivalent	metr.t			
Rhenium	Re	kg	Rhenium		metr.t	Rhenium		kg			
Selenium	Se	metr.t	Selenium	refined	metr.t	Selenium	refined, Se content, w/o USA	kg			
Tellurium	Te	metr.t	Tellurium	refined	metr.t	Tellurium	refined, Te content, w/o USA	kg			
Tin	Sn	metr.t	Tin	metal content	metr.t	Tin	mine, tin content	metr.t	Tin		metr.t
				smelter	metr.t		smelter, primary and secondary, tin content	metr.t			
Zinc	Zn	metr.t	Zinc	metal content	metr.t	Zinc	mine, Zn content	metr.t	Zinc		
				slab zinc	metr.t		smelter, primary and secondary, Zn content	metr.t			
Gold	Au	kg	Gold		kg	Gold	metal content	kg	Gold, Silver, Platin and other precious metals		
Palladium	Pd	kg				Platinum	metal content	kg			
Platinum	Pt	kg	Platinum	Platinum group metals, metal content	kg	Palladium	metal content	kg			
Rhodium	Rh	kg				Other Platinum-Group Metals	metal content	kg			
Silver	Ag	kg	Silver	metal content	kg	Silver	mine	metr.t			
Asbestos		metr.t	Asbestos		metr.t	Asbestos		metr.t			
Baryte		metr.t	Barytes		metr.t	Barite		metr.t			
Bentonite		metr.t	Bentonite	Bentonite and Fuller's earth	metr.t	Bentonite		metr.t			
			Fuller's earth			Fuller's earth		metr.t			
Boron		metr.t	Borates		metr.t	Boron minerals		metr.t			

WMD			BGS			USGS			Eurostat		
Commodity		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**
Diam. (Gem)		carats	Diamond		carats	Diamond	gemstone	carats			
Diam. (Ind)		carats					industrial (synthetic and natural)	carats			
Diatomite		metr.t	Diatomite		metr.t	Diatomite		metr.t			
Feldspar		metr.t	Feldspar		metr.t	Feldspar		metr.t			
Fluorspar		metr.t	Fluorspar		metr.t	Fluorspar		metr.t			
Graphite		metr.t	Graphite		metr.t	Graphite	natural	metr.t			
Gypsum		metr.t	Gypsum		metr.t	Gypsum		metr.t	Limestone and gypsum		
Kaolin		metr.t	Kaolin		metr.t	Kaolin		metr.t	Clays and kaolin		
Magnesite		metr.t	Magnesite		metr.t	Magnesite		metr.t			
			Magnesium	primary magnesium metal	metr.t						
Perlite		metr.t	Perlite		metr.t	Perlite		metr.t			
Phosphates	P2O5	metr.t	Phosphates	Phosphate rock	metr.t	Phosphate rock		metr.t			
Potash	K2O	metr.t	Potash	K2O	metr.t	Potash	K2O equivalent	metr.t			
Salt		metr.t	Salt		metr.t	Salt		metr.t	Salt		metr.t
Sulfur		metr.t	Sulphur	Sulphur and Pyrites, Sulphur content	metr.t	Sulfur	all forms, incl. Pyrite	metr.t			
			Pyrites		metr.t						
Talc		metr.t	Talc		metr.t	Talc	Talc and Pyrophyllite	metr.t			
Vermiculite		metr.t	Vermiculite		metr.t	Vermiculite		metr.t			
Zircon	conc.	metr.t	Zirconium	Zirconium minerals	metr.t	Zirconium	concentrates	metr.t			
Steam Coal		metr.t	Coal	Bituminous, Subbitminous, Lignite, Brown coal, Anthracite)					Hard coal		
Coking Coal		metr.t									
Lignite		metr.t							Lignite		
Nat. Gas		Mio m3	Natural Gas		Mio m3				Natural gas		
Oilsands	crude	metr.t							Oil shale and tar sands		
Oil shales		metr.t									
Petroleum	crude	metr.t	Petrolium	crude	metr.t				Crude oil, condensate and natural gas liquids (NGL)		
Uranium	U3O8	metr.t	Uranium	metal content	metr.t				Uranium and Thorium		

WMD			BGS			USGS			Eurostat		
Commodity		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**	**Commodity**		**Unit**
			Beryl		metr.t	Beryllium	Beryllium content (estimated based on 4% Be content)	metr.t			
			Bromine		kg	Bromine		metr.t			
			Indium	refinery	metr.t	Indium	primary	kg			
			Iodine		kg	Iodine	w/o USA	metr.t			
			Mica		metr.t	Mica	estimated	metr.t			
			Natural sodium carbonate		metr.t	Soda ash		metr.t			
			Nepheline Syenite		metr.t						
			Sillimanite	Sillimanite minerals	metr.t	Kyanite and related minerals	Kyanite, Sillimanite, Andalusite	metr.t			
			Strontium		metr.t	Strontium	Celestite	metr.t			
			Wollastonite		metr.t						
			Cement clinker	Europe only	metr.t						
			Finished cement	Europe only	metr.t	Hydraulic Cement	estimated	metr.t			
						Garnet	crude	metr.t			
						Lime		metr.t			
						Ammonia	N content	metr.t			
						Peat		metr.t	Peat		
						Pumice and related materials		metr.t			
						Silica		metr.t			
						Thorium	Monazite	metr.t			
						Zeolites	estimated	metr.t			
									Other non-ferrous metals		
									Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)		
									Chalk and dolomite		
									slate		
									chemical and fertiliser minerals		
			Primary Aggregates	Europe only, sand, gravel, crushed rock	metr.t				Sand and gravel		
									other non-metallic minerals		

Comparison of Production Data for the European Union

Table 3: Comparison of production figures for EU-28 between WMD, BGS, USGS, Eurostat

Iron	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	18,558,536	14,594,291	16,592,307	15,053,288	15,479,383	13,400,338	11,740,005	11,231,784	14,714,412	13,501,798	14,507,494	13,697,919	14,180,977	15,031,087
BGS pig iron	128,742,660	116,995,582	111,229,249	112,009,931	119,389,558	120,267,978	112,828,028	120,005,410	117,076,782	110,037,566	115,266,150	108,957,489	110,000,099	113,479,582
BGS iron ore	38,349,087	35,783,242	34,846,994	30,667,817	30,903,437	31,492,104	30,769,608	28,680,614	28,377,463	25,334,074	27,716,035	25,490,724	26,411,750	28,398,128
USGS iron content	19,811,000	17,387,000	14,799,000	15,771,000	16,359,000	15,861,000	17,088,000	15,277,000	14,136,700	13,123,000	15,666,000	14,399,000	14,940,443	15,982,423
USGS iron ore	41,089,000	38,713,000	33,253,414	29,998,000	30,251,000	26,468,000	29,296,000	26,123,000	25,026,000	23,585,000	25,486,000	24,398,502	25,080,371	27,262,170
Eurostat	:	:	:	:	:	:	:	:	:	:	:	:	:	:

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	15,284,267	15,838,075	15,871,506	16,755,051	16,119,985	11,992,162	16,889,900	17,469,881	17,718,112	18,265,763	18,882,476	16,849,285	18,179,223
BGS pig iron	116,801,908	112,586,378	115,883,101	117,409,950	108,237,879	72,684,597	94,498,239	94,293,465	91,359,874	92,418,115	95,762,459	93,565,286	91,320,079
BGS iron ore	29,055,225	30,243,198	29,744,021	31,004,993	31,826,916	23,011,830	31,256,206	33,536,001	34,787,770	40,147,727	38,656,757	33,112,017	35,134,264
USGS iron content	16,278,631	16,539,229	16,536,138	17,523,200	18,044,245	13,481,870	19,773,987	18,800,355	17,034,200	16,530,200	16,774,000	16,152,000	17,537,000
USGS iron ore	27,126,657	28,023,056	28,028,996	48,779,010	32,106,671	24,268,830	33,471,353	31,063,091	31,112,000	30,308,000	30,454,000	29,547,000	31,889,000
Eurostat	:	:	:	:	:	23,015,856	31,259,555	33,536,018	34,791,387	:	:	:	:

Nickel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	34,128	29,930	26,520	20,575	23,382	21,555	21,701	20,909	17,000	14,762	21,126	21,875	24,029	21,529
BGS	27,412	29,632	27,311	21,802	26,473	24,329	24,430	24,248	20,511	17,286	27,665	24,442	26,200	22,500
USGS	30,872	29,200	27,311	21,802	26,473	23,386	23,736	21,671	18,952	16,120	22,882	23,430	25,790	25,050
Eurostat	:	:	:	:	:	:	:	:	:	:	3,010,440	2,739,124	2,962,533	3,385,480

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	23,416	32,406	28,245	29,505	31,506	19,751	36,242	41,454	42,620	46,684	50,153	38,491	43,454
BGS	22,951	29,586	31,501	29,256	29,136	18,964	35,066	40,794	42,911	46,504	49,292	38,236	43,224
USGS	25,400	31,982	31,053	31,427	70,125	22,638	34,741	40,510	43,968	46,114	48,766	36,206	40,085
Eurostat	3,352,031	4,079,423	3,743,632	3,953,674	5,391,457	9,285,647	13,594,014	11,691,225	1,243,683	23,682,244	8,011,396	9,651,277	19,123,959

Copper	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	664,501	675,606	666,702	728,496	705,497	732,739	763,990	758,069	777,704	769,006	757,945	776,893	775,161	797,063
BGS	708,164	723,317	672,759	727,937	708,360	733,017	759,926	757,352	779,411	761,155	758,968	773,519	775,089	797,292
USGS	660,300	657,270	667,783	729,400	709,304	735,088	765,774	774,706	782,278	764,073	759,007	766,945	786,084	811,765
Eurostat	:	:	:	:	:	:	:	:	:	:	:	:	:	:

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	826,476	838,149	820,940	709,879	754,690	734,913	762,487	803,023	830,925	856,310	850,039	878,146	931,386
BGS	825,671	839,588	820,741	746,315	714,328	729,679	766,348	796,475	837,385	858,002	841,410	855,702	911,471
USGS	848,298	829,326	804,524	737,714	706,617	725,880	753,921	772,746	798,271	809,067	807,990	818,620	
Eurostat	:	:	:	70,250,345	69,032,113	72,143,502	79,906,866	:	:	:	:	:	:

Lead	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	367,163	351,130	336,794	320,496	337,178	327,447	298,496	314,735	300,452	305,508	319,730	286,363	204,433	198,748
BGS	387,157	365,893	340,980	325,592	333,545	321,324	301,683	310,660	303,445	305,826	319,761	286,912	217,925	231,224
USGS	378,850	364,164	344,316	326,885	347,384	350,908	294,682	311,788	298,202	325,315	306,394	286,951	207,707	250,212
Eurostat	:	:	:	:	:	:	:	:	:	:	4,744,436	3,886,220	2,957,347	2,954,666

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	209,447	217,555	204,559	201,719	216,407	209,521	184,268	191,045	223,836	217,364	229,680	193,133	181,279
BGS	243,144	256,889	238,534	216,606	209,636	226,097	180,755	199,696	243,374	220,861	231,749	215,874	203,696
USGS	219,512	227,310	264,469	227,900	230,200	223,730	192,636	201,125	207,342	202,252	192,000	183,000	
Eurostat	2,818,054	2,714,695	2,769,984	:	2,645,320	2,112,257	:	:	:	:	:	:	:

Tin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	7,158	5,467	5,062	7,568	6,237	6,629	6,739	5,970	3,363	2,270	1,228	2,163	361	222
BGS	6,961	5,488	5,055	7,566	6,252	6,599	6,740	5,962	3,406	2,163	1,246	1,201	345	203
USGS	10,607	10,804	8,611	7,568	6,258	6,602	6,742	5,065	3,478	2,202	1,230	1,176	574	465
Eurostat	:	:	:	:	:	:	:	:	:	:	730,245	672,529	210,059	135,005

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	225	232	25	41	49	34	22	48	110	84	75	58	206
BGS	200	243	25	41	29	34	22	48	111	84	75	42	221
USGS	451	243	25	41	29	34	22	39	42	84	75	42	45
Eurostat	152,004	171,045	43,141	42,142	40,299	46,241	34,479	36,981	38,355	35,152	31,515	17,576	22,727

Zinc	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	1,050,762	1,020,821	930,384	837,312	782,179	795,240	727,757	766,970	738,628	763,715	871,083	857,616	754,046	853,810
BGS	1,074,106	1,076,734	921,630	835,369	780,096	793,248	725,107	763,618	737,200	758,189	869,534	864,925	750,858	851,182
USGS	1,049,370	1,042,052	927,816	834,161	772,558	787,732	729,226	789,532	745,811	741,555	881,813	808,908	727,526	856,765
Eurostat	:	:	:	:	:	:	:	:	:	:	:	:	:	:

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	847,400	867,243	845,807	844,917	821,269	760,211	748,510	764,864	758,571	743,828	753,963	722,336	698,141
BGS	849,214	875,850	845,794	844,358	821,320	760,529	764,280	767,840	754,815	741,857	739,108	704,451	687,367
USGS	851,941	808,908	843,556	841,103	818,954	751,907	721,109	733,338	726,114	720,498	745,573	702,594	675,714
Eurostat	:	:	:	:	:	8,916,807	11,683,071	10,771,425	10,582,934	12,123,351	9,224,075	12,178,355	12,838,771

Salt	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WMD	52,674,263	48,166,690	44,130,376	44,238,668	45,494,922	50,367,921	50,816,812	52,573,788	47,486,195	49,717,275	49,580,879	48,738,824	48,053,797	48,385,378
BGS	48,351,092	43,557,398	41,672,208	41,237,675	46,010,755	49,674,854	51,739,105	49,336,747	48,050,155	48,867,016	47,560,485	49,132,746	48,948,685	50,453,727
USGS	50,835,000	50,965,000	45,716,000	46,152,000	50,092,000	52,860,000	53,756,000	51,965,000	52,505,000	47,294,000	34,185,572	48,636,585	49,847,497	52,563,265
Eurostat	:	:	:	:	:	:	:	:	:	:	:	:	:	:

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WMD	52,705,920	54,380,666	54,970,866	49,920,723	50,536,952	53,847,115	57,617,135	55,164,611	51,703,803	55,847,279	50,507,719	50,268,164	50,153,118
BGS	52,893,344	55,161,253	57,474,363	50,786,214	52,581,580	53,146,688	57,522,208	58,066,262	56,133,649	57,253,637	47,246,263	50,740,661	49,759,232
USGS	55,456,903	56,553,521	58,028,988	52,525,582	45,047,434	48,645,437	51,650,855	47,979,457	44,626,187	48,778,000	41,121,000	41,038,000	40,534,000
Eurostat	:	61,621,762	:	:	55,328,553	54,070,125	54,747,241	:	49,393,445	54,842,749	47,298,268	48,421,447	47,237,717

Hydraulic Cement	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
BGS	2,374,200	2,393,900	13,294,300	13,137,900	14,470,500	14,350,300	14,672,000	14,910,000	201,267,858	227,571,887	233,222,547	228,176,121	227,365,606	233,830,813
USGS	233,356,000	215,215,000	215,309,000	204,284,000	211,039,000	209,677,000	207,319,000	218,170,000	226,684,000	231,202,000	235,191,000	230,228,000	229,573,000	236,529,763

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BGS	236,537,563	248,517,382	264,548,495	268,408,120	250,753,408	199,171,192	193,104,287	196,439,231	176,176,339	166,786,192	168,650,257	165,296,334	167,732,834
USGS	244,968,068	246,797,679	270,228,659	282,810,817	256,815,000	199,491,000	190,646,000	192,904,000	170,002,000	165,119,000	166,126,000	169,953,000	168,403,000

Sand and Gravel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
BGS	0	0	98,912,000	100,017,000	109,419,000	101,732,000	93,947,000	98,383,000	1,128,257,905	1,345,525,918	1,283,223,513	1,307,543,059
Eurostat	:	:	:	:	:	:	:	:	:	:	2,475,155,646	2,486,034,488

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
BGS	1,273,294,310	1,278,857,979	1,424,319,638	1,456,689,616	1,514,818,664	1,518,128,347	1,482,074,554	1,277,865,282	1,177,969,757	1,210,285,288	1,066,611,584	1,034,575,262
Eurostat	2,376,108,177	2,352,946,685	2,391,109,155	2,502,707,725	2,626,227,552	2,770,542,982	2,680,518,968	2,320,185,983	2,158,056,464	2,326,514,105	2,078,394,573	1,975,698,616

	2014	2015	2016
BGS	1,024,434,671	1,058,641,303	1,078,969,912
Eurostat	1,988,369,022	2,068,326,480	2,084,080,567

As the comparison of the four data providers in Table 2 demonstrates the difference between the three international collections (WMD, BGS, USGS) is minor. BGS and USGS provide additional data in some cases, for example iron, where they also report iron ore, pig iron, steel, etc. However, BGS does not report iron content. WMD focuses on the content or the form traded on the world market (e.g. Arsenic as diarsenic trioxide As_2O_3) for maximum comparability. USGS does not provide any data on energy raw materials in the Minerals Yearbook, for that they have a separate collection. Eurostat on the other hand does not report as many commodities, and in some cases, they are very aggregated, for example Gold, silver, platinum and other precious metals.

In terms of reported figures Table 3 shows a comparison of certain commodities. Also, in this case it can be seen that WMD, BGS, and USGS are very similar. Minor differences are probably due to different sources. A comparison with Eurostat data is difficult, as they have major issues with the confidentiality of data. Many companies and countries report data as confidential, but they are already available in other collections. This is an issue Eurostat is working on and tries to resolve.
Moreover, Eurostat usually reports ores (run-of-mine) in contrast to the three other collections. However, if a general conversion factor (listed in (Eurostat, 2018) is applied, Eurostat figures can be compared to WMD, BGS, and USGS.

Example: Copper 2010

Copper	**2010**		
WMD	762,487		
BGS	766,348		
USGS	753,921		
Eurostat	79,906,866	*0.0104	831,031

The remaining deviation is likely due to the fact that not an exact conversion factor is applied, but only an estimation and generalisation for the copper content in ore.

An objective recommendation on which data source to use cannot be given following this evaluation, it truly depends on the intended purpose.
Considering the three global providers, BGS is preferable if long-term observations are conducted. USGS is very useful if additional information about the raw material is required, i.e. information on uses, deposits, prices, etc. WMD is very easy to use and provides ready-made comparisons of country groups and economic blocks, as well as concentration of production with the Herfindahl-Hirschman Index.
Eurostat MFA data on European level might not be useful for comparisons of metal production data, as it reports ores rather than metal content.
However, it offers an overview of material flows (incl. imports and exports) of European countries and can be a useful tool for sustainability considerations, if the confidentiality issues are resolved.
Moreover, Eurostat gives figures of aggregates, such as sand and gravel.

As a next step the countries covered by the three international data providers are compared. This comparison can be seen in Table 4. As a reference the list of independent states by the Bureau of Intelligence and Research of the U.S. Department of State is used. (Bureau of Intelligence and Research, 2019)
Written in red are countries not covered by a data collection, highlighted in yellow are additional (non-independent) countries separately covered by a collection, and highlighted in green are alternative or former names and country conglomerates.

Table 4: Comparison of countries covered by WMD, BGS, USGS
red…country not covered, yellow…additional (non-independent) country, green…alternative/former name of country

WMD	BGS	USGS
1. Afghanistan	1. Afghanistan	1. Afghanistan
2. Albania	2. Albania	2. Albania
3. Algeria	3. Algeria	3. Algeria
4. Andorra	4. Andorra	4. Andorra
5. Angola	5. Angola	5. Angola
6. Antigua and Barbuda	6. Antigua and Barbuda	6. Antigua and Barbuda
7. Argentina	7. Argentina	7. Argentina
8. Armenia	8. Armenia	8. Armenia
9. Australia	9. Australia	9. Australia
a. Christmas Island	a. Christmas Island	a. Christmas Island
10. Austria	10. Austria	10. Austria
11. Azerbaijan	11. Azerbaijan	11. Azerbaijan
12. Bahamas	12. Bahamas	12. Bahamas
13. Bahrain	13. Bahrain	13. Bahrain
14. Bangladesh	14. Bangladesh	14. Bangladesh
15. Barbados	15. Barbados	15. Barbados
16. Belarus	16. Belarus	16. Belarus
17. Belgium	17. Belgium	17. Belgium
18. Belize	18. Belize	18. Belize
19. Benin	19. Benin	19. Benin
20. Bhutan	20. Bhutan	20. Bhutan
21. Bolivia	21. Bolivia	21. Bolivia
22. Bosnia-Herzegovina	22. Bosnia and Herzegovina	22. Bosnia and Herzegovina
23. Botswana	23. Botswana	23. Botswana
24. Brazil	24. Brazil	24. Brazil
25. Brunei	25. Brunei	25. Brunei
26. Bulgaria	26. Bulgaria	26. Bulgaria
27. Burkina Faso	27. Burkina Faso	27. Burkina Faso
28. Myanmar	28. Burma	28. Burma
29. Burundi	29. Burundi	29. Burundi
30. Cape Verde (Cabo Verde)	30. Cape Verde (Cabo Verde)	30. Cabo Verde
31. Cambodia	31. Cambodia	31. Cambodia
32. Cameroon	32. Cameroon	32. Cameroon
33. Canada	33. Canada	33. Canada
34. Central African Republic	34. Central African Republic	34. Central African Republic
35. Chad	35. Chad	35. Chad
36. Chile	36. Chile	36. Chile

WMD	BGS	USGS
37. China a. Hong Kong b. Taiwan	37. China a. Taiwan	37. China a. Hong Kong b. Taiwan
38. Colombia	38. Colombia	38. Colombia
39. Comoros	39. Comoros	39. Comoros
40. Congo, D.R. a. Zaire	40. Congo, D.R.	40. Congo (Kinshasa)
41. Congo, Rep.	41. Congo	41. Congo (Brazzaville)
42. Costa Rica	42. Costa Rica	42. Costa Rica
43. Cote d'Ivoire	43. Ivory Coast	43. Cote d'Ivoire
44. Croatia	44. Croatia	44. Croatia
45. Cuba	45. Cuba	45. Cuba
46. Cyprus	46. Cyprus	46. Cyprus
47. Czech Republic a. Czecho-slovakia	47. Czech Republic	47. Czechia
48. Denmark a. Greenland	48. Denmark a. Greenland	48. Denmark a. Greenland
49. Djibouti	49. Djibouti	49. Djibouti
50. Dominica	50. Dominica	50. Dominica
51. Dominican Republic	51. Dominican Republic	51. Dominican Republic
52. Ecuador	52. Ecuador	52. Ecuador
53. Egypt	53. Egypt	53. Egypt
54. El Salvador	54. El Salvador	54. El Salvador
55. Equatorial Guinea	55. Equatorial Guinea	55. Equatorial Guinea
56. Eritrea	56. Eritrea	56. Eritrea
57. Estonia	57. Estonia	57. Estonia
58. Eswatini a. Swaziland	58. Swaziland	58. Swaziland
59. Ethiopia	59. Ethiopia	59. Ethiopia
60. Fiji	60. Fiji	60. Fiji
61. Finland	61. Finland	61. Finland
62. France a. French Guiana b. New Caledonia	62. France a. French Guiana b. New Caledonia	62. France a. French Guiana b. New Caledonia c. Guadeloupe d. Martinique e. Reunion
63. Gabon	63. Gabon	63. Gabon

WMD	BGS	USGS
64. Gambia, Rep. of The	64. Gambia, Rep. of The	64. Gambia
65. Georgia	65. Georgia	65. Georgia
66. Germany a. German Dem. Rep.	66. Germany	66. Germany
67. Ghana	67. Ghana	67. Ghana
68. Greece	68. Greece	68. Greece
69. Grenada	69. Grenada	69. Grenada
70. Guatemala	70. Guatemala	70. Guatemala
71. Guinea	71. Guinea	71. Guinea
72. Guinea-Bissau	72. Guinea-Bissau	72. Guinea-Bissau
73. Guyana	73. Guyana	73. Guyana
74. Haiti	74. Haiti	74. Haiti
75. Holy See	75. Holy See	75. Holy See
76. Honduras	76. Honduras	76. Honduras
77. Hungary	77. Hungary	77. Hungary
78. Iceland	78. Iceland	78. Iceland
79. India	79. India	79. India
80. Indonesia	80. Indonesia	80. Indonesia
81. Iran	81. Iran	81. Iran
82. Iraq	82. Iraq	82. Iraq
83. Ireland	83. Ireland, Rep.	83. Ireland
84. Israel	84. Israel	84. Israel
85. Italy	85. Italy	85. Italy
86. Jamaica	86. Jamaica	86. Jamaica
87. Japan	87. Japan	87. Japan
88. Jordan	88. Jordan	88. Jordan
89. Kazakhstan	89. Kazakhstan	89. Kazakhstan
90. Kenya	90. Kenya	90. Kenya
91. Kiribati	91. Kiribati	91. Kiribati
92. Korea, North	92. Korea, Dem. P.R.	92. Korea, North
93. Korea, South	93. Korea, Rep.	93. Korea, Rep. of
94. Kosovo	94. Kosovo	94. Kosovo
95. Kuwait	95. Kuwait	95. Kuwait
96. Kyrgyzstan	96. Kyrgystan	96. Kyrgyzstan
97. Laos	97. Laos	97. Laos
98. Latvia	98. Latvia	98. Latvia
99. Lebanon	99. Lebanon	99. Lebanon
100. Lesotho	100. Lesotho	100. Lesotho
101. Liberia	101. Liberia	101. Liberia
102. Libya	102. Libya	102. Libya
103. Liechtenstein	103. Liechtenstein	103. Liechtenstein
104. Lithuania	104. Lithuania	104. Lithuania
105. Luxembourg	105. Luxembourg	105. Luxembourg
106. Macedonia	106. Macedonia	106. Macedonia

WMD	BGS	USGS
107. Madagascar	107. Madagaskar	107. Madagascar
108. Malawi	108. Malawi	108. Malawi
109. Malaysia	109. Malaysia	109. Malaysia
110. Maldives	110. Maldives	110. Maldives
111. Mali	111. Mali	111. Mali
112. Malta	112. Malta	112. Malta
113. Marshall Islands	113. Marshall Islands	113. Marshall Islands
114. Mauritania	114. Mauritania	114. Mauritania
115. Mauritius	115. Mauritius	115. Mauritius
116. Mexico	116. Mexico	116. Mexico
117. Micronesia, Federated States of	117. Micronesia, Federated States of	117. Micronesia, Federated States of
118. Moldova	118. Moldova	118. Moldova
119. Monaco	119. Monaco	119. Monaco
120. Mongolia	120. Mongolia	120. Mongolia
121. Montenegro	121. Montenegro	121. Montenegro
122. Morocco	122. Morocco	122. Morocco a. Western Sahara
123. Mozambique	123. Mozambique	123. Mozambique
124. Namibia	124. Namibia	124. Namibia
125. Nauru	125. Nauru	125. Nauru
126. Nepal	126. Nepal	126. Nepal
127. Netherlands	127. Netherlands	127. Netherlands a. Netherlands Antilles b. Aruba c. Curaçao
128. New Zealand	128. New Zealand	128. New Zealand
129. Nicaragua	129. Nicaragua	129. Nicaragua
130. Niger	130. Niger	130. Niger
131. Nigeria	131. Nigeria	131. Nigeria
132. Norway	132. Norway	132. Norway
133. Oman	133. Oman	133. Oman
134. Pakistan	134. Pakistan	134. Pakistan
135. Palau	135. Palau	135. Palau
136. Panama	136. Panama	136. Panama
137. Papua New Guinea	137. Papua New Guinea	137. Papua New Guinea
138. Paraguay	138. Paraguay	138. Paraguay
139. Peru	139. Peru	139. Peru
140. Philippines	140. Philippines	140. Philippines
141. Poland	141. Poland	141. Poland

WMD	BGS	USGS
142. Portugal	142. Portugal	142. Portugal
143. Qatar	143. Qatar	143. Qatar
144. Romania	144. Romania	144. Romania
145. Russia a. Russia, Asia b. Russia, Europe c. USSR (Asia) d. USSR (Europe)	145. Russia	145. Russia
146. Rwanda	146. Rwanda	146. Rwanda
147. Saint Kitts and Nevis	147. Saint Kitts and Nevis	147. Saint Kitts and Nevis
148. Saint Lucia	148. Saint Lucia	148. Saint Lucia
149. Saint Vincent and the Grenadines	149. Saint Vincent and the Grenadines	149. Saint Vincent and the Grenadines
150. Samoa	150. Samoa	150. Samoa
151. San Marino	151. San Marino	151. San Marino
152. Sao Tome and Principe	152. Sao Tome and Principe	152. Sao Tome and Principe
153. Saudi Arabia	153. Saudi Arabia	153. Saudi Arabia
154. Senegal	154. Senegal	154. Senegal
155. Serbia, Rep. Of a. Serbia and Montenegro b. Yugoslavia	155. Serbia	155. Serbia
156. Seychelles	156. Seychelles	156. Seychelles
157. Sierra Leone	157. Sierra Leone	157. Sierra Leone
158. Singapore	158. Singapore	158. Singapore
159. Slovakia	159. Slovakia	159. Slovakia
160. Slovenia	160. Slovenia	160. Slovenia
161. Solomon Islands	161. Solomon Islands	161. Solomon Islands
162. Somalia	162. Somalia	162. Somalia
163. South Africa	163. South Africa	163. South Africa
164. South Sudan	164. South Sudan	164. South Sudan
165. Spain	165. Spain	165. Spain
166. Sri Lanka	166. Sri Lanka	166. Sri Lanka
167. Sudan	167. Sudan	167. Sudan
168. Suriname	168. Suriname	168. Suriname
169. Sweden	169. Sweden	169. Sweden
170. Switzerland	170. Switzerland	170. Switzerland
171. Syria	171. Syria	171. Syria

WMD	BGS	USGS
172. Tajikistan	172. Tajikistan	172. Tajikistan
173. Tanzania	173. Tanzania	173. Tanzania
174. Thailand	174. Thailand	174. Thailand
175. Timor-Leste	175. East Timor	175. Timor-Leste
176. Togo	176. Togo	176. Togo
177. Tonga	177. Tonga	177. Tonga
178. Trinidad and Tobago	178. Trinidad and Tobago	178. Trinidad and Tobago
179. Tunisia	179. Tunesia	179. Tunisia
180. Turkey	180. Turkey	180. Turkey
181. Turkmenistan	181. Turkmenistan	181. Turkmenistan
182. Tuvalu	182. Tuvalu	182. Tuvalu
183. Uganda	183. Uganda	183. Uganda
184. Ukraine	184. Ukraine	184. Ukraine
185. United Arab Emirates	185. United Arab Emirates	185. United Arab Emirates
186. United Kingdom	186. United Kingdom	186. United Kingdom a. Bermuda b. Montserrat
187. United States of America a. Puerto Rico	187. United States of America	187. United States of America
188. Uruguay	188. Uruguay	188. Uruguay
189. Uzbekistan	189. Uzbekistan	189. Uzbekistan
190. Vanuatu	190. Vanuatu	190. Vanuatu
191. Venezuela	191. Venezuela	191. Venezuela
192. Vietnam	192. Vietnam	192. Vietnam
193. Yemen, Rep. Of a. Yemen Arab Republic b. Yemen, PDR	193. Yemen	193. Yemen
194. Zambia	194. Zambia	194. Zambia
195. Zimbabwe	195. Zimbabwe	195. Zimbabwe Antarctica

According to the website for the WMD the report covers 168 countries. In the report of 2019, figures for 165 countries could be found. This number includes seven non-independent countries, e.g. Greenland or Puerto Rico. However, WMD includes all of the red-marked countries (apart from the Holy See and San Marino) in the regional and development status groups section.

BGS covers 167 countries, these include five additional (non-independent) countries.

USGS covers the most countries of all reports especially considering the additional countries covered separately from their sovereignty state. It covers 174 countries including nine non-independent countries plus Antarctica.

There are thirteen countries not covered by any of the three data providers. These are Andorra, Holy See, Kiribati, Maldives, Marshall Islands, Micronesia, Monaco, Palau, Samoa, San Marino, Tonga, Tuvalu, and Vanuatu. However, it is likely that these states don't have any mineral production whatsoever and are fully dependent on imports.

3 Applications

This chapter aims at explaining the importance of production data reported by the organisations analysed in chapter 2 Collections of Raw Material's Production Data by showing some applications where they are invaluable. Production data is not only an important tool for strategic planning by companies but also for policy makers enabling them to make forecasts and adapt commodity planning. For instance, the data is used by the European Union to develop their list of critical raw materials where economic importance and the supply risk of different commodities are evaluated.

3.1 European Commission List of Critical Raw Materials

In 2008 the European Commission launched the raw materials initiative with the goal of ensuring access and affordability of mineral raw materials; thereby securing a functioning economy. Sectors such as construction, chemicals, and automotive, etc. are all highly dependent on raw materials, and provide 30 million jobs in Europe. This means supporting these industries by changing towards a more efficient use of materials, especially those where the EU depends on import, and a sustainable development is necessary.

The raw materials initiative acts on three different pillars:

1. Ensure access to raw materials on the world market
2. Foster supply of raw materials from European sources
3. Boost resource efficiency and recycling

One priority action is the development of a list of materials critical for the EU. This is an important decision as the number and amount of raw materials required for industry and end-use purposes increases steadily. Between 2010 and 2030 an increase of global resource use of 100% can be expected and technological progress and quality of life rely on an undisturbed access to raw materials. (Gislev *et al.*, 2018; European Commission, 2008)

Since 2011 the European Commission publishes a list of critical raw materials in a three-year interval. The last list was published in 2017 evaluating 61 materials on economic importance and supply risk for the EU. For this assessment the collections investigated in chapter 2 are the main source of data.

The purpose of the criticality assessment is to enhance the European minerals sector and support policy making on EU level.

The main targets are:

- Implementation of the industrial strategy by strengthening the competitiveness of European industry.
- Enhancing the European mining and recycling industry and stimulating production of critical raw materials.
- Enforce the EU circular economy action plan by promoting efficient use and recycling of critical raw materials.
- Identify and inform about potential supply risks and related opportunities of critical raw materials.
- Negotiate trade agreements, dispute existing trade distortion measures, enhance research and innovation, as well as implementation of Sustainable Development Goals.

(DG Grow, Unit C2 Resource Efficiency and Raw Materials, 2019)

Many of the critical raw materials are used for high tech products and emerging innovations, for example solar panels, wind turbines, and electric vehicles. Due to their importance for fighting climate change the demand for certain materials might rise by a factor of 20 until 2030. However, the EU faces an imbalance between upstream industries (extraction of raw materials) and downstream industries (manufacturing and use) with European industry dominated by manufacturing rather than mining. Also recycling of critical raw materials must be improved – the supply from secondary sources is very limited. This is why enhancing those two industries has to be a main target and requires careful attention. (Gislev *et al.*, 2018)

3.1.1 Evaluation of criticality

The indicators used to assess the criticality of a raw material for the EU economy are “Economic Importance” and “Supply Risk” based on historical data rather than forecasts. Economic Importance defines the severity of the consequences for the economy if the supply of a raw material is not sufficient. The methodology for the assessment of critical raw materials was changed between 2014 and 2017 in order to improve allocation of the raw material to the associated industry sectors. Moreover, substitution has been included in both economic importance and supply risk as a mitigating factor. (Blengini *et al.*, 2017; Gislev *et al.*, 2018)

Economic Importance is calculated as follows (Blengini *et al.*, 2017):

$$EI = \sum_{s} (As \times Qs) \times SI_{EI}$$

Equation 1: Economic Importance

EI…Economic Importance
As…Share of end use of a raw material in a NACE Rev. 2 2-digit level sector
Qs… NACE Rev. 2 2-digit level sector’s value added
SI_{EI}…substitution index of a raw material
s…sector

Supply Risk describes the vulnerability of the supply chain to disruptions leading to an insufficient supply of a raw material for EU industry. It is calculated using the following equation (Blengini *et al.*, 2017):

$$SR = \left[\left(HHI_{WGI,t}\right)_{GS} \times \frac{IR}{2} + \left(HHI_{WGI,t}\right)_{EUsourcing} \left(1 - \frac{IR}{2}\right) \right] \times (1 - EoL_{RIR}) \times SI_{SR}$$

Equation 2:Supply Risk

SR…Supply Risk
HHI…Herfindahl-Hirschman Index
WGI…World Governance Index
t…trade adjustment of WGI
IR…Import Reliance
GS…global supply
$EU_{sourcing}$…EU suppliers
EoL_{RIR}…End-of-Life Recycling Input Rate
SI_{SR}…Substitution Index

If possible WMD is used for production data because they are most coherent in terms of what is reported (metal content or concentrate), and in terms of sources and accuracy of data which are all clearly stated. However, in some cases BGS data is used, for example, in the case of Strontium (evaluated for the first time in the study to be published in 2020) because it is not reported in WMD. For helium and silicon metal BGS is the source of data. Hafnium, which is on the criticality list of 2017, is not reported in WMD. However, neither BGS nor USGS, who both include it in their data, report any production of Hafnium in recent years. For import and export figures Eurostat COMEXT database is used (also basis for MFA trade data evaluated in chapter 2) and USGS is an important source for information on the raw material itself, incl. uses, deposits, international market structure, etc.

Figure 6 shows the main producer in the year 2017 of each critical raw material of the 2017 list including production figures and share of global production. The data is taken from WMD, apart from helium and silicon metal where BGS data is used. (Hafnium is not included.)

The CRM list differentiates between light and heavy rare earth metals. The rare earth element scandium is also evaluated separately. However, WMD, BGS, and USGS report them aggregated as rare earths minerals. The same issue arises for phosphate rock and phosphorus, both are analysed individually, but the three global data providers cover phosphate rock (BGS, USGS) or phosphates (P_2O_5 content, WMD). Differences can also be seen for borate (BGS) or boron (WMD), USGS reports boron minerals, and magnesium (BGS) or magnesite (WMD), USGS documents magnesium compounds as MgO equivalent. On the other hand, the criticality study includes platinum group metals in an aggregated form, whereas, WMD, BGS, and USGS all report platinum, palladium, and rhodium separately.

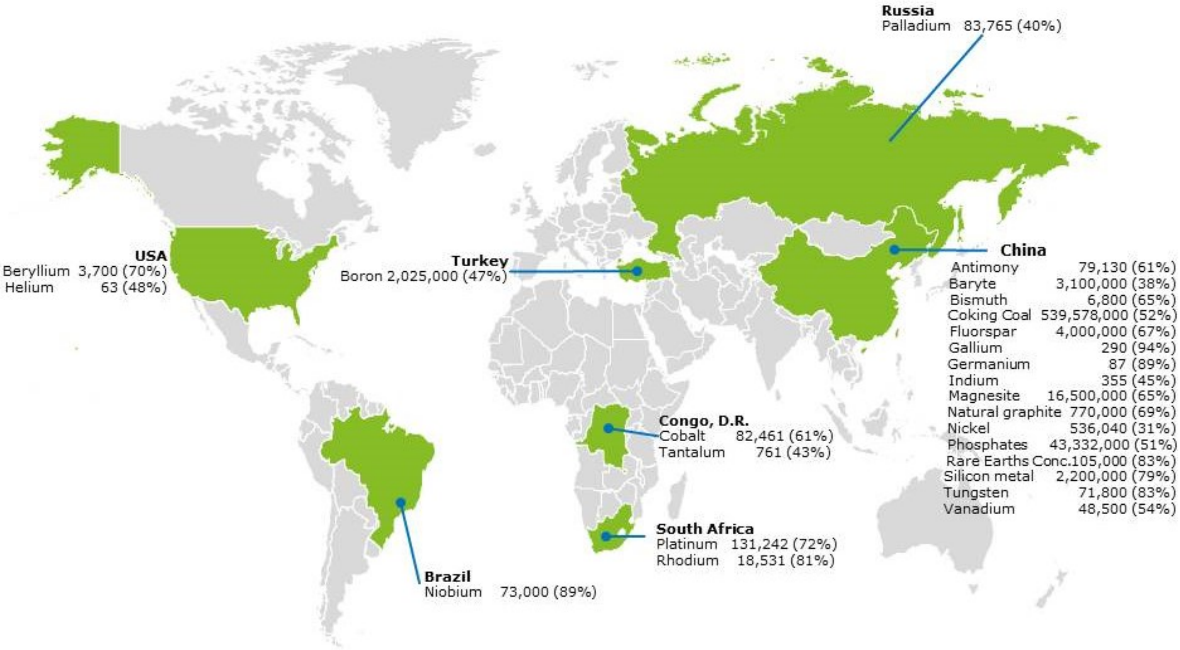

Figure 6: Main global suppliers of CRM in metr. tonnes and percent, Source: (Reichl *et al.*, 2019; Brown *et al.*, 2019) (Brown *et al.*, 2019 (helium, silicon metal)), adapted from (Gislev *et al.*, 2018)

This figure shows clearly the dominance of China in critical raw material production. China is number one producer of 16 of the critical raw materials with market shares between 31% (nickel) and 94% (gallium). Further major producers are South Africa, Congo D.R., USA, Brazil, Turkey, and Russia.

The main issue the criticality study has to face is the lack of data specifically for Europe. WMD and BGS focus on production data only. BGS publishes some mineral profiles, however, only for a very limited number of minerals. A further provider of information on minerals is the German Minerals Resources Agency (DERA), but the number of assessed minerals is again rather small. The project Minerals4EU provides an overview of resources and reserves in European countries on their website, but the number of commodities is very limited and there are no current updates as this project finished in 2014. Therefore, most information is from global or US sources and it is questionable whether this is valid for the EU as well.

Arsenic, for example, is a popular chemical for wood treatment in form of the compound chromated copper arsenate (CCA). In the US this is the main use of Arsenic making up for almost 90% of total consumption. (George, 2019)
However, this application is highly restricted and subject to prior authorisation in the EU due to its toxicity, meaning US consumption patterns cannot be used for the EU and a source providing a distribution of European arsenic consumption is not available.

This is an issue addressed by the Strategic Implementation Plan for European Innovation Partnership on Raw Materials which emphasises the need for a Geological Knowledge Base and Minerals Intelligence Information. For this purpose DG JRC in cooperation with DG GROWTH has established RMIS – Raw Materials Information System, a platform providing information on non-fuel, non-agricultural raw materials from primary and secondary sources. However, especially the raw materials' profiles are incomplete for the time being. (EuroGeoSurveys, 2016; Joint Research Centre, 2019)

Furthermore, as noted by the European Commission (2014) in a communication on the list of critical raw materials and the implementation of the Raw Materials Initiative, this initiative has not yet had a quantifiable effect on European production. It is also not known how EU member states implement the suggestions of the raw materials initiative. However, the Horizon 2020 programme supports a number of projects aiming at creating guidelines for EU policies in order to develop a harmonised framework for EU members to implement, supporting the raw materials industry in Europe. One example of such a project is MinLand where Montanuniversitaet Leoben is a consortium partner.
The main objective of MinLand is to enable extraction of mineral raw materials by securing access to land for exploration and extraction. This is not an easy task due to different interests regarding land-use. However, in order to decrease EU's dependencies from imports (especially of the critical raw materials) it is necessary to strengthen domestic production. (MinLand, 2019)

Another project within the Horizon 2020 framework supporting the extractive industry is MIREU (Mining and Metallurgy Regions of EU) also supported by Montanuniversitaet Leoben. On the one hand MIREU aims at improving conditions for the development and supply of raw materials in the EU. On the other hand, it also works at the creation of a social guidance to operate on EU level to develop standards for responsible and sustainable mining including the incorporation of affected stakeholders. MIREU also wants to raise awareness about mining and the need for mineral raw materials. (MIREU, 2017)

3.2 Circular Economy

One of the reasons for launching the Raw Materials Initiative is to enforce the Circular Economy Action Plan. Circular economy is a concept of reducing the input of primary raw materials, keeping their value in the economy for as long as possible, and minimising the output of waste by recycling, repairing, and reusing products and materials. At the moment this seems to be the best way forward in order to maintain and promote high standards of living without completely depleting Earth's resources.

When talking about circular economy, two forms of "loop closing" have to be differentiated:

- Socioeconomic loop closing (recycling materials as secondary material inputs)
- Ecological loop closing (use of renewable biomass)

(Mayer *et al.*, 2018; Gislev *et al.*, 2018; European Commission, 2015; Haas *et al.*, 2015)

Considering the critical raw materials, the recycling input rate is fairly low to non-existent. In 2011 Braedel *et al.* (UNEP) published a status report on the recycling rates of metals showing that many metals included in the EU list of critical raw materials are virtually not recycled at all, for example boron and scandium, all evaluated indicators – old scrap ratio (OSR), collection rate (CR), and end-of-life recycling rate (EOL-RR) – are not ascertainable or below 1%. This is an issue the EU wants to address not only to secure the supply for the European industry, but also because energy and water use is usually significantly lower for secondary materials than for primary raw materials.

Circular economy is believed to help industries in the EU by boosting competitiveness, protecting it against volatile raw material prices and insufficient supply, and by creating new business opportunities. An example is “eco-design” of products. The goal is to improve the reparability and disassembly of products which helps the recycling process. Both design, allowing dismantling and recycling of the contained raw materials, and a better communication between manufacturers and recyclers need to be addressed. A model case for these improvement requirements is the electronics sector, especially considering smart phones, often containing critical raw materials. (Gislev *et al.*, 2018; European Commission, 2015; Haas *et al.*, 2015; Mayer *et al.*, 2018; Braedel *et al.*, 2011)

Apart from the Action Plan for the Circular Economy also the Extractive Waste Directive takes important steps towards a sustainable use of resources. Mining companies are required to provide a waste management plan for the minimisation, treatment, recovery, and disposal of extractive waste. This is to make sure that adverse effects on the environment and human health are minimised, and raw materials from extractive waste are recovered as completely as possible. (Gislev *et al.*, 2018)

The concept of a circular economy (with a focus on mineral raw materials) is shown in the following figure:

Figure 7: Diagram illustrating the concept of a circular economy, focusing on mineral raw materials (EIT RawMaterials, 2019)

Haas *et al.* present material flows in 2005 for the EU-27 in their report “How Circular is the Global Economy”. Their study shows that EU-27 account for 7.5% of global population. However, the material use is 12.4% of globally extracted materials (this includes fossil fuels, biomass, metals, waste rock, industrial minerals, and construction minerals). With an average material use of 15.8 gigatonnes (Gt) per capita per year the EU has a 64% higher consumption than global average. In 2005 the EU imported 1.2 Gt and extracted 5.5 Gt of materials, in total 7.7 Gt of materials were processed (incl. recycled material). Energetic uses account for 3.5 Gt (approx. 45%), 4.2 Gt or 54% went into material use, including 3.5 Gt additions to stocks. Recycling rates in the EU are fairly high at 12.6% of total processed material which is twice the global average. Nevertheless, the domestic processed output of the EU at 10.4 tonnes (t) per capita per year (5.0 Gt total) is still significantly higher than the global average at 6.3 t per capita per year. Contrary to the relatively high recycling rates the flow of renewable biomass is lower than the global average, 28% and 32% respectively.

This study shows that both EU and global economy are still far away from a truly circular economy and there is still a lot that needs to be done. The authors underline that focusing on recycling only will not solve the issue, as a large fraction of the material input contributes to stocks and is not available for recycling. Another factor that needs to be considered is the consumption of fossil fuels that simply cannot be recycled.

More recently Mayer *et al.* (2018) expanded this study in order to measure and monitor the effects of EU policies on the circularity of the economy. As most research is done on recycling of specific products or circularity of industry sectors, assessments on macro-scale (in this case EU-26-wide) are rare. The authors propose (new) indicators to measure the circularity of an economy:

- Three pairs of indicators to measure the scale of material and waste flows
    - Input: Domestic Material Consumption (DMC) measures all materials directly used in national production

      Output: Domestic Processed Output (DPO), for monitoring the amount of waste and emission outflows of an economy
    - Raw Material Consumption (RMC) measures material use associated with domestic final consumption
    - Input: Processed Materials (PM) = DMC + input of secondary materials

      Output: Interim Outputs (IntOut) for waste and emissions before materials for recycling and downcycling are diverted
- Input Socioeconomic Cycling rate (ISCr) measuring the input of secondary materials to PM

  Output Socioeconomic Cycling rate (OSCr) for the share of IntOut that is reused as secondary material
- Input Ecological Cycling rate potential (IECrp) = share of biomass in PM

  Output Ecological Cycling rate potential (OECrp) = share of DPO from biomass in IntOut

With this framework Mayer *et al.* modelled the material flows of the European Union for the year 2014.

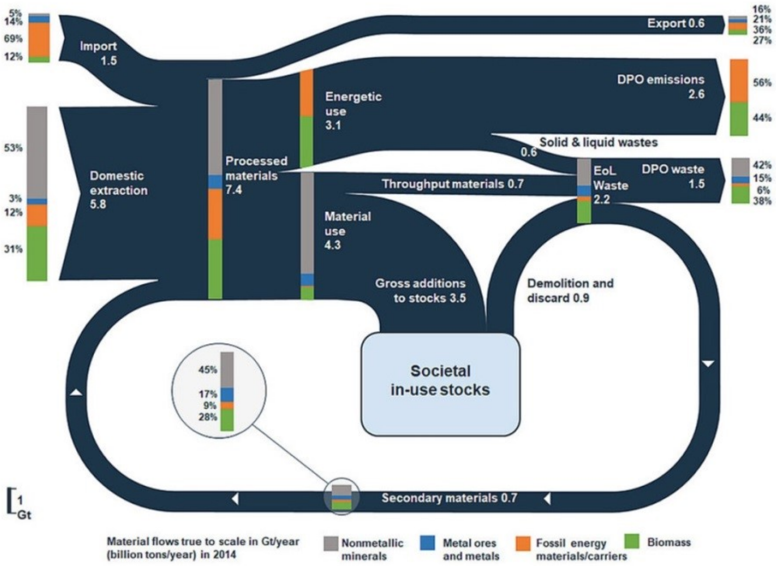

Figure 8: EU-28 material flow for 2014 (Mayer *et al.*, 2018)

A total of 7.4 Gt of materials were processed in 2014, of this only 0.7 Gt came from secondary sources. Non-metallic minerals and metal ores make up for 56% of domestic extraction, the largest share of imports are fossil fuels (69%). DPO (emissions + waste) was at 4.1 Gt. This results in an input socioeconomic cycling rate of 9.6% and an output SCr of 14.8% both are fairly low values.
The ecological cycling rate potentials were already at a higher level with 24.6% input and 35.3% output.

Recommendations of the authors include improved collaboration between output- and input-related (environmental and economic) policies, and between policy makers and industry. However, above all they stress the need for improved data collection and quality in order to allow monitoring of circular economy initiatives. (Mayer *et al.*, 2018)

3.3 Global Material Flow

Economy-wide Material Flow Accounting (EW-MFA) measures the flow of (raw) materials between environment and economy – either between natural and socio-economic system or between national economies. Inputs come from domestically extracted materials or other economies, and outputs are emissions, waste, losses, and exports to other economies. Within the considered economic system there are stocks. Stocks are human population, animal livestock, and so-called artefacts (= manufactured capital and in-use stocks of material) including buildings, infrastructure, machines, devices, etc. MFA differentiates between extracted materials that do not enter the economy, so called "unused extraction", for example removed overburden or bed rock from mining, and material entering the economic system, "used extraction". (Lutter, 2018; Krausmann *et al.*, 2018)

A schematic graph of MFA can be seen in Figure 9.

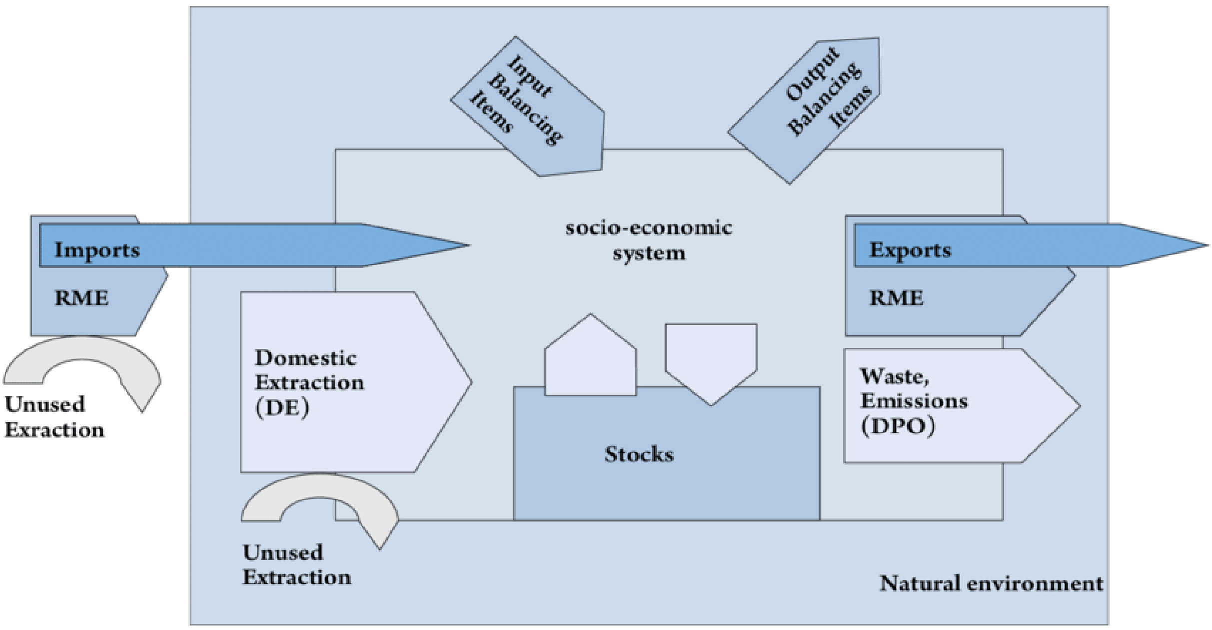

Figure 9: Schematics of material flow into, inside, and out of an economy (Schaffartzik *et al.*, 2015)

In chapter one material flow accounts by Eurostat were introduced. Apart from the assessed raw materials production data this database also provides import and export data, direct material inputs, physical trade balance, and domestic material consumption. This is an ideal basis for evaluating material flows for the European economy. Unfortunately, this database is incomplete, as Table 3 has already shown production data is only available for some years making a long-term analysis impossible. Therefore, import and export data provided by Eurostat material flow accounts has to be combined with production data of one of the other data providers discussed in chapter 2 (WMD, BGS, or USGS) to examine material flows of EU's economy. However, in order to do so production data has to be converted from metal content to ores (see chapter 2.4 for conversion factors).

Moreover, Eurostat data is rather aggregated, and it is not always clear what materials are included, e.g. "Other non-ferrous metals". Comext database for trade figures by Eurostat is a lot more comprehensive, including data for all materials classified via the combined nomenclature (CN) and it is easier to find a suitable match for production data, but again sometimes conversions are necessary. For example, Potash production figures are usually reported as potassium oxide, K_2O, equivalent, whereas trade data reports sylvite (KCl).

A better suited source for material flows is found in the Global Material Flows Database by the International Resource Panel (IRP). From this database it is possible to extract figures for the same indicators as Eurostat MFA database for 13 different material flow categories (International Resource Panel, 2019):
coal, crop residues, crops, ferrous ores, grazed biomass and fodder crops, natural gas, no ferrous ores, non-metallic minerals – construction dominant, non-metallic minerals – industrial or agricultural dominant, oil shale and tar sands, petroleum, wild catch and harvest, wood

These categories might be sufficient for material flow accounts of economic systems, but considering a more detailed analysis of a specific raw material, this data cannot be used due to the aggregation of materials.

Considering the need for a reduction of primary raw materials use (as discussed in chapter 3.2) it is interesting to look at the development of domestic consumption over the previous years. The Domestic Material Consumption is calculated as domestic extraction + weight of imports – weight of exports. Therefore, they only provide an apparent and not a real consumption of a country. Using data by the IRP, following developments can be observed for the EU-28.

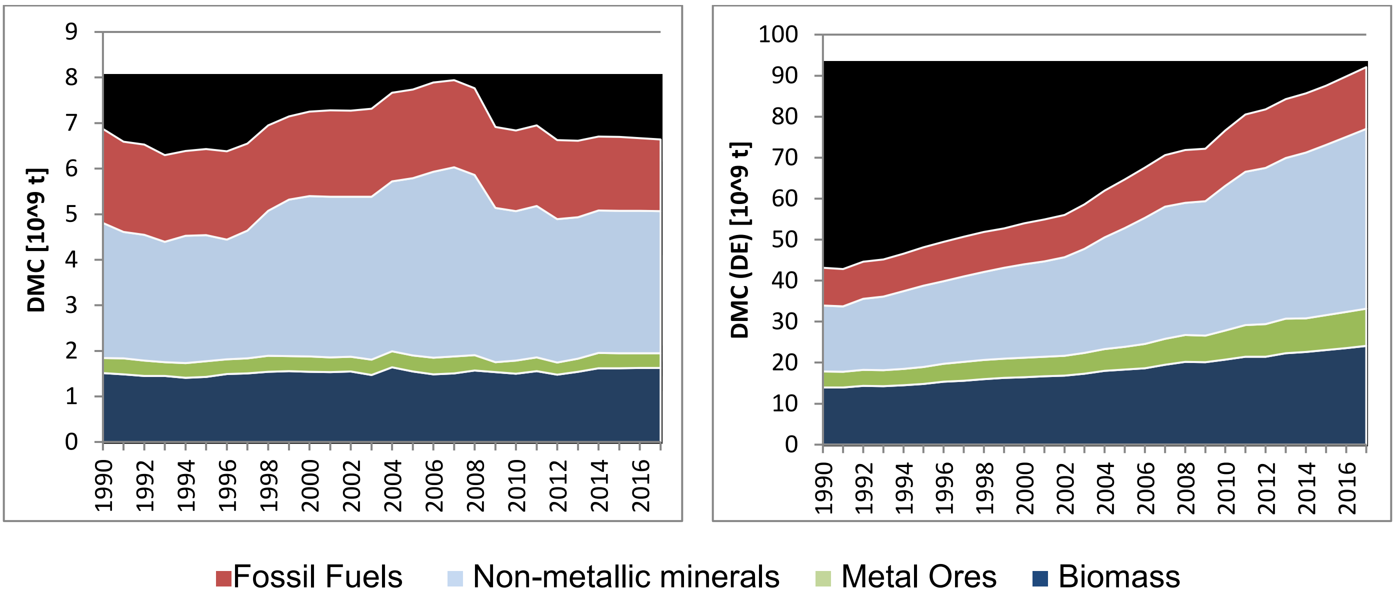

Figure 10: EU-28 Domestic Material Consumption 1990-2017 (left), Global Domestic Material Consumption 1990-2017 (right), data source: International Resource Panel (2019)

According to IRP data biomass consumption remained almost at the same level for the years 1990-2017 at approx. 1.4 to 1.6 Gt, this is also valid for metal ores with an EU consumption of about 0.3 Gt. Fossil fuels and non-metallic minerals show larger volatility during that period. Since mid-1990 there was a steady increase of consumption until 2007. Then a significant drop was registered, likely due to the economic crisis. After that consumption recovered slightly, but did not increase to previous levels again. Overall fossil fuel consumption in 2017 was approx. 0.5 Gt lower than in 1990. Considering the more recent years overall domestic consumption decreased by 8% between 2000 and 2017.

World-wide consumption shows a very different picture (assuming world consumption equals world production of raw materials). All material groups show a steady increase of consumption since 1990. Especially for non-metallic minerals a strong boost can be observed. The reduction between 2007 and 2010 is not as distinct as for the EU-28. In the considered period total consumption increased by 113%.

It is important to note the limitations of the indicator Domestic Material Consumption (DMC). First of all, as already mentioned it does not state the actual consumption of a country. Furthermore, it does not include materials consumed along the supply chains, so-called raw material equivalents. An alternative indicator making up for these shortcomings of DMC is the Raw Material Consumption (RMC), also known as Material Footprint. To calculate the RMC imports and exports are considered in raw material equivalents. Considering the highly international trade of mineral raw materials, this indicator might be better suited for evaluating the actual raw material consumption of countries, especially considering differences between service-oriented and heavy-industry-oriented economies. The differences of the results of the two indicators can be seen in Figure 11 for the year 2013.

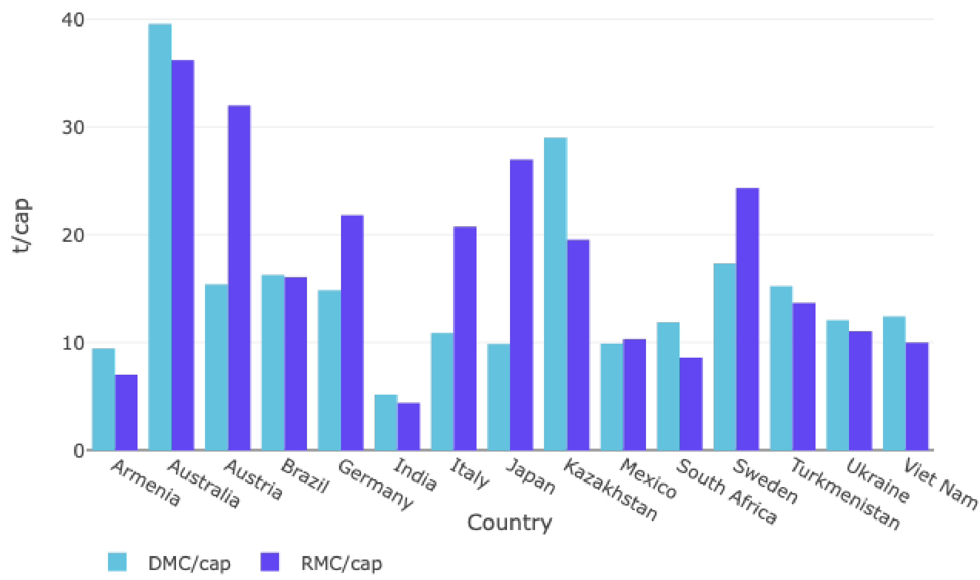

Figure 11: Comparison of DMC per capita and RMC per capita for selected countries in 2013, (Lutter *et al.*, 2018)

Noteworthy are the large differences of DMC and RMC for western countries with a high share of the service sector, such as Austria, Germany, Italy, and Sweden.

Steinberger and Krausmann et al. (2010; 2018a) are two of the few studies assessing global material flows using not only material flow accounting, but also dynamic stock-flow modelling to take the development of in-use stocks into account that enables tracing materials from extraction to end-use. These studies are conducted on a long-term basis, starting in 1900 and evaluate four material groups, biomass, fossil energy carriers, ores, and non-metallic minerals, covering in total 150 different materials. A result of this analysis is global material extraction between 1900 and 2015. This can be seen in Figure 12, in order to have a comparison to global material consumption using IRP data. For mineral raw materials (metal ores and non-metallic minerals) they rely mainly on data by USGS as they range back to 1900 and offer additional information in their factsheets.

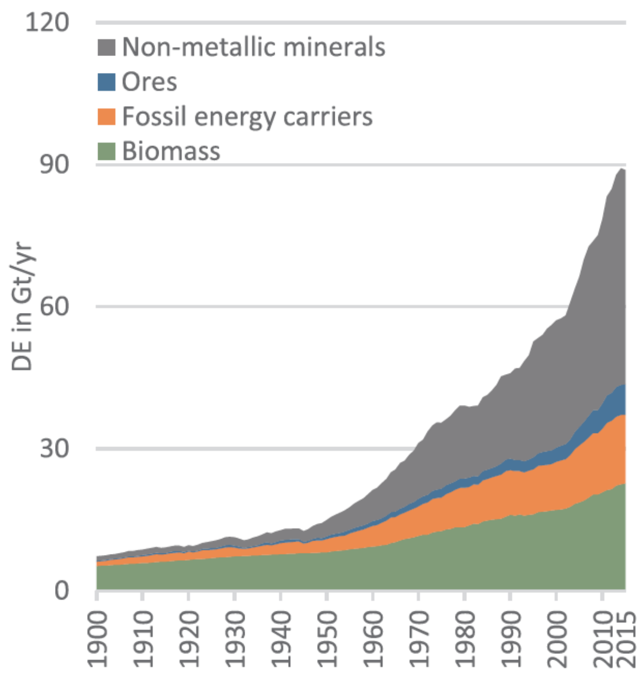

Figure 12: Development of domestic extraction between 1900 and 2015 (Krausmann *et al.*, 2018a)

This graph shows a similar development as Figure 10 (right, IRP data), the different timelines must not be disregarded! IRP also has the four main material categories, which they divide into 62 subcategories. A comparison of materials included in both the study of Krausmann *et al.* and IRP data is therefore not possible.

Differences can occur for the ore's category and some minerals of the non-metallic mineral's category due to different factors for converting metal (mineral) contents from data providers mentioned in chapter 2 to gross ores which are usually used for material flow analysis. How this is conducted is explained in the technical annexes of both studies. Krausmann *et al.* extrapolate the amount of gross ore using metal content (mainly provided by USGS) and average global ore grades. This might cause deviations as grades vary significantly between countries and deposits. IRP on the other hand states it uses at least country-specific average ore grades that may lead to more accurate estimations. The most difficult part is the estimation of construction raw materials such as sand, gravel, clay, limestone, gypsum, etc. The extraction of these minerals is (almost) not reported by the international data providers (exceptions mentioned in chapter 2).

Krausmann et al. describe a "bottom-up" approach – they use kilometres of roads, buildings, railways, etc. built to deduct the extracted amount of raw materials used for these kinds of construction. A similar approach is described in the technical annex of IRP database. (Krausmann *et al.*, 2018a, 2018b; International Resource Panel, 2018)

For material flow analysis a collection of extraction of raw materials for construction purposes would be a great help. BGS is already attempting it on a European level and USGS on US level, however, there is no international data provider due to fragmentary or not existing data collections on national level. Another point for improvement for MFA-studies would be the cooperation with the data providers in order to obtain the exact metal contents used by BGS, USGS, and WMD to avoid deviations due to different conversion factors.

Furthermore, according to Prof. Krausmann they do not consider by-products in their MFA studies. That means the difference between metal content and gross ore is considered tailings (waste).
This suggests tailings are overestimated, considering that many metals are won as by-products only during the production of other metals.

(Additional information kindly provided by Prof. Fridolin Krausmann, Institute of Social Ecology, University of Natural Resources and Life Sciences.)

3.3.1 Demand Drivers

This section aims at evaluating drivers of raw material consumption. Resource consumption can be calculated using the IPAT theory, stating that environmental impact or resource consumption (I) depend on population (P) times affluence (A, e.g. GDP per capita) times technology (e.g. energy per GDP). This takes resource decoupling from economic growth, increasing resource- and eco-efficiency due to new technologies or changing lifestyles into account. In general, we can differentiate five different factors influencing the amount of resource consumption of an economy. (Boumphrey, 2016; Kalmykova *et al.*, 2016)

Those drivers are:

1. Economic growth
2. Income growth
3. Demographic growth
4. Prices
5. Environmental Concerns
6. Technology

Ad 1. Economic Growth

Especially developing countries are considered drivers of resource consumption, above all energy consumption. Considering the amount of energy used in China – in 2010 China used more energy than the United States and became the World's largest consumer of energy. However, in terms of use per capita, China still has a long way to go to catch up to the global leaders. This is even more apparent looking at India. India was the fastest growing economy in 2016, but energy consumption per capita levels are approx. 70% less than China's.

Fossil fuel consumption of industrialised countries, such as Sweden, do not necessarily show an increase of fossil fuel consumption due to economic or income growth. Here increases are more related to the economic structure.
This is in contrast to construction minerals, which show a connection to the development of the economy even in industrialised countries. (Boumphrey, 2016; Kalmykova *et al.*, 2016)

A comparison of energy consumption in industrialised and developing countries can be seen in Figure 13.

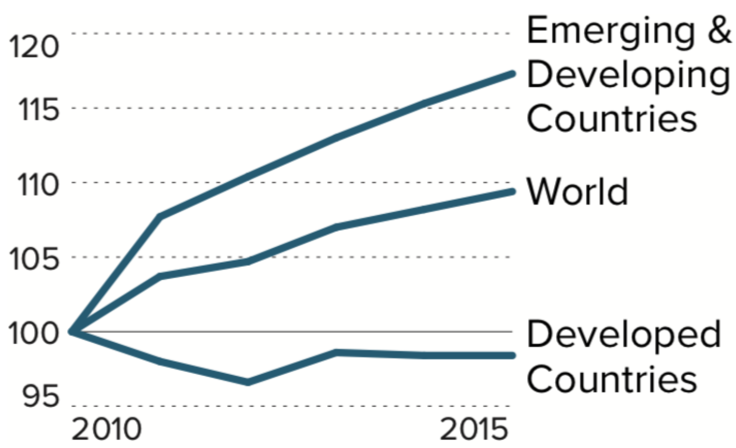

Figure 13: Development of energy consumption 2010-2015, 2010 = 100% (Boumphrey, 2016)

This graph clearly shows the gap between developing and fully developed countries. The latter show a fairly constant energy use, whereas, developing countries show a growth of almost 20% within 5 years.

Ad 2. Income Growth

With the growth of income, the consumer expenditure increases as well. Between 2010 and 2015 the number of households earning more than 10.000 USD increased by 37%. This development is expected to continue. Consumer expense is forecast to increase by 89% until 2030. Growing expenditures means that the demand for consumer goods is boosted – in turn pushing the demand for raw materials. Interestingly, material consumption is by far the most equally distributed form of wealth. Considering land area owned, 54% are controlled by only 10% of global population. From the total material consumption on the other hand only 27% are consumed by 10% of the population.

Material categories show large differences, biomass is considered the most equally distributed material, whereas ores and industrial minerals, or fossil fuels are again rather concentrated to the top 10% of the population with 44% and 42% respectively. (Steinberger *et al.*, 2010; Boumphrey, 2016)

Steinberger et al. (2009) present this comparison in form of Lorenz curves as shown in Figure 14.

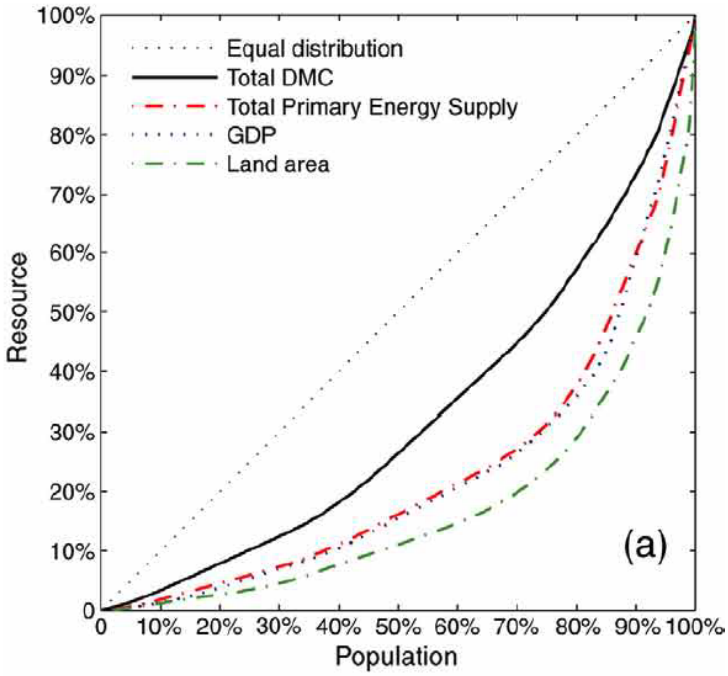

Figure 14: Lorenz curve - Comparison of wealth distribution to percent of population (Steinberger *et al.*, 2010)

The Lorenz curve plots wealth distribution by ranking population according to per capita wealth. The y-coordinate gives the cumulated fraction of wealth and the x-coordinate the cumulative lower income fraction of population. The curves for different categories of wealth (DMC, energy supply, GDP, land area) are compared to equal distribution.

Ad 3. Demographic Growth

World population is expected to reach 8.5 billion by 2030 (compared to 7.7 billion in 2019). This increases the need for infrastructure, including housing, transport, etc. therefore boosting raw material demand as well. Especially since the urban population is growing steadily at twice the rate than total global population.

Globally urban population is larger than rural population making up for more than 50% since 2007. This also means that the largest share of resource consumption can be attributed to cities with approx. 75% of total consumption, and even more so they are responsible for economic growth with about 80%.

However, this could also be a possible starting point for reducing resource consumption and decoupling it from demographic growth in the future. Living in cities usually means living in apartments rather than detached houses increasing resource efficiency due to smaller living space and more people living in the same structure.

Another aspect of demographic growth is the growth of car registrations. A study for Sweden shows that even with a more efficient fuel consumption of new cars it has not been possible to reduce overall fuel consumption due to a higher population requiring more cars. (Boumphrey, 2016; Kalmykova *et al.*, 2016)

Ad 4. Environmental Concerns

Due to growing environmental concerns the demand for renewable energy increases. This demand-shift also influences the type of raw materials required. Coal use, for example, is declining while solar, wind, and other renewable energy sources are on an upturn. The production facilities for these energy sources require different materials than thermal power plants, including some critical raw materials, leading to a demand shift. Moreover, sustainability considerations push the demand towards responsibly produced and recycled materials.

An example for such a change is the use of plastic bags in supermarkets.
Since the introduction of a small charge for bags, supermarkets in the UK report a decrease of 80% of used plastic bags. (Boumphrey, 2016)

Ad 5. Price

An obvious factor influencing material consumption is the price. With the renewable energy sources getting increasingly cheaper, their demand experiences a major boost at the same time leading to a decreased demand of other materials for non-renewable energy production. (Boumphrey, 2016)

Ad 6. Technology

Technology goes hand in hand with prices to a certain extent. New technologies for renewable energy, for example, that are easier and therefore cheaper to produce influence their turnover in a positive manner.
This effect is enhanced, if these technologies support the sustainability aspect, such as electric vehicles. (Boumphrey, 2016)

3.4 Sustainable Development Goals

The Sustainable Development Goals (SDGs) are part of Agenda 2030 a concept for sustainable development by the United Nations adopted by all 193 members in 2015. This agenda includes “17 goals to transform our world” whose main purpose is to tackle social inequality issues (poverty, health, education, etc.) while protecting the planet and taking action on climate change. (United Nations, 2019a)

Figure 15: The 17 Sustainable Development Goals by the United Nations (United Nations, 2019b)

From a raw materials point of view Goal 12 “Ensuring sustainable consumption and production patterns” is the most relevant. This goal is supporting actions on the issues of the strongly increasing material consumption and material footprint mentioned in chapter 3.3 Global Material Flow. Since the adoption of the SDGs the material consumption and footprint continued to grow and there is a serious risk that this goal will not be met.

Without determined actions by all involved stakeholders global resource extraction (assumption: global resource extraction is equal to global material consumption) is projected to increase to 190 billion tons by 2060 compared to 92.1 billion tons in 2017. (United Nations, 2019c)

What is sustainable production and consumption? This term was defined by the Oslo Symposium on Sustainable Consumption in 1994 as

> "[…] the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations." (United Nations, 2019d)

One of the actions taken by the European Union is the Circular Economy Package discussed in chapter 3.2 Circular Economy covering raw materials in environment and economy from extraction to recycling or waste. Another key initiative is the 7th Environment Action Programme. However, the EU is not only focussing on developments within its borders, but it also invests in responsible supply chains promoting fair trade, human rights and good governance in producer countries outside the EU. (European Commission, 2019)

The International Institute for Applied Sciences established an initiative called "TWI2050 - The World in 2050 initiative" in order to provide scientific foundations for the Agenda 2030. This initiative involves dozens of researchers and experts from different institutions and organisations including academia, business, government, etc. attempting to develop roadmaps towards the SDGs. In 2018 this initiative published a report on the necessary transformations of society and economy to achieve the SDGs.

A main focus of this report is SDG 12 making suggestions for more efficient use of resources and reduction of raw materials consumption. The authors of this study highlight the need for a mind-set shift of our society, away from thinking wellbeing and status are linked to the consumption of resources, but rather to the services that are provided by these resources.

They mention the example of a smartphone providing services such as phone, camera, email, radio, and many more with one single device. In earlier days we would have needed one device for each service.
Therefore, the smartphone is actually using resources much more efficiently. However, to keep this efficiency over the whole lifecycle of a product and to move towards a circular economy (another necessary change according to the report) these products need to be designed for recycling or reusing. (TWI2050 - The World in 2050 initiative, 2018)

Another interesting aspect mentioned in the report by TWI2050 is the need for inclusion of material stocks in material flow analysis. During the 20th century raw materials used for building up and maintaining global material stocks increased by the factor 23. This means, while in 1900 20% of material input where put in stocks, by 2010 this input rose to 50%. When trying to transform the economy to a more sustainable and resource efficient system this needs to be taken into consideration as these stocks have a very long lifetime and determine long-term pathways. For example, transport or heating infrastructure – once in place they are difficult to change. This also means that materials tied up in stocks are not available for recycling. Due to rising economies of developing countries that still need to expand infrastructure and buildings global material stocks are likely to continue growing and until 2010 only 12% of material inflow were generated from secondary materials. TWI2050 stresses the importance of stocks for our society and economy, because “stocks transform resources into services”. This means that for example the raw material crude oil would not be useful without the necessary infrastructure, such as refineries, roads or cars. However, in order to move towards sustainable production and consumption patterns a decoupling of resource use and economic development have to be achieved. Moreover, stocks have to be used more intensely and for a longer time. Future additions to stocks should be designed in a more efficient way and provide high-quality services relying on a smaller inflow of materials.

Decoupling of resources also includes a more critical look at indicators such as the GDP, because trying to continuously increase the GDP might not be consistent with sustainable development. As an example, for unsustainable or inefficient use steel can be considered. Globally only 47% of primary iron and steel scrap end up in purchased products. The recycling rate is at 13%. Considering the transformation of primary energy to useful energy the efficiency is even worse at approx. 40%. (Krausmann *et al.*, 2017; TWI2050 - The World in 2050 initiative, 2018)

These two cascades are depicted in Figure 16 and Figure 17.

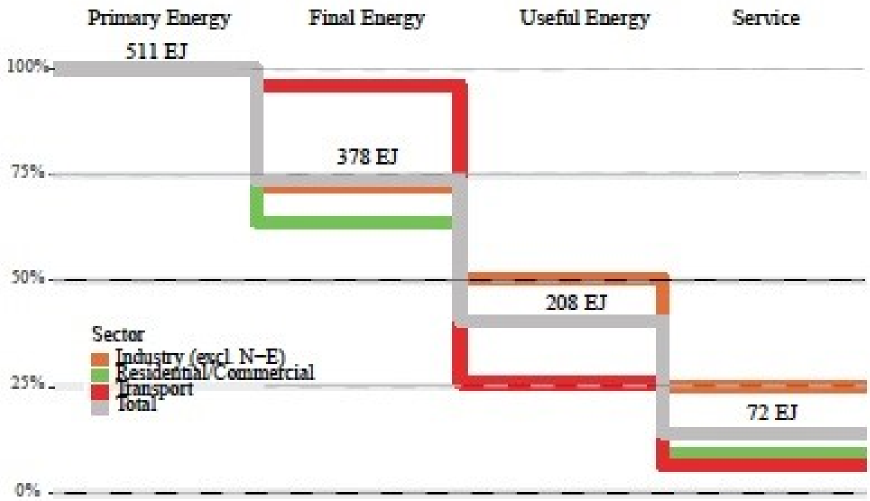

Figure 16: Transformation of primary energy into useful energy (TWI2050 - The World in 2050 initiative, 2018)

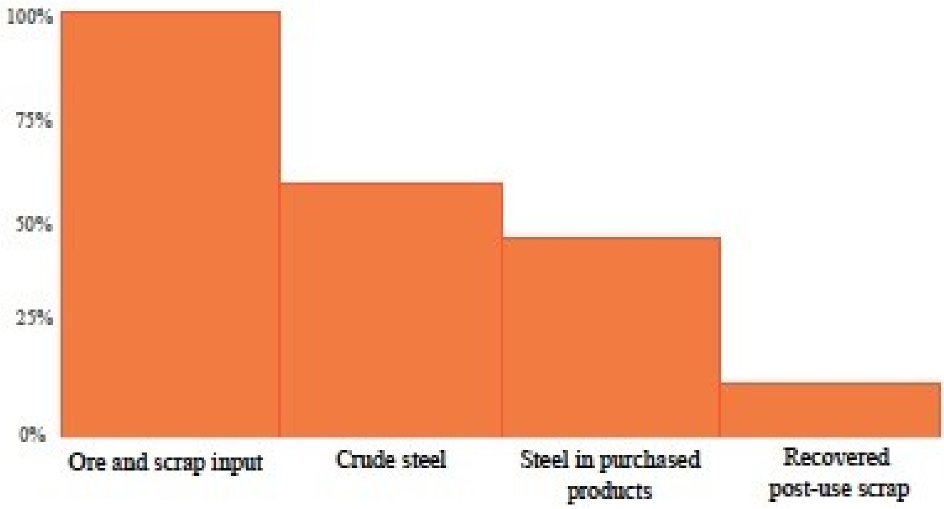

Figure 17: Cascadic use of iron ore to recovered scrap (TWI2050 - The World in 2050 initiative, 2018)

How is progress towards achieving SDG12 measured?

SDG12 is subdivided into eleven targets and each target has its own set of indicators to measure progress. Targets and indicators defined by the United Nations for SDG12 are given in Table 5.

Table 5: Sub-targets SDG12 and relevant indicators of progress (United Nations, 2019c)

Target		**Indicator**
12.1	Implementation of ten-year framework of programmes on sustainable consumption and production	Number of countries with national action plans or policies targeting sustainable consumption and production patterns
12.2	Achievement of sustainable management and efficient resource use by 2030	Material footprint, material footprint per capita, material footprint per GDP
		Domestic Material Consumption, DMC per capita, DMC per GDP
12.3	Reduction of global food waste per capita at retail and consumer levels by 50%, reduction of food losses along supply chains (incl. post-harvest losses)	Global food loss index
12.4	Environmentally sound management of chemicals and wastes throughout their life cycle (incl. reduction of emissions to air, water, and soil) minimising negative influences on humans and environment by 2020	Number of countries agreeing on international and multilateral environmental management plans for hazardous waste and meeting their commitments
		Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment

12.5	Reduction of waste generation through prevention, reduction, recycling, and reuse by 2030	National recycling rate, tons of material recycled
12.6	Companies are asked to incorporate sustainable practices and sustainability information into their reporting	Number of companies publishing sustainability reports
12.7	Promoting sustainable public procurement practices according to national policies and priorities	Number of countries implementing sustainable public procurement policies and action plans
12.8	Informing people and raising awareness for sustainable development and lifestyles in harmony with nature worldwide by 2030	Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment
12.A	Support of developing countries to introduce sustainable consumption and production patterns by strengthening their scientific and technological capacity	Amount of support for developing countries
12.B	Enhance sustainable tourism creating jobs, promoting local culture, and products; evaluate impacts of its sustainable development by introducing monitoring tools	Number of implemented sustainable tourism strategies, policies, and action plans incl. stipulated tools for monitoring and evaluating

12.C	Removal of market distortions through subsidies to prevent inefficient and wasteful fossil-fuel consumption (special needs of developing countries must be taken into account as not to hinder their development and protect poor and affected communities)	Amount of fossil-fuel subsidies per unit of GDP, and as a proportion of total national expenditure on fossil-fuels.

Every year Sachs *et al.* publish a report - the SDG Index and Dashboards, on the performance of countries committed to the SDGs. This report includes the SDG Index assessing the achievements of countries towards reaching the SDGs. In 2019's evaluation Denmark is in the lead with a sore of 85.2 meaning it has achieved the SDGs with an average of 85%. The country with the lowest score is the Central African Republic with 39.1. Considering the EU, 27 of the 28 members are among the 50 highest scoring countries, only Cyprus is behind on place 61. Furthermore, this report publishes the SDG dashboards evaluating each SDG per country to determine strength, weaknesses, and goals where immediate actions are necessary.

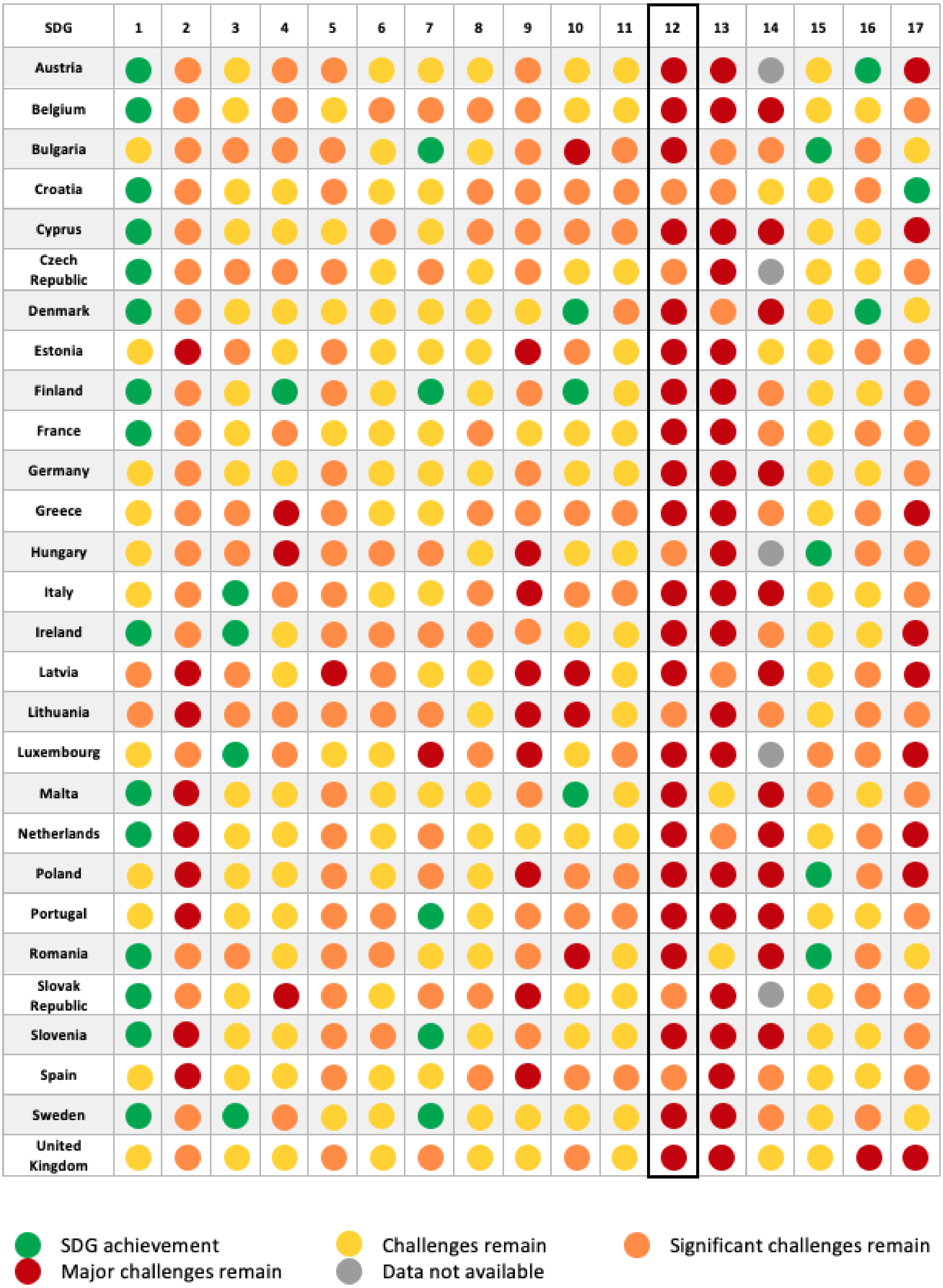

Figure 18: Progress of EU-28 members towards achieving the SDGs, data source: Sachs *et al.*, 2019

This table shows that all EU members are struggling with SDG12. Even the Scandinavian countries Denmark, Sweden, and Finland, who are leading in the SDG index representing overall achievement of all SDGs, have major issues in reaching this goal and rank among the bottom 40 countries. For this reason, the Nordic Council of Ministers representing Denmark, Finland, Iceland, Norway, Sweden, Greenland, Faroe Islands, and Åland analysed the progress of these countries towards SDG12, making recommendations for necessary actions to achieve the sub-goals. (Sachs *et al.*, 2019; Bauer *et al.*, 2018)

The most critical topics are sustainable management of natural resources and rationalising fossil-fuel subsidies:

- Sustainable Management of Natural Resources
  Bauer *et al.* use the indicators proposed by the UN for target 12.2 (see Table 5), additionally they included the percentage of anthropogenic wastewater treated, and environmental taxes as a share of total taxes and social contributions.
  The Nordic region's material footprint is at the top of the European countries, mainly due to high levels of wealth and comparatively low resource productivity. However, a main issue the authors address is the lack of material footprint indicators based on Raw Material Consumption on a global level, rather than Domestic Material Consumption. This falsifies the actual material consumption of a country as it does not take "outsourcing" of heavy industries into account. A good performance in DMC might simply entail a higher level of outsourcing and stronger focus on service industries. Nordic countries still have a large extractive industry. Considering Sweden metal ore and biomass extraction alone make up 50% of its material footprint.
  Many European countries showed a decline of DMC due to the economic crisis until 2013 caused by a reduction of construction projects. This decline is likely to be overturned as the construction industry recovers. Construction materials are responsible for 50% of DMC, however, of all material resources they have only a 1% impact on the climate.

Nordic countries make an effort to develop and adopt green national accounts (Green GDP or Beyond GDP indicators) to adjust for quality losses of raw materials currently not being considered in the evaluation. (Bauer *et al.*, 2018, p. 18)

- Rationalise Fossil-Fuel Subsidies
  For this evaluation the UN indicator for target 12.C was used (see Table 5). According to research subsidies on fossil-fuels amounted to 425 billion USD in 2015 and their phasing out could decrease carbon emissions by 6.4-8.2%. By supporting the use of fossil fuels a change to other energy sources is prevented. This impacts not only the achievement of SDG12, but also other SDGs covering education, skills, and physical infrastructure.
  It increases the use of fossil-fuels increasing pollution and therefore impacting human health. Denmark is closest to the abolishment of subsidies having already phased out support for bituminous coal and petroleum, and significantly decreasing subsidies for diesel fuels.
  Finland allocates the largest subsidies to fossil-fuels per GDP of all OECD countries. Especially peat harvesting is strongly supported. Also, Norway supports the petroleum industry by aiding research and development of new resources. Moreover, coal mining company Store Norske is supported. Norway is far away from reaching an abolishment of subsidies. On the contrary, between 2011 and 2016 subsidies were increased by 400%. (Bauer *et al.*, 2018, p. 37)

Endl *et al.* investigate the opportunities of the mining sector to contribute to the achievement of the SDGs focusing on contributions through innovations. Innovations are divided into two groups – innovations driven by economic considerations, and innovations driven by societal considerations. Each SDG is considered in respect of aspects that can be influenced by the mining sector.
For example, SDG1 “End poverty in all its forms everywhere” includes the aspects ‘inclusive employment’, and ‘local procurement’. New technologies require a more skilled workforce which is usually not available in highly remote areas where mining is usually conducted.

Innovations focusing on shared infrastructure or new business models and customer relations can facilitate local procurement and employment opportunities in a positive way.

Another example is SDG6 “Ensure availability and sustainable management of water and sanitation for all”. This includes the aspects ‘conserve and recycle water’ and ‘manage water holistically’. Mining innovations can improve the recycling of wastewater due to better process control.

Considering SDG12 innovations found focus on minimising waste by developing more efficient processes. However, this might also have negative effects, for example bioleaching could require a higher use of water if waste material is reduced, or areas are developed for mining that have not been affected before.

The following table shows innovation concepts found by the study authors and their anticipated input towards achieving the SDGs.

	SDG 1	SDG 2	SDG 3	SDG 4	SDG 5	SDG 6	SDG 7	SDG 8	SDG 9	SDG 10	SDG 11	SDG 12	SDG 13	SDG 14	SDG 15	SDG 16	SDG 17
Autonomous equipment and operations	–		+	+			+	+		–	+	+	+			–	+
IT platforms and process control systems	–		+	+		+	+	+		–	+	+	+			–	+
Continuous mining processes	–		+	+			+	+		–	+	+	+		+	–	+
Better resource characterisation			+	+			+	+			+	+	+		+		+
Better mine design			+	+		+	+	+			+	+	+		+		+
Equipment Scale Up	–		+				+					+	+				
Digitally enabled worker			+	+				+									+
Disruptive new or alternative mining methods	–	+/–	+/–	+		–	+	+			+	+	+		+	+/–	+
Deep sea mining	–		–	+			+	+			+	–		–		–	+
New financing models								+									
New business models and customer relations	+			+		+	+	+	+			+	+		+	+	
Enhanced transparency and traceability			+					+		+		+				+	+
Better land use planning	+	+				+		+	+		+				+	+	
Shared infrastructure	+	+							+		+/–	+/–				+	+
Low environmental footprint mining			+			+	+					+	+		+	+	+
Renewable energy solutions			+				+					+	+			+	+
Towards zero accidents			+	+													
Better skills base	+			+					+							+	+

Figure 19: Innovations and the SDGs they affect (Endl et al. 2019)

4 Raw Material’s Consumption in Light of New Technologies

In this chapter, two technologies for electricity production are compared on the basis of materials used for the construction of the production units. On the one hand, a thermal power plant is considered as “old-technology”, and on the other hand, wind turbines represent the “new technologies. The goal is to gain an overview, what changes in materials used are caused by this technology-shift and whether this can be seen in the production numbers of these materials. This shall be done using data collections evaluated in chapter 2. Moreover, the use of critical raw materials, lifetime, and recycling shall be considered in terms of sustainability and efficiency of electricity production.

4.1 Thermal Power Plant

A thermal power plant generates electricity by converting heat (thermal energy) from burning some sort of fuel, typically coal, oil or gas, newer models also use e.g. biomass, into electric energy which can then supply the grid with current.
Different types of thermal power plants have to be differentiated according to the units used for electricity production (Verbund AG, 2019; TEPCO Fuel & Power Inc., 2019):

1. Steam power generation
2. Combined-cycle power generation
3. ACC power generation
4. MACC power generation
5. Combined heat and power generation

Ad 1. Steam power generation

This type of power plant generates steam with high-temperature and -pressure by burning fuel in the boiler. The steam leaves the boiler and is driven through guide and rotor vanes of a turbine causing it to rotate. The turbine in turn is connected to a generator via a shaft and powers it to generate electricity.

The steam precipitates and the water can be reused by feeding it back into the boiler. A flow chart of this process can be seen in Figure 20. A comparatively low temperature is sufficient for this kind of power generation (approx. 600°C), however, also the thermal efficiency is not very high with 41.6-45.2%. (TEPCO Fuel & Power Inc., 2019; Verbund AG, 2019)

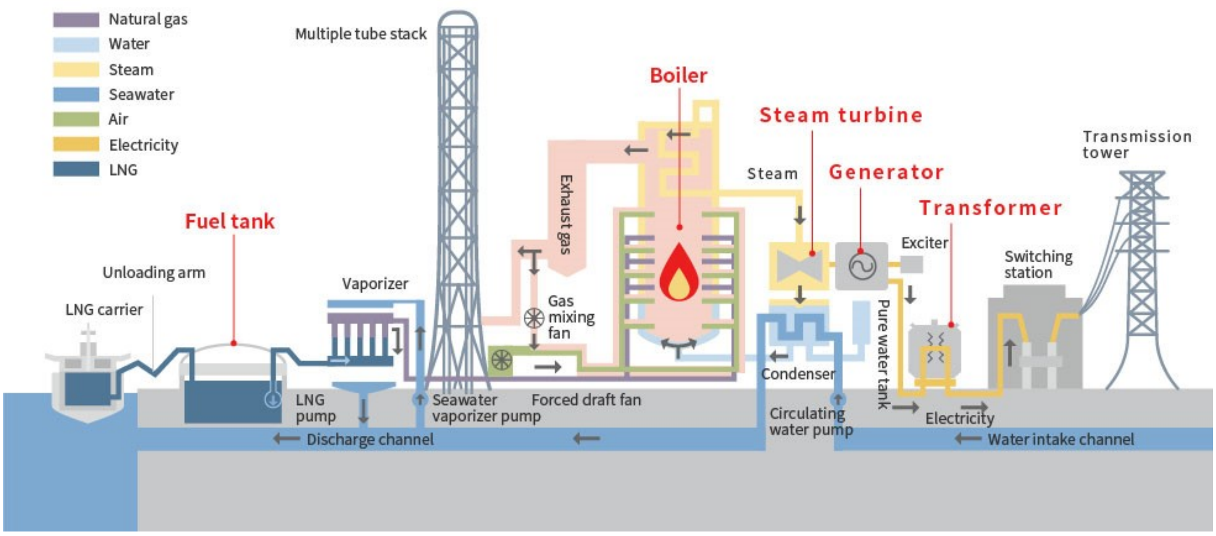

Figure 20: Schematic graphic of a thermal power plant using a combined-cycle (TEPCO Fuel & Power Inc., 2019)

Ad 2. Combined-cycle power generation

A combined-cycle power plant uses steam power exactly like in the steam power generation, additionally it generates combustion gas by burning a mixture of fuel and air that has been compressed in a gas turbine beforehand. The gas flows through the power turbine of the gas turbine that is also connected to the generator, which is driven by the expansion of the gas. The remaining gas is then used to heat the water to generate steam.

This power plant operates at a higher temperature (1100 °C gas temperature after burning process, 560°C steam temperature) and has a higher thermal efficiency of 47.2% than a steam power plant. (TEPCO Fuel & Power Inc., 2019)

Ad 3., Ad 4. (More) Advanced Combined Cycle ((M)ACC) generation

Power plants of this type work based on the same principles as the combined-cycle power generation, the only difference is the higher temperature of the combustion gas (ACC: approx. 1300°C, MACC: approx. 1500°C) and therefore the higher thermal efficiency of 54.1-57.2% and 58.6% respectively. (TEPCO Fuel & Power Inc., 2019)

Ad 5. Combined heat and power generation

Combined heat and power generation can use any of the above-mentioned types of electricity generation. The difference is that not all of the produced steam is used for driving the turbine, but some is redirected to heat exchangers transferring heat to the hot water network for district heating. (Verbund AG, 2019) The efficiency of this type of power plant is a combination of the efficiency of the power production and the heat production. The total efficiency ranges up to 85%.

For further evaluations a combined heat and power plant using biomass is chosen due to the lack of data on materials and their amounts used for the construction of the other power plant types. So, in fact, two types of renewable energy production are compared. This power plant usually consists of a main building and a storage building. The main building houses the facilities for the actual heat and power production, including a block-type power station, gas buffer, scrubber, cooler, biochar mixer, biomass feeding, pyrolysis, reduction reactor, hot gas filter, balance tank district heating, and control units. (Käppler, 2015)

Käppler conducts a life cycle assessment of a combined heat and power plant. The power plant evaluated has a nominal power of 250 kW_{el} and 260 kW_{therm}. In 2016 1,517 MWh of electricity and 2,189 MWh of thermal energy were produced in 7,986 operating hours resulting in an average power output of 190 kW_{el}. However, this plant also has a power demand of 161 MWh per year.

Unfortunately, this was the first year of production of this power plant, meaning there were numerous unplanned downtimes and the production was not as efficient as planned. More current numbers could not be obtained.
The material flow diagram for energy in and output, as well as a layout for the main building can be found in the Annex.

According to this study the materials and their amounts required for building such a plant are as follows. (Käppler, 2015)

Main building

- Foundation:
  - 700 kg sand and gravel
  - 312 m^3 reinforced concrete
  - 480 m^2 moulding, i.e. 18 m^3 wood
- 17 m^2 glass windows, i.e. 850 kg glass
- 150 m^2 tar paper, i.e. 1,500 kg bitumen seal
- 1,050 kg roof insulation, i.e. polystyrene foam stab

Storage building

- Foundation:
  - 798 t gravel
  - 108 m^3 concreate (sole plate and foundation)
- Walls:
  - 56 m^3 reinforced concrete
  - 76 m^3 moulding from wood
- 24 steel pillars, i.e. 16,800 kg steel
- Roof: 1,100 m^2 troughed sheet, i.e. 14.68 kg steel
- 300 kg steel fan

Carburettor

- 7.2 t chromium alloy steel
- 9.6 t galvanised steel (stairs and other plant components)
- 350 kg aluminium
- 350 kg copper (electric components)
- 3 t rock wool (insulation)
- 24 ceramic filter cartridges 3,50 kg each

Block-type power station

- 240 kW gas engine
- Control unit: 275 kg steel, 0.15 kg aluminium, 10.8 kg copper, 78.5 kg polyethylene
- Noise protection: 1,919 kg steel, 480 kg rock wool
- Converter: 488 kg steel

Main building, storage building, and carburettor have an expected useful life of 30 years, whereas the block-type power station itself has a service life of approx. 8 years. The carburettor needs to be refurbished after 15 years – half the components have to be exchanged enabling a further 15 years of operating time. Steel used for construction of the storage building can be recycled. The same is valid for aluminium, copper, and steel from the carburettor, and copper and steel from the power station. However, recyclable components make up less than 2% of total material input for construction. Not recyclable wastes are concrete, wood, insulation, bitumen seal, glass, rock wool, and filter cartridges. (Käppler, 2015) Wood is also counted as unrecyclable, nevertheless, it is a renewable material and easy to dispose of.

In order to be able to compare the material input of the two different electricity production plants the input is summarised per material group and calculated in kg per kWh in the next step.

Table 6: Materials for combined heat and power plant in [kg] and [kg/kWh]

Material	**[kg]**	**[kg/kWh]**
Aggregates	798,700	0.2
Concrete [1]	1,190,000	0.3
Steel (low alloyed)	29,396.7	0.008
Chromium alloy steel	7,200	0.002
Aluminium	350.2	0.0001
Copper	360.8	0.0001
Glass	934	0.0002
Insulation (Polyethylene/Polystyrene)	1,128.5	0.0003
Rock Wool	3,480	0.0009
Wood [2]	38,540	0.01
Bitumen Seal	1,500	0.0004
Total	**207,159.1**	**0.6**

[1]assumption: reinforced concrete density	2,500	kg/m3
[2]assumption: fir density	410	kg/m3
electricity	1,517,000	kWh per year
heating	2,189,000	kWh per year

Highlighted in green are renewable materials – here wood. Which means 1.86 % of total material input comes from renewable materials.

4.2 Wind Turbine

According to Komusanac *et al.* (WindEurope) 362 TWh of electricity were generated by wind turbines in 2018 covering 14% of the electricity demand of the EU. Wind energy is also the renewable energy technology accounting for most investments (63%) in 2018. Germany is the EU country accounting for the highest number of new installations as well as the highest installed wind power capacity. However, in terms of wind energy covering the electricity demand of a country, Denmark is in the lead with a share of 41%. Considering global electricity production, the total share of renewable energy in 2016 was 13.7%. Wind energy only takes up a share of 0.6%. This is significantly lower than EU average. The highest share of renewables is accounted for by biofuels and waste with 9.5% followed by hydropower with a share of 2.5% of global electricity production. Overall, oil is still the most important electricity source (31.9%), followed by coal (27.1%), and natural gas (22.1). However, renewable energy sources are catching up and have overtaken nuclear and other forms of power production (5.2%). (Komusanac *et al.*, 2019; International Energy Agency, 2018)

Wind turbines utilise the same principle for energy production as the turbines in thermal power plants. Wind (or air movement) is a form of kinetic energy, driving the turbine's blades creating rotational energy. Rotational energy is then converted into electricity via electromagnetic induction. The amount of wind power generated depends on the size of the rotor and the speed of the wind.

$$\text{wind power} \propto \text{rotor dimensions} \propto (\text{wind speed})^3$$

A typical wind turbine consists of three main components independent of its size: nacelle, rotor, and tower.

The materials used, the size, and the configuration of the wind turbine can vary. The largest wind turbines currently on the market have a power rating of 8.8 MW with a rotor diameter of 164 m. Offshore turbines are usually larger with a higher capacity than onshore turbines.

A turbine has an expected service life of 20 to 30 years, which is comparable to the combined heat and power plant discussed in the previous chapter (chapter 4.1). Additionally, a plus of 15 years can be achieved by refurbishing the turbine. (IRENA and IEA-ETSAP, 2016; Wilburn, 2011)

The nacelle houses the main components for electricity production, gearbox, rotor shaft and brake, generator, and yaw system. It is directly connected to the blades that capture the kinetic energy of the wind. The yaw system is responsible for aligning the nacelle with the wind direction. (IRENA and IEA-ETSAP, 2016)

Commonly, there are three blades due to better balance of gyroscopic forces. The profile of the blades is similar to that of airplane wings. Materials used are balsa wood or polymer foam for the core, and a fiberglass-reinforced plastic and epoxy adhesive mixture. Another possible material is carbon fibre-reinforced plastic that offers higher strengths for sites where the blades have to endure high stresses, however, costs are significantly higher. For smaller blades laminated wood is also an option. The blades are supported by the blade extender made of steel, mounted on the hub (the base) which is made of cast iron. Responsible for the blade angle in order to achieve the best possible energy recovery, or other adjustments according to wind and weather conditions, is the pitch drive, which consists of stainless and alloy steels.

The nacelle usually is responsible for 25-40% of the total weight the turbine, the rotor (incl. blades, blade extender, hub, and pitch drive system) for 10-14%.

The tower itself consists of a concrete foundation and steel sections accounting for approx. 30-65% of the weight. The tower is designed for each site individually in order to optimise the capture of wind energy. A graphical illustration of the main components is shown in Figure 21.

(IRENA and IEA-ETSAP, 2016; Wilburn, 2011)

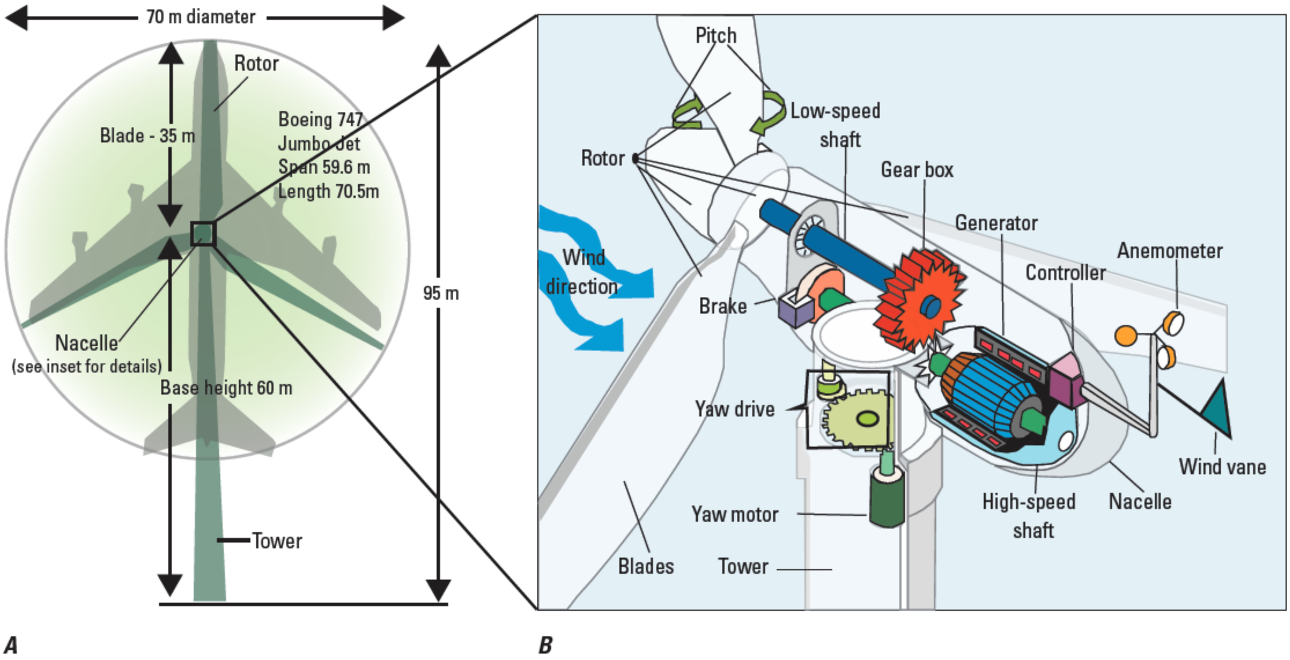

Figure 21: Dimensions (A) and main components (B) of a typical wind turbine (Wilburn, 2011)

There are different generator systems that can be used for electricity production in a wind turbine:

- double-fed, asynchronous wound-rotor generators
- asynchronous generators with a cage rotor
- direct drive, synchronous
- permanent magnet generators

The most frequently used generator type is currently the double-fed, asynchronous wound-rotor generator. The permanent magnet generators are used in approx. 23% of all wind turbines. Further development however, is somewhat unclear. Some forecasts predict a significant increase to 72% by 2030, other forecasts show a more conservative increase. Depending on the type of generator the raw materials required vary greatly. Permanent magnets rely on rare earths (neodymium and dysprosium) and no substitutes have yet been found. Wind turbines are responsible for 10% of total consumption of rare earths neodymium and dysprosium. (Wilburn, 2011; Dickson, 2018; Schüler *et al.*, 2011)

There are numerous authors conducting life cycle assessment (LCA) for wind turbines, e.g. (Haapala and Prempreeda, 2014) (InTech, 2012) (Asdrubali *et al.*, 2015) to mention just a few. Among other things, they provide a good overview of materials required for the production.

The LCA conducted by Venås (2015) compares two turbines for offshore electricity production - a conventional turbine with double-fed induction generator and a direct drive permanent magnet generator.

The materials used for the nacelle and respective amounts are stated in the following:

Conventional Generator

- Generator:
  10,426 kg copper
  23,406 kg low-alloyed and electrical steel
- Gearbox:
  41,703 kg cast iron
  41,703 kg (high alloy) chromium steel 18/8
- Housing:
  10,426 kg glass-fibre reinforced plastic, polyamide, injection moulding
- Main frame:
  35,259 kg cast iron
  19,476 kg low alloyed and electrical steel
- Main shaft:
  27,029 kg (high alloy) chromium steel 18/8
  4,770 kg low-alloyed and electrical steel
- Transformer:
  7,819 kg copper
  17,984 kg low-alloyed and electrical steel

(Venås, 2015)

Permanent Magnet Generator

- Generator:
  6,029 kg copper
  74,290 kg low-alloyed and electrical steel
  3,014 kg neodymium-iron-boron (NdFeB) material
- Housing:
  9,200 kg glass-fibre reinforced plastic, polyamide, injection moulding
- Main frame:
  31,115 kg cast iron
  17,187 kg low alloyed and electrical steel
- Main shaft:
  23,852 kg (high alloy) chromium steel 18/8
  4,208 kg low-alloyed and electrical steel
- Transformer:
  6,900 kg copper
  15,870 kg low-alloyed and electrical steel

Permanent magnets using NdFeB-materials consist of 70% iron, 29% neodymium, and 1% boron. Usually, it is not pure neodymium but rather an alloy of neodymium with another rare earth element. Preferably, praseodymium as it has very similar properties to neodymium and does not change the magnetic field. The ratio of the mixture depends on the ore used, as separation is very difficult and expensive (commonly 4 parts neodymium to 1 part praseodymium). Adding dysprosium can have positive effects on the strength of the magnetic field especially at higher temperatures. It also improves the corrosion resistance of the magnet. Alternatively, terbium can be used with similar effects. Dysprosium is added with 3-5% of the total weight of the magnet, terbium with < 1%. (Venås, 2015)

Breaking down the amount of NdFeB-material used for the turbine (3,014 kg), 2,109.8 kg iron, 874.1 kg rare earths, and 30.1 kg boron are required.

The comparison of material input for a conventional generator to a permanent magnet generator shows that the permanent magnet generator does not require a gearbox. Therefore, it is saving more than 80 t of cast iron and high alloy chromium steel (approx. 41 t each). Also, for the other parts the permanent magnet turbine has a lower material input than the conventional turbine. However, it requires 50 t more low alloyed steel for the generator and additionally 3 t of NdFeB-material. In total the material input for the permanent magnet turbine is 41 t lower than for the conventional turbine. (Venås, 2015)

While permanent magnets seemed to be the way forward for some time, it is currently not clear how their application will develop in the future. One of the largest wind turbine producers, Vestas, pursues the production of conventional drive turbines which require approx. 1/10 of rare earth elements, as opposed to direct-drive (without gearbox) turbines. In conventional drive turbines rare earth elements are still used in generator magnets and magnets used in the tower, however, they do not contain permanent magnets and contribute < 0.1% to life cycle impacts. (Vestas, 2019)

On the other hand, the company ENERCON, the wind turbine producer with the largest market share in Germany, switched its production completely to gearless systems. Also, Siemens and GE Renewable Energy offer direct drive turbines. Permanent magnets are very useful for offshore wind farms. (Schüler *et al.*, 2011; GE Renewable Energy, 2019; Siemens, 2017)

As they operate without a gearbox, they are very robust in harsh weather conditions, achieve higher efficiencies, and are lighter. However, the high costs for the magnets are a major drawback. (Schüler *et al.*, 2011; GE Renewable Energy, 2019; Siemens, 2017)

For further evaluations a current model Vestas V116 – 2.0 MW (induction generator) onshore wind farm will be considered. This turbine is 80 m high and has a rotor diameter of 116 m. The farm contains 25 turbines and has a capacity of 50 MW. The proposed lifetime is 20 years. The electricity production depends on the wind speed, assuming medium wind speed at 8.5 m/s the farm produces 243.85 GWh per year (9,755 MWh per turbine per year). These numbers assume an availability of 98.5% and include total plant electrical losses up to the grid of 2.5% and average plant wake losses of 6%. (Razdan and Garrett, 2018)

The materials for this farm are again summarised and stated in kg and kg per kWh (see Table 7).

Table 7: Materials for wind farm in [kg] and [kg/kWh]

Material	[kg]	[kg/kWh]
Concrete	18,328,000	0.08
Steel (low alloyed/cast iron)	5,419,000	0.02
High alloyed steel	727,000	0.003
Aluminium/ -alloys	221,000	0.001
Copper	102,000	0.0004
Ceramic/glass	365,000	0.001
Modified organic natural materials	94,000	0.0004
Other materials and compounds	48,000	0.0002
Magnets	1,000	0.000004
SF_6 gas	243	0.000001
Electronics	77,000	0.0003
Lubricants and liquids	41,000	0.0002
Not specified	11,000	0.00004
Total	**25,434,243**	**0.1**

electricity	243,850,000	kWh per year

Considering the materials used for the construction of the wind farm it cannot be identified whether any renewable materials are used, as “modified organic natural materials” is not specified in more detail. Many first-generation wind farms are about to reach their end-of-life, so considering recyclability is of utmost importance.

According to Vestas many parts of the turbine can be recycled almost entirely. For example, tower sections consisting mainly of mono-material (steel, cast iron, etc.) can be recycled up to 98%. Gearbox, generator, cables, and yaw system reach 95% recyclability. In general, steel, aluminium, and copper used are 92% recyclable, 8% go to landfills. Not recyclable materials are polymers, fluids, and other materials.

These make up 74% of total material input of the wind farms considered in Table 7 (incl. concrete, ceramic/glass, modified organic natural materials, other materials and compounds, lubricants and liquids, and not specified).

4.3 Comparison

To evaluate differences between thermal power plants and wind turbines in terms of raw material input for construction, Table 8 shows a comparison of both.

Table 8: Comparison of material input for combined heat and power plant and wind farm in g per kWh

Material	Combined heat and power plant [g/kWh]	Wind turbine [g/kWh]
Aggregates	215.5	
Concrete	321.1	75.2
Steel	7.9	22.2
Chromium alloy steel	1.9	3.0
Aluminium	0.1	0.9
Copper	0.1	0.4
Ceramic/glass	0.3	1.5
Insulation (Polyethylene/Polystyrene)	0.3	
Rock Wool	0.9	
Wood	10.4	
Bitumen Seal	0.4	
Modified organic natural materials		0.4
Polymer materials		2.2
Other materials and compounds		0.2
Magnets		0.004
SF_6 gas		0.001
Electronics		0.3
Lubricants and liquids		0.2
Not specified		0.04
Total	**558.9**	**106.5**

Table 8 shows that the material input in grams per kilowatt hour for the biomass combined heat and power plant (558.98 g/kWh) is approx. five times larger than for the wind farm (106.54 kg/kWh). As already mentioned in chapter 4.1, the produced energy amount of the combined heat and power plant used for this calculation is marked by higher downtimes than usual. This means that the material input per kilowatt hour is likely lower for ‘normal’ production years. However, it is doubtful whether a similarly low amount as for the wind farm can be achieved.

Materials used for both power plants are similar. The largest share of material input is concrete for the foundations, followed by low alloyed steel or cast iron. The relative amounts of recyclable materials used in the construction of the wind farm are significantly higher than for the combined heat and power plant – 26% to 2%. However, the combined heat and power plant also uses renewable materials (wood) for its construction, approx. 1.86% of total raw material input.

Another important aspect to consider is the operating time of the power plants. While the combined heat and power plant has a service life of approx. 30 years (apart from the carburettor, and the block-type power station), the wind turbine only has an operating time of approx. 20 years. For that reason, the material input in gram per kilowatt hour and year is used.

Table 9: Comparison of material input for combined heat and power plant and wind farm in g per kWh and year

Material	**Combined heat and power plant [g/(kWh*a)]**	**Wind turbine [g/(kWh*a)]**
Aggregates	7.2	
Concrete	10.7	3.8
Steel	0.4	1.1
Chromium alloy steel	0.1	0.1
Aluminium	0.004	0.04
Copper	0.004	0.02
Ceramic/glass	0.01	0.07
Insulation (Polyethylene/Polystyrene)	0.01	
Rock Wool	0.06	
Wood	0.3	
Bitumen Seal	0.01	
Modified organic natural materials		0.02
Polymer materials		0.1
Other materials and compounds		0.01
Magnets		0.0002
SF_6 gas		0.0000
Electronics		0.02
Lubricants and liquids		0.01
Not specified		0.002
Total	**18.8**	**5.3**

For this comparison the materials required for the carburettor are multiplied with 1.5, and for the block-type power station times 3.75. Table 9 shows that including the service life of the two power plants into the considerations the difference of the material input decreases. Now the material input for the combined heat and power plant is only 3.5 times higher than for the wind farm.

The metals used in both power plants show a high recyclability. According to Braedel *et al.* (2011) the End-of-life Recycling Rate for chromium is 90% (average value), for iron 72% (average), for aluminium 58% (average), and for copper 68%. Moreover, none of these metals are considered as critical for the EU. The largest producers of iron in 2017 were Australia, China, and Brazil. There is also iron production in the EU – for example, in Sweden and Austria. EU producers of aluminium are among others Germany and France. The largest producers worldwide are China and Russia. Chromium is produced in Finland and Greece, Copper in Spain and Bulgaria. More detailed information on countries producing the metals discussed can be found in the Annex. The tables are organised by the largest producer in 2017.

Wind turbines also contain sulphur hexafluoride gas (SF_6). It is used in switchgears that are used in every turbine and to connect turbines and transformer stations. SF_6 is a very powerful greenhouse gas and its disposal has to be done very carefully as to not release it into the atmosphere. Therefore, the switchgears have to be collected and SF_6 gas is reclaimed for reuse. (Vestas, 2019)

For the sake of completeness, materials used for permanent magnets in wind turbines shall be considered as well. Schüler *et al.* find that the recycling of permanent magnet materials is far from ideal. Especially during the production process a lot of material is lost, which is not yet recovered. Studies show that approx. 20-30% of rare earth magnets are lost during production. There are various approaches on lab-scale on the reclamation of rare earth scrap from these processes; however, none are in use on large scale yet. Also, in terms of substitution (apart from the conventional drive for wind turbines) there are no commercially available alternatives offering the same performance, incl. coercivity, corrosion resistance, etc.

Rare earths are considered critical for the EU. The largest producer in 2017 was China producing 82% of global amounts. Between the years 2000 to 2010 the Chinese market share even increased to more than 95% (largest share in 2009 with 98%)! There is no rare earth production in Europe.

Wind wheels exist since the early days, they were already used in the 1st century AD to power machines. However, the first large scale wind farm was built in 1975 in the United States of America. The first off-shore wind farm was built in Denmark in 1991, that is also the time of the first direct drive turbines using permanent magnets with neodymium. (Schüler *et al.*, 2011; Shahan, 2014)

Beginning in the 1990 wind energy experienced an upswing. For example, in the United States the government established incentives for the use of renewable energy. They also funded research into more efficient and cheaper technologies. (U.S. Energy Information Administration, 2019)

Therefore, the development of production figures for the metals iron, aluminium, copper, chromium will be considered from 1990-2017 (most current figures) using WMD, rare earth elements from 1984-2017.

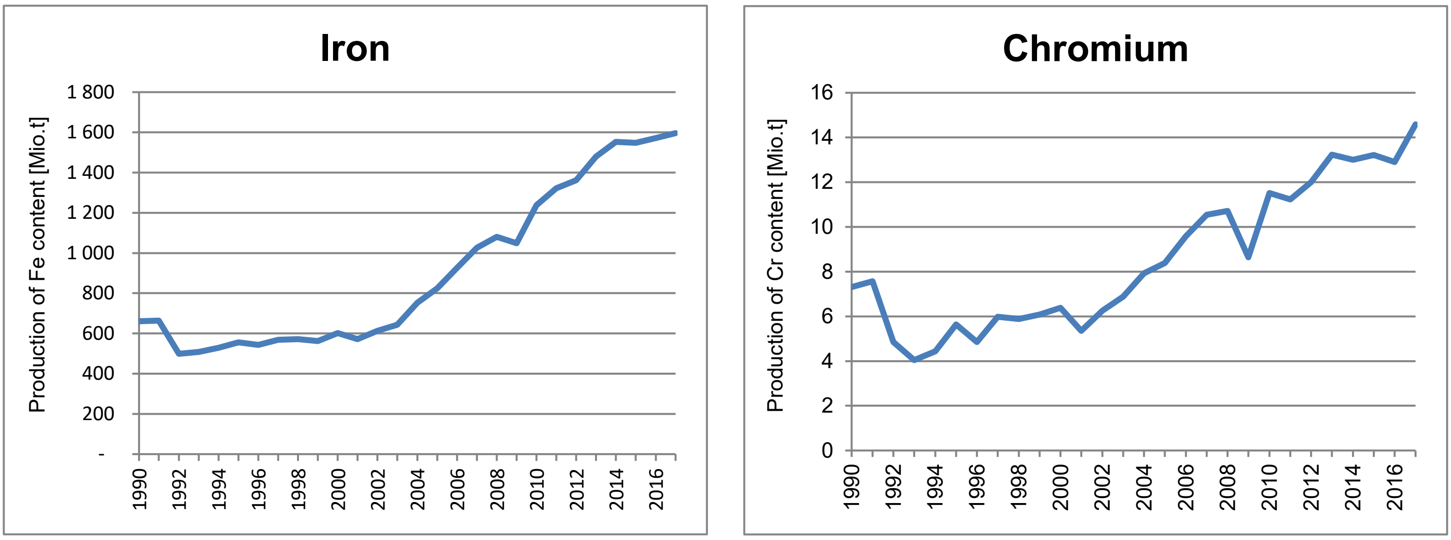

Figure 22: Development of production amounts of Iron content, Chromium content data source: Reichl *et al.*, 2019

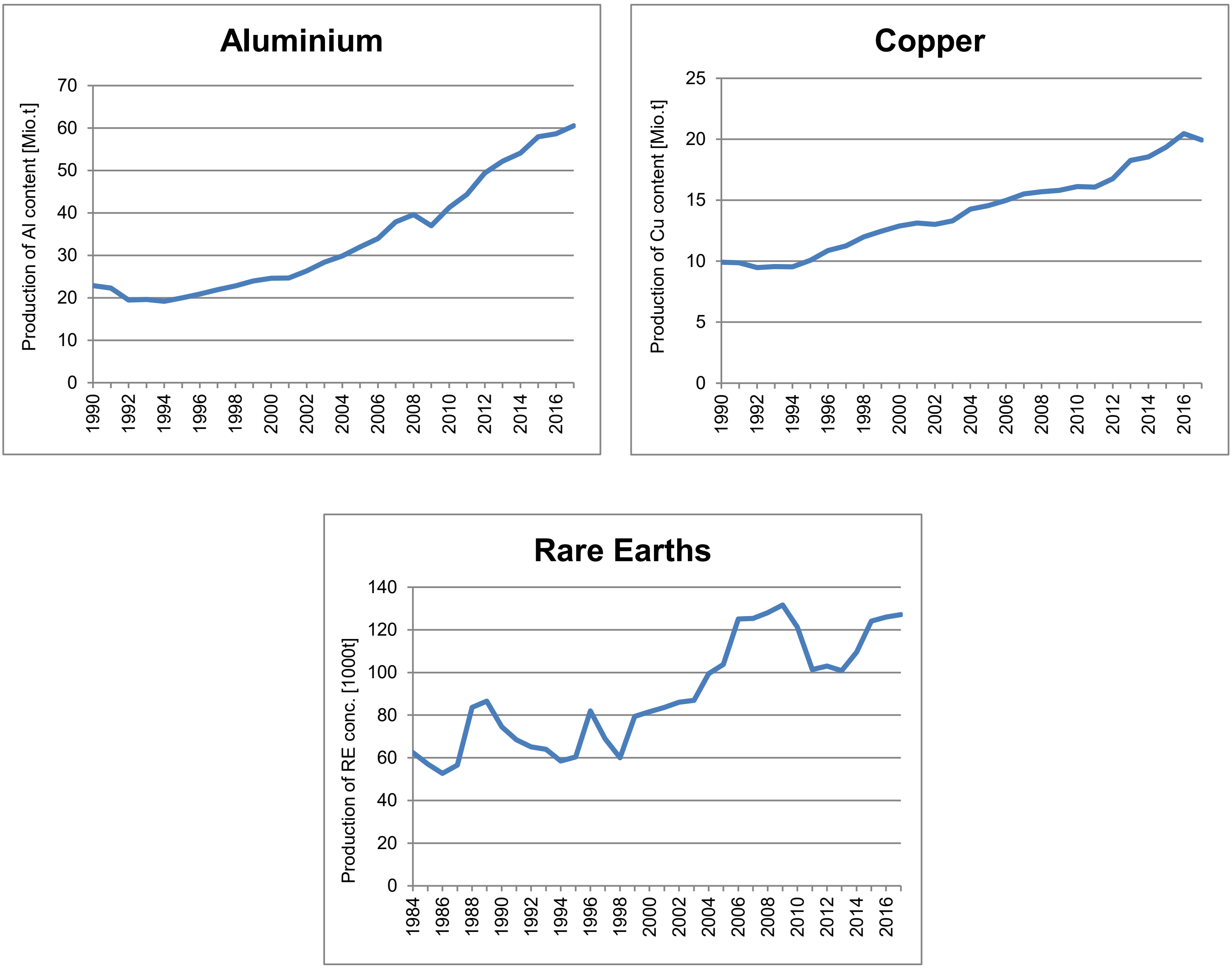

Figure 23: Development of production amounts of Aluminium content, Copper content, Rare Earth concentrates, data source: Reichl *et al.*, 2019

All five metals show an increase of production during the considered time span. However, iron, copper, aluminium, and chromium developments cannot be connected to either of the power plants directly. All of them are important construction materials and an increase of produced amounts is mainly due to economic developments, as discussed in chapters 3.3. and 3.3.1

Nevertheless, wind turbines are responsible for at least 10% of rare earth consumption. Their production shows a significant increase during the second half of the 1990s and especially between the years 2000 and 2010. In 2010 rare earth prices spiked, and China imposed export restrictions. (Schüler *et al.*, 2011)

In combination with economic recession rare earth production decreased. The recovery started in 2013. These developments correlate with the expansion of wind energy.
Another important difference is the energy and material input for electricity production. Firstly, the combined heat and power plant requires energy (electricity and heat) for the drying process of the wood chippings. For the assessed power plant this amounts to approx. 560 MWh. Secondly, in order to produce electricity and heat, it requires a constant input of biomass for the burning process. In 2016 that meant an input of 1,179 t wood chippings with a total energy content of 5,171.17 MWh. (Käppler, 2015)
The electricity required for operating wind turbines is neglectable. There are only minor amounts used for system controls.

This thesis does not consider material input for maintenance. Moreover, the transport, construction processes, grids, etc. are not evaluated. It can be assumed that distances between combined heat and power plant and its consumers are generally smaller than for wind farms. Wind farms, especially offshore farms, are usually long distances from the consumer, or existing electricity grids. That means, construction of new infrastructure is likely very resource intensive. Logistics and transport probably involve greater effort than for combined heat and power plants as well.
Another point not considered in this evaluation is the use of land which would be significantly higher for the wind farm by a factor of at least 10. The combined heat and power plant assessed here requires a space of 33,510 m². The wind farm consists of 25 turbines each with a rotor diameter of 116 m. That equals an area of 336.400 m² without considering the distance that needs to be included in between the turbines. (Käppler, 2015; Razdan and Garrett, 2018)

5 Conclusion

In chapter 2 Collections of Raw Material's Production Data, four different data collections for raw material production data are introduced. The data collections were chosen according to their public availability and the amount of countries and raw materials covered. These are three providers reporting global production, the Austrian Federal Ministry for Sustainability and Tourism and their World Mining Data (WMD), the British Geological Survey (BGS) and their World Mineral Production, and the United States Geological Survey (USGS) with their Minerals Yearbook. Moreover, one data provider for European production data is considered – Eurostat Material Flow Database in order to include a different form of reporting and see its advantages and disadvantages.

The goal is to assess the collections in terms of data reported (countries and raw materials included, physical form of raw material reported), methods of data collection, etc. These are then compared to find strengths and weaknesses.

It is also attempted to provide a guideline on which collection to use for what kind of information.

The conclusion is that the three international data reports provide very similar data, both in terms of commodities reported, and countries covered. Moreover, the methods of data collection also show a lot of commonalities. Mainly desktop research and information by contacts in governments and companies are employed, but also questionnaires are sent out to embassies or responsible government agencies.

The main differences can be seen in the setup of the reports and the additional data provided. BGS only reports production numbers sorted by commodity and subdivided by continent and country respectively. WMD has additional sections sorting production by development status of the countries, political stability, economic blocks, etc. It also provides graphics illustrating, for example, the distribution of raw material production among continents or major developments in global mining production. (Reichl *et al.*, 2019)

USGS has a different approach for the Minerals Yearbook as the other two international collections. Each commodity is published in a separate report, which also includes background information on the industry, uses, reserves, and resources. However, the main focus is on developments in the United States. This shows the manpower employed by the USGS. Each commodity report is edited by a commodity-specialist supported by data analysts. The same is the case for the country reports in Volume III of the Minerals Yearbook.

No clear recommendation as to what report to use can be given. All three providers have their strengths and the ideal collection depends on the application it is used for. The quality of data appears to be very similar; no major differences could be found. It seems the WMD are most coherent in terms of what form of raw material is reported, always focusing on metal content or concentrate/product available on the market. Moreover, it is very favourable that sources and reliability of data are clearly stated. BGS is preferred if long-term evaluations are conducted. They offer coherent data since 1913 and do not change the form a raw material is reported in in order to allow maximum comparability. USGS is most useful if additional data is required. One example for its application is the Critical Raw Materials list by the European Commission where information on the application, industry, etc. are an important input. However, a lot of the information provided is focused on the US.

Eurostat provides different data for European countries than the international collections. First of all, they report ores rather than metal contents. Secondly, many commodities are aggregated in groups and not reported separately, for example, precious metals, instead of gold, silver, etc. One advantage of this collection is the additional data provided, such as import and export figures, or physical trade balance. Moreover, very recent data is published usually with only a one-year delay. However, unfortunately the database is very incomplete, and a lot of data is not published due to privacy issues. Which makes a comparison of the actual figures with the international collections difficult and its use for long-term evaluations is not possible.

A comparison of actual production figures of the three international providers showed that there are differences, but they are usually minor. However, a comparison with Eurostat figures proved difficult, as many raw materials are aggregated in groups. Moreover, there are large gaps where figures are not published due to the mentioned privacy issues and in order to be able to compare the figures ores had to be converted to metal content (see chapter 2.5).

Chapter 3 Applications assesses different uses of raw material production data. There are many studies relying on the data providers discussed before.
The production figures are relevant for companies, both upstream and downstream for their strategic planning. Furthermore, they are a very important tool for policy makers, not only for ensuring raw material supply for the economies, but also for reaching targets in line with sustainability and circular economy considerations.

Two applications discussed in this chapter are the criticality assessment of the European Union, and the Sustainable Development Goals. The criticality assessment is a study conducted by the European Commission in a three-year interval. This study has the purpose of showing which minerals are of fundamental importance for the European economy, but are connected to supply risks. Without the production data and additional information by above mentioned reports, this evaluation would not be possible. However, this assessment also shows the need for improved data collection for Europe. For example, for many raw materials there is no information on their uses in the EU, but the criticality study has to rely on information by USGS for the US.

Production data is also highly relevant for assessing the progress towards achieving the Sustainable Development Goals, especially Goal 12 Responsible Production and Consumption. Production data, as well as import and export figures are used for modelling material flows of economic systems which show the material intensity of an economy. This is useful information for evaluating where policies have to act in order to achieve a more sustainable and efficient use of raw materials. Goal 12 needs special consideration in the European Union.

Even though most EU members show great progress towards achieving the SDGs in general, all of them struggle with Goal 12. The most critical issues are the sustainable management of natural resources and the abolishment of fossil fuel subsidies. (Sachs *et al.*, 2019; Bauer *et al.*, 2018)

Another interesting application of raw material production data is material flow accounting (MFA). MFA analyses the material flows into, inside, and out of an economic system.

With this analysis consumption patterns can be identified which makes it a very useful tool in the efforts for achieving SDG 12 and circular economy. For this purpose, long-term data is necessary. Therefore, Krausmann *et al.* mainly use USGS as a source of production data as they range back to 1900. However, MFA utilises the "run-of-mine"-concept which means metal contents reported by USGS (or the other international collections) need to be converted to gross ores. The conversion requires the knowledge of the percentage of metal inside the ore which varies greatly between different deposits. Usually an average value is chosen. This can lead to deviations between gross ore calculated and actual produced amount.

Another issue for MFA is the missing recording of aggregates, such as sand and gravel, or limestone. In order to conduct a complete MFA for an economy these materials are very important as they are a major input in infrastructure and building stock. To evaluate these amounts a bottom-up approach is used for estimations – number of kilometres of roads built requires so much material, etc.

The last part of this thesis, chapter 4 Raw Material's Consumption in Light of New Technologies, compares the raw material input of two electricity producers. It evaluates a combined heat and power plant, producing electricity and heat for district heating by burning biomass, and an onshore wind farm of 25 wind turbines. The material input for building both types of power plants is put in relation to the amount of energy produced per year and the lifetime of the power plant. This comparison shows that the material input in gram per kilowatt hour and operating year for a wind farm (5.33 g/(kWh*a)) is lower than for a combined heat and power plant (18.80 g/(kWh*a)). The wind farm also uses a higher percentage of recyclable materials. On the other hand, the combined heat and power plant utilises renewable materials for the construction.

The combined heat and power plant also relies on constant energy and material input (electricity and biomass) for electricity and heat production.
However, certain kinds of wind turbines use rare earths for permanent magnet generators and are responsible for approx. 10% of total global consumption of neodymium and dysprosium. Not only are rare earths considered critical for the European Union as China is the main producer with a market share of over 82% in 2017. (Reichl *et al.*, 2019) But also, the processing is a very inefficient process causing a lot of material loss and the recycling rates of rare earth magnets are still very low. (Schüler *et al.*, 2011; Dickson, G., 2018)

Considering the materials used for the construction, it was not possible to show a relation between the production figures of the metals and the type of power plant being constructed, as both types of plants use the same common materials that are used in all forms of construction worldwide. Only rare earth production likely shows a connection to increasing wind turbine production.

Not assessed are the construction of new infrastructure, logistics, and transport. Which are probably higher for the wind farm due to longer distances from the existing grid and its consumers. Also, the area required for both types of power plants was not evaluated. Again, this would mean a much higher consumption of resources from the wind farm than the combined heat and power plant. The considered combined heat and power plant utilises a space of 33,510 m², whereas the wind farm requires more than 336,400 m² (25 turbines with 116 m rotor diameter each, not considering the distance between the turbines). (Käppler, 2015; Razdan and Garrett, 2018)

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7 List of Figures

8 List of Tables

9 List of Equations

10 List of Abbreviations

Approx.	approximately
BGS	British Geological Survey
BRICS	Brazil, Russia, India, China, South Africa
conc.	concentrate
CR	Old Scrap Collection Rate
DE	Domestic Extraction
DG	Directorate General
DMC	Domestic Material Consumption
DPO	Domestic Processed Outputs
D.R.	Democratic Republic
EC	European Commission
e.g.	for example
EoL-RR	End-of-Life Recycling Rate
EU	European Union
et al.	Lat. et alia, and others
etc.	Lat. et cetera, and so forth
GE	General Electric
Gt	Gigatonne
GWh	Gigawatt hour
HHI	Herfindahl-Hirschmann Index
IECrp	Input ecological cycling rate potential
IIASA	International Institute for Applied System Analysis
i.e.	Lat. id est, that means
IntOut	Interim outputs
IRP	International Resource Panel
ISCr	Input socioeconomic cycling rate
JRC	Joint Research Centre
kg	kilogram
kW_{el}	Kilowatt electric

kWh	Kilowatt hour
kW_{therm}	Kilowatt thermal
LCA	Life cycle assessment
LKAB	Luossavaara-Kiirunavaara Aktiebolag
m^2	Square meter
m^3	Cubic meter
metr.	metric
MFA	Material Flow Analysis
Mt	Megatonne
MW	Megawatt
MWh	Megawatt hour
OECD	Organisation for Economic Co-operation and development
OECrp	Output ecological cycling rate potential
OSCr	Output socioeconomic cycling rate
OSR	Old Scrap Ratio
PM	Processed materials
RMC	Raw Material Consumption
RMIS	Raw Material Information System
SDG(s)	Sustainable Development Goal(s)
t	metric ton
UN	United Nations
TWI	The World in 2050 initiative
UNEP	United Nations Environment Programme
USA (U.S.)	United States of America (United States)
USGS	United States Geological Survey
vs	versus
WMD	World Mining Data

Annex

Annex Table of Contents

1. Combined Heat and Power Plant

- Energy Flows of Biomass Heat and Power Plant used for comparison in chapters 4.1 and 4.3

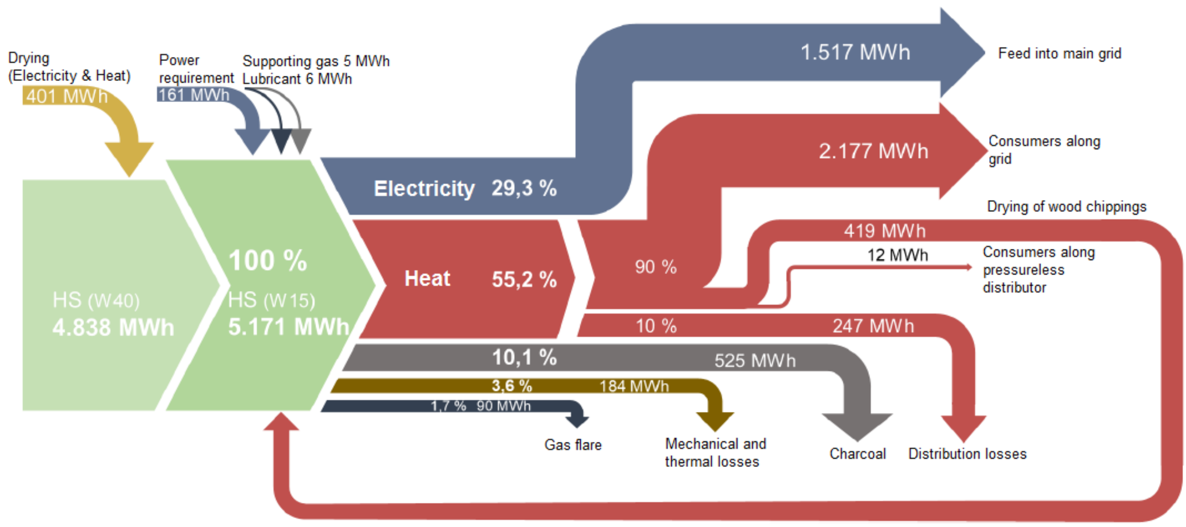

Figure 24: Energy flows of biomass heat and power plant, adapted from Käppler (2015)

- Layout of main building

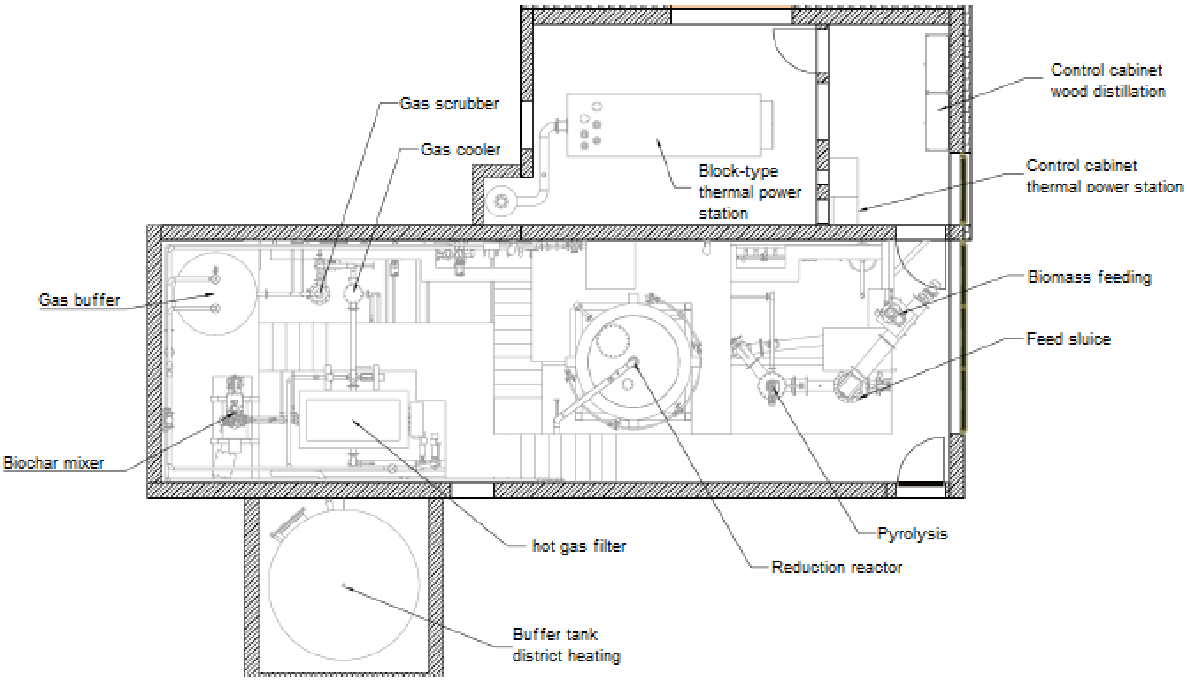

Figure 25: Layout main building biomass heat and power plant, adapted from Käppler

2. Raw Material Production Data for Chapter 4.3

Iron

Table 10: Iron producers [metr. t iron content], organised by largest producer in 2017 (Reichl, *et al.* 2019)

Country	1990	1991	1992	1993	1994	1995	1996	1997
Total	661,058,221	663,870,013	499,118,560	508,864,219	528,153,135	555,323,949	543,420,383	568,832,928
Australia	66,402,630	74,133,990	72,075,000	75,334,406	80,950,590	90,049,680	92,698,830	100,583,910
China	48,424,500	51,450,600	56,635,200	61,114,500	63,180,000	66,150,000	68,116,400	67,230,000
Brazil	98,808,800	98,234,500	95,037,200	101,925,600	112,812,800	119,951,300	113,230,000	120,230,500
India	34,384,700	36,202,950	34,421,310	36,208,620	38,110,270	37,788,000	38,856,000	46,900,000
Russia	132,000,000	132,000,000	43,361,784	41,250,000	40,319,400	43,065,000	39,655,000	38,940,000
South Africa	19,725,500	17,574,050	16,361,150	17,659,850	19,817,200	20,763,600	20,038,200	21,595,600
Ukraine			47,936,904	41,600,000	30,878,400	30,240,000	28,560,000	31,800,000
United States	35,695,000	35,333,000	35,251,000	35,116,000	36,788,000	39,577,000	39,186,000	38,000,000
Canada	21,760,000	21,936,200	19,265,020	19,349,200	22,329,660	22,343,080	21,965,400	22,744,000
Iran	1,100,000	1,800,000	2,382,600	5,625,900	5,214,000	5,448,000	4,455,964	4,828,300
Sweden	12,727,700	9,260,590	12,337,280	11,900,790	12,584,384	10,678,841	9,416,960	9,809,205
Kazakhstan			13,836,478	13,130,000	13,458,000	18,525,000	16,250,000	13,700,000
Chile	5,035,031	5,163,894	4,406,640	4,350,405	5,272,758	5,142,300	5,539,471	5,330,180
Mauritania	7,304,000	6,200,000	5,090,200	6,279,000	6,722,300	7,484,100	7,252,700	7,663,500
Mexico	5,327,900	4,976,100	5,154,000	5,597,000	5,516,200	5,625,100	6,109,500	6,279,800
Turkey	2,708,680	2,728,895	3,254,440	3,563,760	3,175,175	2,712,147	3,453,973	3,292,795
Peru	2,181,321	2,460,338	1,976,663	3,474,378	4,636,628	3,948,200	2,915,691	2,965,889
Venezuela	13,224,830	13,793,900	12,576,625	10,628,775	11,535,922	12,274,920	13,130,460	15,775,200
Mongolia								
Sierra Leone								
Vietnam								
Malaysia	216,840	236,800	201,549	140,394	202,682	181,972	285,294	269,087
New Zealand	1,285,846	1,324,940	1,716,455	1,521,000	1,200,600	1,370,074	1,353,578	1,450,000

Country	1990	1991	1992	1993	1994	1995	1996	1997
Liberia	2,750,000	550,000	923,400		-	-	-	-
Norway	1,498,324	1,593,304	1,521,604	1,531,552	1,650,000	1,458,300	1,117,651	478,000
Austria	652,969	480,867	510,033	448,080	519,137	664,455	634,226	574,121
Bosnia-Herzegovina				250,000	200,000	150,000	100,000	100,000
Indonesia	79,970	95,280	158,300	200,662	192,899	191,604	233,800	284,000
Korea, North	3,600,000	4,200,000	4,200,000	4,500,000	4,500,000	4,000,000	3,800,000	3,700,000
Colombia	282,716	308,471	320,951	245,149	274,462	330,300	272,572	339,647
Algeria	1,588,140	1,266,000	1,362,400	1,228,500	1,105,380	1,188,000	1,212,300	883,980
Saudi Arabia						155,000	139,160	110,000
Egypt	1,350,000	957,900	1,076,200	985,423	1,741,050	1,094,944	1,000,000	1,233,000
Pakistan	1,700	125	222	1,164	2,504	-	-	2,015
Korea, South	178,980	132,920	132,900	131,200	114,790	110,670	132,700	177,580
Tunisia	196,000	204,700	179,300	191,000	155,500	122,100	129,000	142,800
Laos								
Germany	11,686	16,841	15,326	20,400	20,400	9,600	14,600	32,046
Morocco	88,480	62,166	50,850	39,800	38,110	27,383	7,105	7,207
Argentina	444,115	88,932	2,502	1,372	28,181	310	-	-
Bolivia	125,264	101,642	34,945	32,118	35,400	-	-	-
Bhutan								
Malawi								
Guatemala				2,486	2,400	1,680	2,053	2,100
Namibia								
Uganda								
Uruguay	151	1,400	1,640	-	-	735	845	2,210
Thailand	79,750	148,850	264,890	129,500	88,533	34,480	85,880	44,000
Azerbaijan			18,500	18,900	19,000	19,800	20,000	21,900
Kenya								
Nigeria	80,000	149,701	130,000	100,000	100,000	107,520	20,423	48,988
Philippines								
Sudan								

Country	1990	1991	1992	1993	1994	1995	1996	1997
Swaziland								
Albania	425,697	203,830	10,000	8,000	7,000	7,000	6,500	6,000
Bulgaria	289,528	196,344	239,000	185,965	197,456	215,945	222,424	260,550
Czech Republic				-				
Czechoslovakia	467,500	416,900	269,580					
Ecuador			-					
Finland		-		-				
France	2,790,000	2,256,000	1,692,000	1,020,000	706,000	432,000	422,000	145,300
Japan	21,000	31,444	39,791	10,621	3,058	1,301	3,563	1,537
Portugal	4,810	6,080	5,382	6,114	5,409	5,417	7,876	7,933
Romania	273,730	199,576	182,100	169,000	165,050	159,000	159,250	110,373
Slovakia				162,740	289,400	261,027	256,000	264,174
Spain	1,327,873	1,747,523	1,334,476	1,139,946	991,848	973,823	606,393	27,806
Sri Lanka	-							
United Kingdom	12,740	13,570	7,130	253	299	230	276	276
USSR (Asia)	22,902,000	22,902,000						
USSR (Europe)	109,098,000	109,098,000						
Yugoslavia	1,367,690	947,100	450,000	110,000	84,900	96,200	150,000	150,000
Zimbabwe	756,130	681,800	707,640	224,696	210,000	186,811	194,365	287,419

Country	1998	1999	2000	2001	2002	2003	2004	2005
Total	572,243,077	562,252,632	601,478,218	571,259,047	613,184,841	643,160,500	752,391,134	823,854,202
Australia	96,997,320	100,641,870	107,728,740	113,000,000	114,000,000	116,000,000	145,501,650	164,710,350
China	66,663,000	64,052,100	60,102,000	58,594,000	62,486,100	70,575,300	93,511,800	113,532,300
Brazil	128,375,000	126,428,300	138,174,400	132,228,200	140,579,700	147,052,900	173,766,200	185,849,400
India	45,223,000	47,946,000	53,993,290	57,771,420	66,378,240	82,301,460	97,781,140	110,704,100
Russia	39,765,000	45,210,000	47,905,000	45,100,000	46,310,000	47,000,000	52,800,000	52,250,000
South Africa	21,426,600	19,179,346	21,909,787	22,592,050	23,714,610	24,755,900	25,559,300	25,702,347
Ukraine	30,420,000	28,661,400	33,390,000	32,796,000	35,580,000	30,464,000	32,320,000	34,048,000
United States	37,926,000	36,381,870	39,690,000	20,962,557	32,489,100	28,053,270	34,083,000	34,650,000
Canada	23,774,000	20,734,000	21,781,000	16,458,410	18,891,090	20,103,770	17,159,910	17,289,230
Iran	7,380,000	7,419,764	7,422,000	6,500,000	8,960,199	7,478,646	7,959,000	9,162,000
Sweden	13,461,760	12,096,000	13,156,480	12,471,040	12,979,840	13,758,720	14,254,080	14,883,200
Kazakhstan	8,693,000	9,607,000	10,553,000	10,335,000	9,898,000	12,532,585	13,196,625	12,656,215
Chile	5,681,224	5,090,450	5,324,629	5,388,862	4,433,968	4,864,718	4,849,878	4,707,000
Mauritania	6,726,200	6,604,000	7,527,000	7,004,000	6,125,600	6,890,000	6,828,315	7,236,450
Mexico	6,334,300	6,885,200	6,795,400	5,269,800	5,965,400	6,759,200	6,889,500	7,012,300
Turkey	3,281,268	2,712,717	2,233,309	2,439,042	1,888,027	2,819,500	2,760,100	3,080,800
Peru	3,282,118	2,672,630	1,882,573	2,066,113	2,078,117	2,369,732	2,888,078	3,104,193
Venezuela	16,214,192	9,328,344	11,092,014	11,250,262	11,259,209	11,935,819	12,477,550	13,766,000
Mongolia							21,000	109,000
Sierra Leone								
Vietnam								463,380
Malaysia	376,090	337,462	258,553	376,476	404,350	596,612	663,732	598,251
New Zealand	1,276,000	1,333,208	1,558,002	947,293	1,007,244	1,127,021	1,348,453	1,277,729
Liberia	-							
Norway	409,200	338,000	458,000	381,000	476,000	398,868	573,000	448,000
Austria	573,440	559,040	595,024	589,848	621,363	679,932	604,614	665,344
Bosnia-Herzegovina	100,000	100,000	363,351	264,540	212,114	126,929	130,000	1,390,000

Country	1998	1999	2000	2001	2002	2003	2004	2005
Indonesia	280,500	276,200	231,200	242,400	105,000	135,300	43,800	48,400
Korea, North	3,500,000	3,300,000	3,200,000	3,000,000	2,900,000	1,260,000	1,300,000	1,400,000
Colombia	236,621	259,386	297,049	286,577	309,648	281,251	264,250	273,402
Algeria	972,000	721,440	720,000	719,000	718,000	744,120	763,560	828,900
Saudi Arabia	100,000	132,810	141,000	235,000	224,700	220,000	268,200	280,000
Egypt	1,350,639	1,500,000	1,451,545	829,362	800,000	780,000	760,000	800,000
Pakistan	6,291	17,320	18,000	20,000	22,000	23,000	25,000	33,000
Korea, South	142,950	112,790	97,920	13,620	94,060	104,410	135,770	127,780
Tunisia	119,800	120,000	99,000	110,000	109,100	86,600	138,200	111,500
Laos								
Germany	84,680	114,000	73,844	65,120	58,711	60,300	57,700	37,796
Morocco	5,685	6,625	5,615	5,006	5,736	1,450	4,390	5,870
Argentina	-	-	-	-	-	-		
Bolivia	-	-	-	-	-			
Bhutan								
Malawi								
Guatemala	3,265	6,742	10,402	9,600	22,544	1,456	1,807	7,211
Namibia								
Uganda							-	125
Uruguay	2,500	3,837	6,000	9,743	7,768	5,941	9,319	12,435
Thailand	90,700	122,633	150,000	32,000	285,000	4,800	68,000	143,186
Azerbaijan	22,000	7,100	8,200	4,700	9,000	12,000	19,100	3,066
Kenya								
Nigeria	12,029	14,000	15,909	16,306	10,000	36,855	59,440	54,270
Philippines								
Sudan								
Swaziland								
Albania	5,500	5,300	5,000	4,800	4,600	4,500	4,400	4,300
Bulgaria	185,039	361,200	304,100	240,000	217,553	205,000	36,400	16,940

Country	1998	1999	2000	2001	2002	2003	2004	2005
Czech Republic								
Czechoslovakia								
Ecuador								
Finland								
France	-	-	-	-	-			
Japan	1,720	1,800	1,454	1,449	1,440	1,300	1,200	1,100
Portugal	8,159	4,739	4,766	4,700	4,500	4,300	4,200	4,100
Romania	113,605	82,478	81,768	62,626	80,000	108,286	99,776	48,500
Slovakia	262,416	255,200	255,356	238,075	207,000	214,000	222,000	182,000
Spain	25,037	28,911	36,026	26,229	11,755	274	5,222	-
Sri Lanka								
United Kingdom	276	230	130	281	255	275	275	195
USSR (Asia)								
USSR (Europe)								
Yugoslavia	130,000	120,000	100,000	80,000	75,000			
Zimbabwe	222,953	359,190	270,382	216,540	163,200	220,200	172,200	134,537

Country	2006	2007	2008	2009	2010	2011	2012
Total	926,980,601	1,025,848,994	1,080,173,963	1,049,002,200	1,238,640,983	1,321,534,877	1,361,404,901
Australia	173,276,460	188,408,430	214,889,850	228,000,000	272,790,000	277,000,250	321,952,505
China	158,806,300	190,909,700	222,483,000	237,646,300	290,980,400	358,778,300	353,602,000
Brazil	207,682,400	233,978,700	227,503,300	194,878,900	242,920,000	257,550,800	258,129,700
India	125,756,320	142,874,820	142,683,200	146,430,510	138,795,190	112,949,940	91,534,060
Russia	57,000,000	57,707,500	54,945,000	47,740,000	52,745,000	57,200,000	57,200,000
South Africa	26,891,732	27,354,003	31,838,649	35,953,484	38,161,065	37,736,983	43,615,310
Ukraine	36,544,000	39,990,100	36,423,700	35,083,500	41,141,800	42,551,000	42,975,400
United States	33,201,000	32,760,000	33,769,000	16,821,000	31,437,000	34,461,000	34,461,000
Canada	20,797,340	20,226,380	20,640,180	19,354,100	22,068,600	21,780,100	23,724,100
Iran	10,154,015	11,130,000	13,250,000	14,637,000	16,445,200	18,996,900	21,085,200
Sweden	14,913,280	15,816,960	15,288,320	11,313,280	16,186,880	16,712,320	16,985,600
Kazakhstan	14,470,690	15,492,165	13,966,095	14,482,845	15,610,530	16,078,465	16,827,530
Chile	5,235,000	5,379,000	5,670,000	5,006,000	5,852,000	7,747,000	9,429,000
Mauritania	7,249,450	7,741,500	7,342,400	6,840,600	7,497,100	7,264,400	7,272,900
Mexico	5,768,774	6,549,682	7,012,864	7,006,496	8,398,964	7,683,467	8,949,565
Turkey	2,536,000	3,249,100	3,147,000	2,582,800	3,895,400	4,321,800	3,329,800
Peru	3,253,529	3,470,446	3,509,281	3,004,762	4,108,998	4,767,438	4,545,490
Venezuela	13,554,500	12,760,800	12,565,800	9,234,300	9,315,000	10,625,600	10,012,000
Mongolia	108,000	159,060	832,440	827,400	1,921,920	3,406,980	4,536,840
Sierra Leone						196,811	3,018,024
Vietnam	510,000	530,000	822,960	1,142,700	1,183,260	1,422,780	903,720
Malaysia	420,262	505,279	618,617	926,217	2,241,420	5,044,960	6,858,190
New Zealand	1,242,564	997,831	1,171,732	1,213,731	1,414,620	1,367,315	1,389,000
Liberia						193,500	1,184,900
Norway	396,800	403,200	477,440	567,426	1,987,200	1,620,500	2,189,200
Austria	669,438	688,904	650,455	640,682	662,033	706,211	685,522
Bosnia-Herzegovina	1,513,000	1,295,000	749,460	678,000	987,615	1,367,490	1,058,620

Country	2006	2007	2008	2009	2010	2011	2012
Indonesia	46,700	46,400	2,450,400	2,508,600	4,936,500	6,498,000	6,350,200
Korea, North	1,400,000	1,400,000	1,200,000	1,500,000	1,500,000	1,500,000	1,450,000
Colombia	289,868	280,769	212,973	126,348	34,672	78,507	364,150
Algeria	1,263,600	1,070,335	1,121,580	705,780	658,800	712,800	842,400
Saudi Arabia	290,000	219,000	209,160	216,000	198,000	234,720	355,300
Egypt	820,000	720,000	814,773	801,100	1,041,500	1,494,400	1,768,500
Pakistan	49,878	47,834	108,777	121,680	166,060	125,060	146,260
Korea, South	136,460	174,480	219,530	273,240	307,590	324,920	355,650
Tunisia	115,700	97,400	113,700	81,200	92,600	90,900	116,300
Laos					31,560	26,470	121,630
Germany	43,680	44,300	47,785	38,200	40,987	51,350	46,990
Morocco	12,780	17,280	8,244	10,980	16,092	28,404	93,850
Argentina		55,705	141,855	128,440	190,000	205,650	332,470
Bolivia							
Bhutan						-	2,400
Malawi							
Guatemala	3,083	13,023	190	2,294	674	487	4,540
Namibia							
Uganda	125	220	1,044	583	2,277	1,280	2,659
Uruguay	15,525	19,275	21,740	20,230	16,800	8,360	9,500
Thailand	168,859	964,013	1,060,045	382,170	605,700	303,403	188,000
Azerbaijan	4,746	7,392	11,802	28,500	24,276	90,006	87,066
Kenya						71,200	43,700
Nigeria	56,435	37,056	39,680	41,800	26,500	29,400	29,400
Philippines						75,700	688,900
Sudan						8,580	33,740
Swaziland						39,770	516,120
Albania	3,600	3,600	4,766	3,022	3,200	3,200	-
Bulgaria	-						

Country	2006	2007	2008	2009	2010	2011	2012
Czech Republic							
Czechoslovakia							
Ecuador							
Finland							
France							
Japan	1,000	-					
Portugal	-	-					
Romania	46,700	10,922	-				
Slovakia	198,220	193,800	133,280				
Spain							
Sri Lanka							
United Kingdom	188	165	145				
USSR (Asia)							
USSR (Europe)							
Yugoslavia							
Zimbabwe	62,600	47,465	1,751				

Country	2013	2014	2015	2016	2017	Total
Total	1,479,167,477	1,552,111,741	1,547,789,579	1,571,998,463	1,596,189,050	25,419,307,888
Australia	377,760,029	457,409,154	500,993,637	531,075,350	548,297,062	5,702,661,693
China	391,773,000	404,379,000	371,250,000	345,841,000	331,931,000	4,730,197,800
Brazil	245,667,800	244,754,400	253,660,900	268,183,617	273,695,000	4,941,290,317
India	101,962,610	80,404,800	98,687,200	119,761,900	124,592,100	2,291,403,150
Russia	60,885,000	58,465,000	58,465,000	58,630,000	59,400,000	1,567,313,684
South Africa	46,569,090	52,493,570	47,323,600	43,196,310	48,657,340	818,166,226
Ukraine	45,056,000	43,712,000	42,817,200	40,240,600	38,767,600	953,997,604
United States	33,264,000	35,343,000	29,043,000	26,334,000	29,988,000	930,063,797
Canada	25,658,400	26,335,400	28,194,100	28,505,600	26,709,500	611,877,770
Iran	25,329,500	25,709,416	25,797,898	21,623,000	21,884,000	319,178,502
Sweden	17,462,400	18,035,840	15,886,720	17,216,000	17,408,000	389,002,470
Kazakhstan	16,398,330	15,965,110	11,122,150	10,632,570	11,705,660	349,123,043
Chile	9,088,000	9,427,640	9,147,839	9,008,873	9,549,327	171,121,087
Mauritania	8,491,300	8,648,800	7,544,600	8,624,200	7,678,500	201,133,115
Mexico	11,303,740	9,976,750	8,077,160	7,253,810	7,027,520	191,505,492
Turkey	5,239,500	7,251,200	4,734,200	4,353,700	6,095,400	96,840,528
Peru	4,542,850	4,890,960	4,978,150	5,210,920	5,988,390	97,173,876
Venezuela	7,278,800	7,318,100	7,615,100	5,070,000	4,615,000	310,229,022
Mongolia	3,366,270	5,745,880	3,704,040	3,407,480	4,309,030	32,455,340
Sierra Leone	6,172,710	10,259,610	1,521,830	3,814,410	3,194,930	28,178,325
Vietnam	1,497,180	1,631,400	1,614,600	1,833,600	3,044,400	16,599,980
Malaysia	7,644,580	6,057,650	1,015,450	1,206,130	2,439,130	40,324,029
New Zealand	1,830,850	1,882,310	1,852,360	2,027,560	2,020,000	39,507,316
Liberia	2,474,000	2,952,800	2,717,700	843,100	1,160,500	15,749,900
Norway	2,181,300	2,466,600	2,252,200	1,425,000	992,700	31,290,369
Austria	743,463	779,736	890,665	888,723	954,156	18,332,481
Bosnia-Herzegovina	1,492,840	1,499,950	1,082,630	893,420	827,170	16,932,129

Country	**2013**	**2014**	**2015**	**2016**	**2017**	**Total**
Indonesia	12,294,300	3,273,300	2,111,200	2,300,000	700,000	46,314,915
Korea, North	865,000	963,600	579,300	600,000	630,000	65,947,900
Colombia	319,520	304,280	405,780	322,060	320,630	7,642,009
Algeria	594,000	492,010	509,800	328,300	268,400	24,589,525
Saudi Arabia	231,800	243,400	241,900	254,200	266,800	4,966,150
Egypt	192,000	639,900	763,700	186,300	200,000	27,152,236
Pakistan	156,600	74,890	124,990	164,220	190,630	1,649,220
Korea, South	397,830	415,960	267,190	266,810	186,330	5,267,030
Tunisia	132,100	179,200	153,700	159,500	152,100	3,699,000
Laos	560,950	680,840	140,850	69,040	150,000	1,781,340
Germany	59,900	66,900	71,900	74,500	75,100	1,354,642
Morocco	108,400	8,250	6,430	5,510	36,120	713,818
Argentina	298,190	224,840	206,060	107,280	28,400	2,484,302
Bolivia	1,550	10,690	14,180	1,710	22,230	379,729
Bhutan	13,100	12,200	27,650	17,960	21,100	94,410
Malawi			-	2,280	3,000	5,280
Guatemala	330	850	7,310	8,210	2,670	117,407
Namibia		-	2,680	5,680	1,640	10,000
Uganda	1,369	25,175	5,400	1,280	1,390	42,927
Uruguay	9,978	15,050	11,520	1,040	1,010	214,552
Thailand	241,560	215,710	10,220	-	85	5,911,967
Azerbaijan	59,388	38,390	53,590	10,710	-	619,132
Kenya	93,000	-	-	-	-	207,900
Nigeria	21,000	20,000	20,000	700	-	1,277,412
Philippines	634,000	92,300	64,300	10,300	-	1,565,500
Sudan	118,790	16,300	-	-	-	177,410
Swaziland	629,280	301,630	-	-	-	1,486,800
Albania	-	-	-	-		733,815
Bulgaria						3,373,444

Country	2013	2014	2015	2016	2017	Total
Czech Republic						0
Czechoslovakia						1,153,980
Ecuador						0
Finland						0
France						9,463,300
Japan						124,778
Portugal						88,485
Romania						2,152,740
Slovakia						3,594,688
Spain						8,283,142
Sri Lanka						0
United Kingdom						37,189
USSR (Asia)						45,804,000
USSR (Europe)						218,196,000
Yugoslavia						3,860,890
Zimbabwe						5,119,879

Chromium

Table 11: Chromium producers [metr. t chromium content], organised by largest producer in 2017 (Reichl, et al. 2019)

Country	1990	1991	1992	1993	1994	1995	1996	1997
Total	7,306,565	7,574,055	4,848,904	4,042,981	4,436,776	5,637,753	4,858,471	5,987,551
South Africa	1,899,920	2,244,000	1,479,720	1,248,720	1,602,480	2,237,840	2,234,320	2,711,280
Kazakhstan			1,535,040	1,290,000	946,000	1,039,310	408,500	774,000
Turkey	505,970	576,058	448,061	322,271	533,581	873,618	537,193	691,493
India	422,000	478,280	478,720	468,518	461,701	460,000	538,182	644,000
Finland	195,720	183,207	199,722	204,367	229,099	239,070	232,870	296,000
Albania	222,369	168,430	49,039	32,911	11,381	30,892	30,402	22,000
Zimbabwe	257,896	253,635	234,906	113,415	232,560	284,122	313,795	341,979
Russia	1,710,000	1,620,000	64,960	54,000	54,000	67,500	43,515	65,250
Brazil	101,300	133,100	85,588	86,759	85,879	100,969	174,150	112,274
Oman	0	0	600	4,094	2,480	2,120	6,100	7,160
Madagascar	53,800	64,060	53,200	29,890	44,198	49,000	67,130	58,800
Iran	77,189	90,119	130,265	114,780	152,290	156,352	138,618	104,509
Pakistan	6,912	8,540	8,683	6,190	2,496	6,800	11,195	7,478
Papua New Guinea								
Cuba	13,000	19,500	19,500	19,500	7,800	11,970	14,547	17,160
China	9,500	9,750	9,750	21,060	24,100	36,660	50,700	75,000
Philippines	73,596	70,260	25,833	7,574	10,881	13,316	18,524	16,673
Sudan	8,000	8,500	10,000	6,500	10,300	9,900	10,560	13,300
Afghanistan						1,764	1,500	1,365
Australia								
Kosovo								
Vietnam	1,800	1,800	1,800	1,500	1,500	1,400	1,300	1,300
Argentina				2	0	0	0	0
Greece	16,990	9,652	1,920	1,440	1,960	2,000	5,620	5,050
Indonesia	3,500	3,870	3,500	0	0	0	0	0
Japan	3,636	3,600	3,600	0	0	0	0	0
Morocco	560	254	147	140	140	0	0	0
Myanmar	1,060	440	400	200	200	200	150	130
New Caledonia	2,147			0		0	0	0

Country	1990	1991	1992	1993	1994	1995	1996	1997
Thailand	0	0	0	0				
United Arab Emirates	0	0	350	6,650	19,250	12,950	19,600	21,350
USSR (Europe)	1,710,000	1,620,000						
Yugoslavia	9,700	7,000	3,600	2,500	2,500	0		

Country	1998	1999	2000	2001	2002	2003	2004	2005
Total	5,875,687	6,087,375	6,375,108	5,345,608	6,257,887	6,879,190	7,929,152	8,377,751
South Africa	2,851,200	2,999,480	2,931,280	2,420,880	2,831,840	3,258,200	3,377,880	3,322,984
Kazakhstan	688,000	946,000	1,126,600	884,359	1,010,345	1,299,600	1,507,900	1,670,300
Turkey	567,014	323,548	236,184	154,565	131,728	96,303	212,697	253,183
India	603,203	677,472	895,579	771,845	1,241,345	1,016,600	1,356,514	1,497,375
Finland	199,230	238,975	260,600	236,000	248,000	250,000	264,000	235,000
Albania	66,622	35,700	26,460	54,474	30,492	41,160	66,525	81,060
Zimbabwe	279,053	288,330	294,066	351,068	337,203	286,695	300,776	301,513
Russia	67,500	51,795	41,400	31,467	33,435	52,405	144,090	347,400
Brazil	171,776	169,676	229,647	163,185	112,153	209,873	231,455	240,448
Oman	10,039	10,402	6,086	12,060	10,978	5,200	10,640	20,160
Madagascar	51,107	28,175	57,820	36,015	30,037	21,609	31,262	41,965
Iran	90,969	109,515	65,790	58,480	34,400	51,600	78,764	96,132
Pakistan	5,180	6,512	10,740	8,673	9,674	12,263	11,412	18,544
Papua New Guinea								
Cuba	19,127	13,943	12,636	10,140	8,249	10,764	16,570	5,744
China	92,515	80,208	85,655	71,955	64,038	77,142	89,700	85,800
Philippines	21,548	7,826	10,544	10,773	9,481	5,187	16,800	15,232
Sudan	14,640	23,040	13,680	9,840	6,720	17,760	12,480	10,394
Afghanistan	1,500	1,900	2,352	2,500	2,700	2,800	2,900	3,000
Australia	31,200	27,300	35,100	4,602	51,739	97,098	103,735	94,327
Kosovo								
Vietnam	13,404	22,936	21,489	48,312	52,420	66,018	89,658	36,301
Argentina	0	0	0	0	0	0		
Greece	1,950	1,000	800	780	770	763	753	709
Indonesia	1,880	2,542						
Japan								

Country	1998	1999	2000	2001	2002	2003	2004	2005
Morocco	0	0	0	0				
Myanmar	120	100	100	135	140	150	160	180
New Caledonia								
Thailand								
United Arab Emirates	26,910	21,000	10,500	3,500	0	0	2,481	0
USSR (Europe)								
Yugoslavia								

Country	2006	2007	2008	2009	2010	2011	2012
Total	9,586,093	10,542,846	10,709,472	8,635,293	11,511,845	11,229,183	11,997,236
South Africa	3,267,378	4,252,449	4,260,362	3,326,813	4,783,282	5,220,770	4,979,650
Kazakhstan	1,662,900	1,790,100	1,640,600	1,675,200	1,737,000	1,780,000	1,909,900
Turkey	426,545	524,154	926,625	657,220	1,033,752	1,000,000	2,083,900
India	2,435,953	2,241,435	1,873,580	1,575,800	1,989,800	1,344,800	1,303,600
Finland	243,000	242,000	234,000	123,000	238,000	231,000	229,000
Albania	96,538	97,138	108,179	136,108	142,700	152,300	156,600
Zimbabwe	315,000	276,552	199,163	87,153	232,549	269,586	183,814
Russia	434,743	349,506	410,850	240,300	236,700	263,300	206,600
Brazil	219,468	243,995	259,095	142,432	202,850	211,580	184,275
Oman	28,200	135,188	343,900	254,600	346,160	253,680	221,920
Madagascar	56,982	26,802	55,180	65,170	65,905	32,683	45,100
Iran	115,670	59,770	115,670	118,250	169,420	189,200	192,210
Pakistan	25,829	41,656	45,954	35,896	102,859	59,210	71,680
Papua New Guinea							3,630
Cuba	1,968	0					
China	85,100	85,100	85,800	109,200	85,500	85,800	59,000
Philippines	18,691	12,637	6,107	5,729	5,923	10,193	14,651
Sudan	13,811	7,428	15,307	6,762	27,275	30,781	8,780
Afghanistan	3,200	2,856	2,856	2,940	2,520	2,730	2,520
Australia	100,654	98,826	87,676	46,532	50,400	66,100	138,500
Kosovo							500
Vietnam	33,597	47,762	25,705	17,068	58,600	24,900	830

Country	2006	2007	2008	2009	2010	2011	2012
Argentina							
Greece	696	672	670	650	650	570	576
Indonesia							
Japan							
Morocco							
Myanmar	170	170	170	150	0		
New Caledonia							
Thailand							
United Arab Emirates	0	6,650	12,023	8,320	0		
USSR (Europe)							
Yugoslavia							

Country	2013	2014	2015	2016	2017	Total
Total	13,228,415	12,997,974	13,221,120	12,903,760	14,586,575	238,970,626
South Africa	6,023,450	5,977,600	6,660,500	6,254,600	7,039,300	101,698,178
Kazakhstan	2,008,400	2,143,900	1,992,400	1,989,500	2,193,500	37,649,354
Turkey	1,865,900	1,806,600	1,464,330	1,070,030	1,779,900	21,102,423
India	1,324,000	995,500	1,335,560	1,728,270	1,601,200	31,760,832
Finland	434,000	441,300	457,100	469,140	416,285	7,469,685
Albania	228,900	309,900	284,100	317,500	317,600	3,317,480
Zimbabwe	159,814	183,790	93,750	128,220	309,980	6,910,383
Russia	147,200	214,200	226,400	209,300	234,000	7,621,816
Brazil	189,521	244,622	179,100	200,000	200,000	4,885,170
Oman	317,000	300,480	179,680	232,820	181,090	2,902,837
Madagascar	57,420	60,750	72,620	52,800	102,000	1,411,480
Iran	191,100	157,953	142,810	162,100	92,850	3,256,775
Pakistan	54,580	34,230	40,700	27,730	42,100	723,716
Papua New Guinea	40,500	42,570	45,000	23,400	34,470	189,570
Cuba	9,000	6,600	13,500	12,000	14,400	277,618
China	50,400	14,400	17,600	12,200	12,000	1,585,633
Philippines	14,110	18,820	6,200	10,300	8,340	465,749
Sudan	14,820	29,440	7,270	1,850	5,560	354,698

Country	2013	2014	2015	2016	2017	Total
Afghanistan	2,500	2,200	2,500	2,000	2,000	55,103
Australia	94,200	10,519	0	0	0	1,138,508
Kosovo	800	1,000	0	0	0	2,300
Vietnam	800	1,600	0	0	0	573,800
Argentina						2
Greece						56,641
Indonesia						15,292
Japan						10,836
Morocco						1,241
Myanmar						4,525
New Caledonia						2,147
Thailand						0
United Arab Emirates						171,534
USSR (Europe)						3,330,000
Yugoslavia						25,300

Aluminium

Table 12: : Aluminium producers [metr. t aluminium content], organised by largest producer in 2017 (Reichl, et al. 2019)

Country	1990	1991	1992	1993	1994	1995	1996	1997
Total	22,873,272	22,305,234	19,466,057	19,621,920	19,179,436	19,986,007	20,856,205	21,927,032
China	854,300	963,000	1,096,400	1,220,400	1,446,000	1,870,000	1,780,000	2,035,000
Russia	3,513,000	2,960,760	2,725,000	2,800,800	2,670,500	2,789,800	2,871,600	2,906,000
India	433,200	511,800	496,300	465,400	476,521	536,500	530,600	547,400
Canada	1,567,395	1,821,600	1,971,843	2,308,900	2,254,683	2,171,992	2,283,000	2,327,200
United Arab Emirates	174,300	240,000	244,600	231,801	246,900	247,000	258,500	379,200
Australia	1,245,000	1,228,600	1,235,500	1,375,600	1,318,000	1,297,000	1,371,000	1,589,000
Norway	871,100	885,900	866,500	867,000	858,200	847,000	863,000	918,600
Bahrain	208,572	210,290	291,309	448,260	449,419	453,900	464,500	489,900
Brazil	930,600	1,141,220	1,193,300	1,174,500	1,185,000	1,188,100	1,197,400	1,189,100
Iceland	86,800	89,100	89,500	94,500	99,000	100,200	103,900	123,356
Saudi Arabia								
Malaysia								
United States	4,048,290	4,121,187	4,042,000	3,695,000	3,299,000	3,375,000	3,577,000	3,603,400
South Africa	157,500	169,400	173,000	175,667	172,111	233,000	617,000	682,900
Qatar								
Mozambique								
Germany	720,300	690,322	602,800	551,931	505,000	575,000	576,492	571,940
Argentina	165,600	168,300	155,600	172,900	175,000	185,500	183,900	187,200
France	324,876	254,627	422,912	431,913	438,000	372,200	386,000	399,300
Spain	355,300	355,150	359,000	364,256	338,000	361,900	361,826	359,900
Iran	59,400	67,400	79,300	91,500	116,000	117,000	80,100	107,000
New Zealand	259,700	260,400	242,900	266,900	268,000	273,300	260,000	310,200
Romania	177,785	167,451	112,000	112,400	119,600	140,500	140,900	161,900
Egypt	179,600	178,000	180,000	180,000	188,464	180,300	179,200	178,200
Kazakhstan								
Oman								
Indonesia	192,100	173,098	186,975	202,197	221,900	228,100	223,100	217,400
Greece	152,362	150,878	150,850	146,800	144,300	131,000	141,295	141,500
Slovakia				40,000	32,800	60,561	111,500	110,100

Country	1990	1991	1992	1993	1994	1995	1996	1997
Venezuela	594,000	610,000	567,400	567,600	585,400	627,900	634,900	640,800
Bosnia-Herzegovina								8,000
Sweden	96,000	96,900	96,800	82,400	83,900	95,170	98,300	98,400
Tajikistan			345,000	252,000	236,500	237,000	198,000	188,900
Slovenia			74,304	75,000	74,282	70,200	65,800	74,400
Turkey	60,900	55,802	58,600	58,501	59,700	61,500	62,100	62,000
Cameroon	87,500	85,600	82,500	86,500	81,100	79,300	82,300	90,900
United Kingdom	289,796	293,512	244,163	239,099	231,200	238,000	240,000	247,700
Ghana	174,200	175,400	179,900	174,100	140,700	135,400	137,000	151,600
Montenegro								
Netherlands	277,100	263,910	235,100	231,800	219,400	215,600	227,000	231,800
Azerbaijan			24,000	7,000	10,000	11,000	0	4,757
Japan	34,200	32,400	18,884	18,263	16,956	18,034	16,959	16,694
Nigeria								2,500
Austria	89,434	80,384	32,866			0	0	
Czechoslovakia	69,815	66,274	63,000					
German Dem, Rep	19,731							
Hungary	74,000	63,000	22,500	27,900	29,400	32,000	32,000	33,671
Italy	228,643	205,636	202,871	129,732	175,600	197,750	192,833	187,700
Korea, North	0	0	0	0	0			
Korea, South	2,000				0	0	0	0
Mexico	70,873	50,796	0	0	0	10,400	61,500	66,400
Poland	46,000	45,800	43,600	46,900	49,400	52,000	52,100	53,614
Serbia and Montenegro								
Suriname	31,300	30,700	32,400	30,100	26,700	28,100	26,000	23,100
Switzerland	71,700	65,877	52,400	36,400	24,200	20,700	26,600	27,300
Ukraine			105,280	104,000	102,000	95,100	89,900	100,500
USSR (Asia)	3,161,700	2,664,360						
USSR (Europe)	351,300	296,400						
Yugoslavia	366,000	314,000	66,900	36,000	10,600	26,000	51,100	80,600

Country	1998	1999	2000	2001	2002	2003	2004	2005
Total	22,828,580	23,942,136	24,601,897	24,641,067	26,356,101	28,384,530	29,843,041	32,007,041
China	2,435,300	2,808,900	2,989,200	3,575,800	4,511,100	5,865,800	6,690,400	7,786,800
Russia	3,010,000	3,149,000	3,247,000	3,302,000	3,500,000	3,470,000	3,600,000	3,650,000
India	543,451	594,000	646,300	625,000	671,200	798,300	860,900	942,400
Canada	2,374,100	2,389,000	2,373,000	2,583,000	2,709,000	2,791,900	2,592,200	2,984,200
United Arab Emirates	386,600	440,700	536,000	536,000	538,000	560,000	683,000	724,600
Australia	1,686,000	1,742,000	1,769,000	1,790,000	1,810,000	1,877,000	1,895,000	1,903,000
Norway	995,500	1,009,000	1,031,100	1,034,200	1,044,000	1,192,000	1,321,700	1,391,000
Bahrain	501,300	502,700	509,000	522,100	517,000	525,800	528,700	744,100
Brazil	1,208,000	1,249,600	1,271,400	1,140,000	1,318,400	1,380,600	1,457,400	1,499,600
Iceland	183,360	221,433	225,721	242,526	283,285	280,194	282,127	274,696
Saudi Arabia								
Malaysia								
United States	3,712,690	3,779,000	3,668,000	2,637,000	2,706,600	2,703,300	2,516,400	2,481,000
South Africa	692,500	689,230	674,167	663,000	706,900	738,000	863,600	846,213
Qatar								
Mozambique			53,800	266,000	273,200	407,400	547,100	553,700
Germany	612,380	633,803	643,545	651,600	652,800	660,800	667,800	647,934
Argentina	186,700	206,400	261,895	247,657	268,806	272,369	272,048	270,714
France	423,600	455,100	441,200	460,900	463,200	444,100	446,900	437,900
Spain	360,400	363,900	365,700	376,400	380,100	389,100	397,500	394,200
Iran	117,000	137,313	145,200	160,000	168,715	181,000	203,200	232,000
New Zealand	317,500	326,700	328,400	322,300	333,900	334,400	350,400	351,400
Romania	174,000	174,100	179,000	181,800	187,100	196,800	222,300	243,600
Egypt	187,200	186,700	162,617	186,479	195,000	194,600	216,000	243,800
Kazakhstan								
Oman								
Indonesia	134,300	112,300	192,300	208,800	162,800	197,300	240,800	252,300
Greece	156,902	170,301	167,507	163,581	165,262	167,797	166,634	165,300
Slovakia	108,006	109,200	109,800	110,100	111,600	131,400	156,900	158,400

Country	1998	1999	2000	2001	2002	2003	2004	2005
Venezuela	584,300	570,300	570,900	570,600	594,638	591,614	631,100	624,000
Bosnia-Herzegovina	28,000	70,000	94,751	95,064	102,271	112,503	121,294	131,200
Sweden	95,700	98,500	100,800	101,400	101,100	100,700	100,600	102,107
Tajikistan	195,600	229,100	269,200	289,100	307,589	319,400	258,100	379,600
Slovenia	73,803	77,200	75,600	76,632	87,600	118,305	120,700	138,500
Turkey	61,800	61,700	61,500	61,700	62,500	62,900	62,400	59,000
Cameroon	81,600	91,900	94,900	80,900	67,000	77,200	85,900	86,400
United Kingdom	258,400	272,211	305,099	340,778	344,318	342,748	359,600	368,477
Ghana	56,100	114,200	155,500	162,300	132,400	15,900	0	13,400
Montenegro								
Netherlands	263,700	287,400	301,700	293,200	284,400	282,800	327,000	333,800
Azerbaijan	3,386	1,278	295	57	58	18,600	29,500	31,800
Japan	16,302	10,900	6,500	6,600	6,400	6,500	6,400	6,400
Nigeria	25,500	15,900			0	0	0	
Austria								
Czechoslovakia								
German Dem, Rep								
Hungary	33,700	34,000	33,900	34,600	35,300	35,000	34,300	31,000
Italy	187,000	205,567	189,200	187,400	190,400	191,400	195,400	192,900
Korea, North								
Korea, South								
Mexico	61,800	62,700	61,200	51,500	39,000	17,600	0	0
Poland	52,500	51,600	55,500	52,600	58,800	57,200	58,900	53,600
Serbia and Montenegro						116,700	115,100	117,000
Suriname	27,100	6,600	0	0	0	0	0	0
Switzerland	32,100	34,400	35,500	36,200	40,000	43,900	44,538	44,800
Ukraine	106,700	115,400	103,500	106,093	112,459	113,600	113,200	114,200
USSR (Asia)								
USSR (Europe)								
Yugoslavia	76,700	80,900	95,500	108,100	111,900			

Country	2006	2007	2008	2009	2010	2011	2012
Total	33,979,925	37,876,437	39,594,446	36,984,535	41,297,617	44,384,916	49,403,677
China	9,265,700	12,339,700	13,176,300	12,886,100	16,131,000	17,786,000	23,534,000
Russia	3,720,000	3,960,000	4,180,000	3,820,000	3,947,000	3,992,000	4,024,000
India	1,113,849	1,239,581	1,347,127	1,480,568	1,621,033	1,654,156	1,720,000
Canada	3,051,100	3,082,600	3,120,148	3,030,300	2,963,210	2,987,964	2,780,556
United Arab Emirates	789,300	889,500	891,700	1,009,800	1,400,000	1,800,000	1,814,000
Australia	1,932,000	1,960,000	1,974,000	1,943,000	1,928,000	1,945,000	1,859,726
Norway	1,383,000	1,362,000	1,358,800	1,098,200	1,090,000	1,201,000	1,110,900
Bahrain	872,000	865,900	871,700	847,700	851,000	881,300	890,217
Brazil	1,765,821	1,654,800	1,661,100	1,535,900	1,536,200	1,440,000	1,436,400
Iceland	326,090	419,149	741,386	817,964	813,338	814,039	801,166
Saudi Arabia							
Malaysia				15,000	60,000	188,100	121,900
United States	2,283,100	2,554,000	2,658,300	1,727,000	1,726,000	1,986,000	2,070,300
South Africa	895,000	899,000	811,000	809,000	811,500	811,483	665,000
Qatar				10,000	126,000	450,000	604,000
Mozambique	564,000	564,000	534,181	541,765	557,000	562,000	562,000
Germany	515,539	551,030	605,876	291,800	402,500	432,500	410,500
Argentina	272,942	286,386	393,900	412,594	417,088	416,177	413,395
France	442,100	427,800	389,000	345,000	356,000	334,000	349,000
Spain	367,400	405,100	405,800	329,500	456,500	408,400	386,400
Iran	205,467	203,600	241,300	281,300	303,000	321,900	336,500
New Zealand	335,300	351,100	315,500	271,000	344,000	357,000	326,963
Romania	258,300	286,300	289,700	229,000	241,000	261,000	248,587
Egypt	252,300	258,300	259,200	245,400	281,100	353,900	393,700
Kazakhstan		12,000	106,000	128,000	227,000	248,800	250,269
Oman			49,000	351,000	367,000	375,000	360,000
Indonesia	250,300	242,100	242,500	257,600	253,300	246,300	253,000
Greece	164,528	167,937	162,339	134,737	136,765	165,147	165,579
Slovakia	158,289	160,461	162,995	149,604	162,997	162,840	160,662

Country	2006	2007	2008	2009	2010	2011	2012
Venezuela	617,100	615,700	607,800	561,100	353,700	330,000	203,000
Bosnia-Herzegovina	136,200	147,000	155,909	130,042	150,488	163,654	159,660
Sweden	101,700	99,800	81,900	69,700	93,000	111,000	129,000
Tajikistan	413,800	419,100	399,500	359,486	348,900	278,364	272,506
Slovenia	118,100	111,000	83,328	35,148	40,177	75,301	83,278
Turkey	60,000	63,400	61,100	30,000	60,000	65,000	43,700
Cameroon	91,000	87,000	89,700	79,400	76,000	69,000	52,000
United Kingdom	360,300	364,595	326,900	252,000	186,000	213,000	60,000
Ghana	75,800	12,900	9,300	0	0	35,213	38,000
Montenegro		124,060	107,457	63,960	82,043	92,838	74,813
Netherlands	285,300	296,900	321,200	165,000	217,000	200,000	86,300
Azerbaijan	31,900	39,238	61,600	10,167	378	740	54,200
Japan	6,400	6,000	6,600	5,100	4,700	4,700	4,500
Nigeria	0	0	10,600	12,900	21,200	15,000	22,000
Austria							
Czechoslovakia							
German Dem, Rep							
Hungary	300	0					
Italy	194,200	179,500	186,400	165,800	129,500	141,900	72,000
Korea, North							
Korea, South							
Mexico	0	0					
Poland	57,600	54,500	47,500				
Serbia and Montenegro	121,800						
Suriname							
Switzerland	12,000	0					
Ukraine	113,000	113,400	88,800	45,900	25,000	7,200	0
USSR (Asia)							
USSR (Europe)							
Yugoslavia							

Copper

Table 13: Copper producers [metr. t Copper content], organised by largest producer in 2017 (Reichl, et al. 2019)

Country	1990	1991	1992	1993	1994	1995	1996	1997
Total	9,924,267	9,883,604	9,479,076	9,552,707	9,547,792	10,086,190	10,877,349	11,253,727
Chile	1,588,400	1,814,300	1,932,700	2,055,400	2,219,900	2,490,000	3,115,800	3,392,000
Peru	323,412	382,277	379,128	381,250	365,513	409,693	485,595	502,970
China	360,000	304,000	334,300	345,700	395,600	445,200	439,200	495,500
United States	1,587,763	1,631,000	1,764,800	1,801,400	1,847,600	1,849,100	1,919,200	1,939,600
Congo, D.R.								
Australia	305,000	320,000	378,000	430,000	418,400	397,800	547,300	558,000
Zambia	496,000	423,000	432,600	431,500	384,400	341,900	339,700	331,200
Mexico	298,695	284,174	279,042	303,989	305,487	339,347	327,978	338,900
Russia	900,000	808,200	624,200	583,600	573,300	525,900	523,000	522,500
Indonesia	169,500	219,803	290,900	309,744	333,800	459,700	386,390	399,934
Canada	793,700	811,100	768,600	732,600	616,800	726,300	688,400	659,500
Kazakhstan			303,700	263,500	215,400	228,500	250,200	316,000
Poland	329,400	340,800	332,000	382,800	378,200	384,200	425,000	414,800
Brazil	34,441	37,947	39,845	43,568	39,674	47,900	46,200	39,952
Mongolia	123,893	90,090	105,000	114,000	119,200	120,200	121,000	130,000
Iran	75,300	97,000	108,000	86,600	117,900	105,710	107,600	110,000
Spain	14,725	11,931	10,863	6,691	5,944	22,923	38,392	38,883
Laos								
Bulgaria	32,900	47,200	47,400	60,400	75,500	77,400	84,800	75,500
Papua New Guinea	170,211	204,459	193,359	203,945	206,329	212,737	186,715	111,515
Sweden	74,283	81,650	89,018	88,909	79,384	83,603	71,554	86,610
Uzbekistan			74,300	78,000	49,500	40,000	64,000	74,400
Armenia			2,000	500	500	8,100	9,100	6,758
Turkey	39,825	41,800	36,426	39,200	43,400	44,500	53,607	64,600
Philippines	180,478	148,000	127,166	136,349	112,075	102,637	61,615	48,638
Myanmar	4,400	5,700	5,000	7,000	6,700	6,000	6,000	6,000
South Africa	188,400	193,642	176,100	166,300	160,100	161,600	152,100	153,100

Country	1990	1991	1992	1993	1994	1995	1996	1997
Portugal	159,839	157,572	150,483	150,431	130,225	130,041	107,773	106,580
Saudi Arabia	895	880	865	925	919	814	786	703
Finland	12,600	11,700	10,200	11,100	9,500	9,500	9,300	8,259
Serbia								
Morocco	15,300	13,651	13,800	14,300	13,400	10,066	10,434	10,456
India	63,520	50,430	49,985	49,400	52,920	46,600	47,800	37,200
Argentina	357	409	297	0	0	0	0	30,400
Mauritania								
Vietnam								
Tanzania								
Namibia	31,327	31,285	29,308	27,373	22,530	29,203	14,904	17,900
Korea, North	12,000	14,000	12,000	12,000	12,000	10,000	10,000	10,000
Georgia			5,000	3,000	2,000	1,000	4,500	5,000
Pakistan						4,400	3,000	
Dominican Republic								
Colombia	230	2,760	2,980	0	2,380	2,280	2,100	1,680
Macedonia		9,200	7,224	10,000	10,000	10,000	13,500	13,000
Zimbabwe	14,698	13,811	12,600	8,187	9,400	8,045	9,028	6,832
Ecuador								0
Romania	31,725	21,389	25,725	26,653	26,000	24,500	24,400	22,600
Kyrgyzstan								
Eritrea								
Bolivia	157	30	101	94	79	127	92	182
Tajikistan								
Azerbaijan								
Cyprus	478	226	173	121	0	0	1,688	3,950
Botswana	19,561	19,345	19,079	20,197	21,563	19,140	20,979	18,350
Slovakia				1,121	570	400	913	691
Korea, South	53	5	0	0	0	33	1	0
Albania	13,565	8,100	1,900	3,400	2,500	3,700	2,600	300
Oman	13,700	13,500	13,400	8,800	4,300	1,067	1,000	1,209
Afghanistan						1,260	1,800	1,065

Country	1990	1991	1992	1993	1994	1995	1996	1997
Cuba	2,000	2,000	1,500	2,000	2,000	1,852	2,227	2,212
Czech Republic				200	0	0	0	0
Czechoslovakia	3,549	2,672	680					
El Salvador								
France	480	166	160	70	174	172	170	196
German Dem, Rep	3,564							
Germany	3			0		0	0	0
Honduras	1,388	1,500	1,600	900	1,000	1,000	300	300
Jamaica								
Japan	12,927	12,414	12,074	10,277	6,043	2,376	1,145	932
Malaysia	24,326	25,581	28,556	25,182	25,267	20,751	20,671	18,900
Mozambique	140	0	0	259	0	0	0	0
Nepal	4	5	5	4	4	4	3	0
Norway	19,700	17,400	12,734	8,868	7,412	6,797	7,389	6,670
Serbia and Montenegro								
United Kingdom	955	300	0		0	0	0	0
USSR (Asia)	630,000	565,740						
USSR (Europe)	270,000	242,460						
Yugoslavia	119,000	112,000	84,900	57,400	74,400	74,600	69,500	73,600
Zaire	355,500	235,000	147,300	47,500	40,600	35,512	38,900	37,700

Country	1998	1999	2000	2001	2002	2003	2004	2005
Total	11,991,960	12,452,727	12,876,125	13,125,582	13,025,473	13,314,352	14,263,275	14,558,764
Chile	3,686,900	4,319,200	4,602,000	4,739,000	4,580,600	4,904,200	5,412,500	5,320,500
Peru	483,338	536,000	553,924	722,355	844,553	842,605	1,035,574	1,009,899
China	486,800	520,000	592,600	587,400	578,100	614,400	754,200	761,600
United States	1,859,400	1,602,247	1,444,100	1,338,000	1,142,400	1,116,000	1,160,000	1,140,000
Congo, D.R.	35,000	33,000	33,000	33,000	32,300	9,370	21,000	28,462
Australia	619,000	741,000	832,000	896,000	876,000	830,000	854,000	921,000
Zambia	378,800	271,000	249,300	306,900	307,800	346,900	411,000	465,000
Mexico	344,800	340,100	339,000	349,400	314,800	303,800	352,300	373,252
Russia	530,000	535,000	530,000	540,000	661,770	650,000	630,000	640,000
Indonesia	580,809	581,940	719,474	531,984	627,262	712,427	618,786	781,838
Canada	705,800	620,100	633,900	633,500	603,500	557,100	562,800	595,400
Kazakhstan	338,600	373,500	430,200	470,100	473,800	485,400	462,000	401,700
Poland	435,800	463,200	454,100	474,000	502,800	503,200	530,500	511,500
Brazil	33,500	31,200	31,800	34,448	32,700	26,275	103,153	133,325
Mongolia	127,800	128,200	126,500	133,503	133,900	130,270	130,000	129,000
Iran	111,000	131,763	155,850	143,500	134,632	127,800	145,668	164,200
Spain	37,217	15,229	24,360	12,159	1,248	635	1,306	7,175
Laos							1,700	30,500
Bulgaria	82,500	87,500	93,200	97,100	84,400	91,600	79,600	111,600
Papua New Guinea	152,200	188,000	203,100	203,800	211,315	202,300	173,400	193,000
Sweden	73,685	71,160	77,765	74,269	71,991	83,100	82,400	87,068
Uzbekistan	65,000	64,000	69,400	77,500	79,900	80,000	80,000	80,000
Armenia	9,158	9,611	12,200	16,800	16,600	18,100	17,700	16,400
Turkey	73,900	74,000	70,400	64,400	60,000	59,000	49,300	54,100
Philippines	45,381	37,631	30,644	20,300	18,364	20,925	16,000	16,300
Myanmar	3,200	26,700	26,700	25,800	27,500	27,900	31,800	34,500
South Africa	164,400	144,300	137,092	141,865	129,452	120,920	102,570	103,856
Portugal	114,515	99,472	76,300	83,000	77,227	77,581	95,743	89,541
Saudi Arabia	782	821	837	839	600	800	652	668
Finland	9,217	10,517	10,810	11,555	14,400	14,900	15,100	14,900
Serbia								

Country	1998	1999	2000	2001	2002	2003	2004	2005
Morocco	8,881	7,256	6,519	5,357	4,994	4,371	4,400	3,200
India	39,900	34,100	31,900	32,400	31,500	28,500	29,500	26,700
Argentina	170,273	210,126	145,197	191,566	218,100	199,020	177,100	187,317
Mauritania								
Vietnam		700	2,400	1,600	1,100	1,200	2,000	3,100
Tanzania				2,651	4,200	3,723	4,249	3,669
Namibia	7,500	0	5,100	15,000	17,850	16,200	11,200	10,157
Korea, North	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Georgia	5,000	8,000	8,000	11,800	13,100	12,000	11,800	9,500
Pakistan						5,400	14,700	17,700
Dominican Republic								
Colombia	1,800	2,020	1,900	1,850	1,710	1,450	1,570	1,750
Macedonia	9,500	10,200	10,000	6,800	5,600	700	0	4,800
Zimbabwe	6,000	4,977	600	2,100	2,500	2,800	2,300	2,570
Ecuador	100	100	100	100	0	0	200	0
Romania	19,100	16,800	16,100	19,200	19,300	23,400	20,400	16,300
Kyrgyzstan								
Eritrea								
Bolivia	48	252	110	18	120	344	576	35
Tajikistan								
Azerbaijan								
Cyprus	5,000	5,004	5,200	5,500	3,695	2,552	1,334	0
Botswana	19,432	18,239	18,722	19,209	21,590	24,289	21,195	26,706
Slovakia	670	124	110	110	100	95	93	65
Korea, South	11	0	0	0	0	0	6	11
Albania	2,300	900					600	1,600
Oman	993							
Afghanistan	680	1,200	1,800	2,000	2,100	2,300	2,500	2,700
Cuba	1,400	1,100	1,300	1,000	0	0	0	0
Czech Republic	0							
Czechoslovakia								
El Salvador								

Country	1998	1999	2000	2001	2002	2003	2004	2005
France	0	0	0	0	0			
German Dem, Rep								
Germany	0							
Honduras	300	300	300	300	300	0	0	0
Jamaica			1,000	800	1,200			
Japan	1,070	1,038	1,211	744	1,500	1,000	1,000	1,000
Malaysia	17,900	10,200	0	0	0	0	0	0
Mozambique	0							
Nepal	0	0	0	0				
Norway	2,700	0	0	0	0	0		
Serbia and Montenegro						15,500	13,800	11,600
United Kingdom								
USSR (Asia)								
USSR (Europe)								
Yugoslavia	70,900	51,700	46,000	31,000	23,000			
Zaire								

Country	2006	2007	2008	2009	2010	2011	2012
Total	14,992,892	15,520,238	15,698,791	15,817,889	16,112,835	16,071,490	16,764,481
Chile	5,360,800	5,557,000	5,327,600	5,394,400	5,418,900	5,262,800	5,433,900
Peru	1,049,472	1,190,274	1,267,867	1,276,249	1,247,184	1,235,345	1,298,761
China	872,900	946,200	1,092,700	1,062,000	1,179,500	1,294,700	1,576,800
United States	1,220,000	1,170,000	1,310,000	1,190,000	1,110,000	1,112,900	1,166,800
Congo, D.R.	65,000	185,147	337,430	309,610	437,755	499,198	619,942
Australia	879,000	869,000	886,000	859,000	870,000	960,000	921,390
Zambia	515,618	550,292	567,700	601,200	731,700	739,800	699,020
Mexico	312,075	337,527	246,593	240,648	270,136	443,621	500,275
Russia	675,000	690,000	705,000	675,700	702,700	587,900	638,000
Indonesia	817,796	796,899	655,046	998,530	879,697	545,263	398,000
Canada	603,295	596,248	607,957	484,600	522,172	568,779	580,082
Kazakhstan	434,100	406,091	421,700	406,100	381,000	405,300	426,200
Poland	497,200	408,000	474,000	439,000	425,400	426,665	427,064
Brazil	147,800	205,700	218,295	211,692	213,548	213,760	223,141
Mongolia	129,675	130,165	126,805	129,815	124,985	126,250	126,550
Iran	216,200	244,200	248,100	262,599	256,700	258,900	238,000
Spain	8,130	6,508	7,067	23,058	50,830	75,057	99,884
Laos	60,800	62,500	89,000	121,580	132,047	138,757	149,580
Bulgaria	124,200	116,200	107,195	110,652	112,900	114,600	107,328
Papua New Guinea	194,400	169,184	159,700	166,700	159,800	130,500	125,348
Sweden	86,746	62,905	57,700	55,414	76,514	82,967	82,422
Uzbekistan	80,000	80,000	80,000	80,000	80,000	80,000	95,600
Armenia	17,726	18,018	18,175	23,188	30,672	32,128	38,968
Turkey	46,400	78,690	86,440	73,390	70,930	93,690	101,700
Philippines	17,700	22,862	21,200	49,060	58,400	63,835	65,444
Myanmar	19,500	15,100	6,900	9,800	12,000	12,000	12,000
South Africa	109,590	117,066	97,185	92,884	83,640	89,298	69,859
Portugal	78,660	97,635	91,440	86,495	74,426	79,686	74,941
Saudi Arabia	700	737	1,465	1,700	1,603	1,954	17,639
Finland	13,000	13,400	13,400	14,800	14,700	14,000	25,445
Serbia		15,400	19,500	22,500	21,200	25,250	32,200

Country	2006	2007	2008	2009	2010	2011	2012
Morocco	5,705	5,590	5,930	11,830	14,980	12,080	16,580
India	27,400	33,102	30,060	28,440	31,480	30,000	28,440
Argentina	180,144	180,223	156,893	143,100	140,300	116,700	135,700
Mauritania	5,000	28,911	32,900	36,600	37,000	39,900	37,670
Vietnam	11,400	12,500	11,520	12,935	12,260	11,890	12,720
Tanzania	3,292	3,283	2,859	2,024	5,337	5,082	5,836
Namibia	6,307	7,616	8,775	0	0	3,400	5,304
Korea, North	12,000	12,000	2,400	2,100	4,600	7,000	6,700
Georgia	9,300	11,000	18,700	16,600	10,660	10,210	6,820
Pakistan	18,700	18,800	18,700	17,605	19,400	15,672	19,229
Dominican Republic			2,109	12,937	10,015	11,777	11,737
Colombia	580	840	1,050	1,140	780	810	750
Macedonia	7,050	7,030	8,050	7,440	7,910	7,550	8,901
Zimbabwe	2,600	2,700	2,800	3,572	4,629	6,555	6,665
Ecuador							2,500
Romania	12,100	2,213	900	3,100	5,100	6,360	9,482
Kyrgyzstan							
Eritrea							0
Bolivia	218	606	600	882	2,063	4,176	8,653
Tajikistan						440	440
Azerbaijan					183	611	502
Cyprus	900	3,012	2,986	2,380	2,595	3,660	4,328
Botswana	24,255	19,996	23,146	24,382	31,200	31,926	35,770
Slovakia	4	6	2	14	22	28	31
Korea, South	4	2	1	4	2		
Albania	1,050	2,760	2,860	2,670	3,010	4,860	5,680
Oman		9,100	16,390	15,770	18,270	23,400	21,760
Afghanistan	0						
Cuba	0						
Czech Republic							
Czechoslovakia							
El Salvador						2,500	

Country	2006	2007	2008	2009	2010	2011	2012
France							
German Dem, Rep							
Germany							
Honduras	0	0	0				
Jamaica							
Japan	300	0					
Malaysia	0						
Mozambique							
Nepal							
Norway							
Serbia and Montenegro	11,100						
United Kingdom							
USSR (Asia)							
USSR (Europe)							
Yugoslavia							
Zaire							

Country	2013	2014	2015	2016	2017	Total
Total	18,271,418	18,560,557	19,363,032	20,464,363	19,939,825	393,790,781
Chile	5,776,000	5,761,100	5,772,100	5,552,600	5,503,500	122,294,100
Peru	1,375,639	1,377,642	1,700,817	2,353,859	2,445,585	27,076,780
China	1,715,200	1,781,000	1,706,400	1,851,000	1,656,400	24,749,400
United States	1,278,200	1,360,000	1,380,000	1,430,000	1,260,000	40,130,510
Congo, D.R.	914,631	1,030,129	1,039,007	1,023,687	1,094,638	7,781,306
Australia	1,000,999	978,534	995,881	947,555	859,811	20,950,670
Zambia	763,805	708,259	711,515	774,290	797,266	14,077,465
Mexico	480,124	515,025	594,451	766,760	742,246	10,644,545
Russia	655,000	691,500	711,400	702,300	705,400	17,917,370
Indonesia	512,033	379,787	586,914	727,959	622,216	15,644,431
Canada	652,595	672,729	714,647	695,508	605,731	18,013,443
Kazakhstan	452,500	471,700	467,500	471,500	540,700	10,296,991
Poland	428,879	421,285	425,870	424,276	419,300	12,079,239
Brazil	270,979	301,197	359,463	337,628	384,400	3,843,531
Mongolia	203,800	274,600	335,850	374,260	314,920	4,360,231
Iran	222,900	216,800	254,709	282,500	295,653	4,919,784
Spain	102,977	104,476	129,788	172,522	204,606	1,234,584
Laos	154,915	159,696	167,702	167,679	153,304	1,589,760
Bulgaria	115,450	115,540	112,600	111,870	110,290	2,587,425
Papua New Guinea	105,523	75,901	45,185	80,022	105,448	4,534,096
Sweden	82,904	79,681	75,113	79,247	104,594	2,202,656
Uzbekistan	98,000	99,500	100,000	100,000	100,000	2,049,100
Armenia	44,797	46,849	51,765	95,080	95,793	656,686
Turkey	120,500	96,300	108,000	107,300	85,200	1,936,998
Philippines	90,861	91,922	83,835	83,649	68,156	1,839,427
Myanmar	20,000	33,200	69,850	71,190	66,960	599,400
South Africa	80,821	78,697	77,360	65,257	65,503	3,422,957
Portugal	77,236	75,433	83,081	74,352	63,812	2,763,520
Saudi Arabia	5,440	11,570	12,340	27,840	59,870	155,644
Finland	38,763	42,810	41,805	47,488	53,144	516,313
Serbia	32,609	31,584	31,601	34,625	45,115	311,584

Country	2013	2014	2015	2016	2017	Total
Morocco	13,020	22,360	26,850	31,810	35,420	348,540
India	32,276	24,750	34,920	32,000	33,680	1,018,903
Argentina	109,631	97,556	61,765	81,902	33,303	2,967,379
Mauritania	37,970	33,079	45,001	32,818	28,791	395,640
Vietnam	14,188	21,762	24,420	22,300	21,100	201,095
Tanzania	15,400	16,400	16,800	17,400	15,800	128,005
Namibia	5,182	5,086	13,913	16,391	15,466	374,277
Korea, North	6,200	14,400	15,000	20,000	15,000	305,400
Georgia	7,800	13,100	11,700	12,200	14,700	242,490
Pakistan	13,500	13,122	13,056	14,136	10,052	237,172
Dominican Republic	10,379	9,262	7,324	9,725	9,618	94,883
Colombia	640	4,118	5,463	8,493	9,356	62,480
Macedonia	10,641	10,241	11,102	10,429	8,966	225,834
Zimbabwe	8,285	8,261	8,218	9,101	8,839	178,673
Ecuador	2,600	3,200	1,400	40,200	8,200	58,700
Romania	6,700	7,680	7,710	8,390	8,160	431,487
Kyrgyzstan	0	700	3,100	8,200	8,000	20,000
Eritrea	21,779	88,900	61,600	25,300	7,900	205,479
Bolivia	7,549	10,746	9,479	8,718	7,219	63,274
Tajikistan	600	940	1,390	2,050	6,060	11,920
Azerbaijan	327	784	969	1,947	2,063	7,386
Cyprus	3,361	3,088	2,121	1,754	1,293	66,399
Botswana	51,300	47,700	22,284	13,120	1,239	653,914
Slovakia	40	46	58	39	32	5,384
Korea, South			0	117	7	257
Albania	5,920	3,690	2,190	2,020	0	78,175
Oman	12,050	15,140	8,650	0	0	198,499
Afghanistan						19,405
Cuba						20,591
Czech Republic						200
Czechoslovakia						6,901
El Salvador						2,500

Country	2013	2014	2015	2016	2017	Total
France						1,588
German Dem, Rep						3,564
Germany						3
Honduras						9,488
Jamaica						3,000
Japan						67,051
Malaysia						217,334
Mozambique						399
Nepal						29
Norway						89,670
Serbia and Montenegro						52,000
United Kingdom						1,255
USSR (Asia)						1,195,740
USSR (Europe)						512,460
Yugoslavia						888,000
Zaire						938,012

Rare Earth Concentrates

Table 14: Rare Earth producers [metr. t rare earth conc.], organised by largest producer in 2017 (Reichl, et al. 2019)

Country	1990	1991	1992	1993	1994	1995	1996	1997
Total	74,569	68,436	65,134	63,934	58,524	60,457	81,951	68,925
China	27,500	26,900	28,300	29,200	29,000	30,000	55,000	53,300
Australia	11,000	8,250	5,813	6,000	3,300	3,000	2,000	1,000
Russia								
Brazil	3,500	1,308	116	770	800	400	200	400
Malaysia	3,488	1,986	791	429	426	814	618	600
Burundi								
United States	22,700	23,000	23,000	20,000	20,000	22,239	20,400	10,000
Congo, D.R.								
India	4,000	4,000	4,000	4,300	2,500	2,500	2,700	2,700
Korea, North	700	1,500	1,500	1,500	1,500	1,000	900	800
Madagascar	5	5	5	5	5	4	3	0
South Africa	900	1,000	1,200	1,250	700	300	0	0
Sri Lanka	200	200	200	200	200	120	120	120
Thailand	391	137	89	220	65	50	0	0
Zaire	185	150	120	60	28	30	10	5

Country	1998	1999	2000	2001	2002	2003	2004	2005
Total	60,000	79,392	81,561	83,635	86,101	86,896	99,475	103,737
China	50,000	70,000	73,000	75,000	75,000	77,000	95,000	100,000
Australia	800	600	300	0	0	0	0	0
Russia					2,631	1,680	1,592	2,027
Brazil	400	350	340	335	0	0	731	958
Malaysia	500	450	420	400	390	795	1,683	320
Burundi								
United States	5,000	5,000	5,000	5,000	5,000	4,180	0	0
Congo, D.R.		2	1	0				
India	2,500	2,300	2,000	2,500	2,700	2,891	149	122
Korea, North	700	600	500	400	380	350	320	310
Madagascar	0	0	0	0				

Country	1998	1999	2000	2001	2002	2003	2004	2005
South Africa	0	0	0	0				
Sri Lanka	100	90	0					
Thailand	0	0	0	0				
Zaire								

Country	2006	2007	2008	2009	2010	2011	2012
Total	125,132	125,401	128,059	131,642	121,267	101,393	103,008
China	120,000	120,800	124,500	129,400	118,900	96,900	95,000
Australia	0	0				2,188	3,222
Russia	2,935	2,711	2,470	1,898	1,496	1,444	2,131
Brazil	958	1,173	834	303	249	290	206
Malaysia	894	682	233	25	622	571	113
Burundi							
United States	0	0					2,336
Congo, D.R.							
India	45	35	22	16	0	0	0
Korea, North	300	0					
Madagascar							
South Africa							
Sri Lanka							
Thailand							
Zaire							

Country	2013	2014	2015	2016	2017	Total
Total	100,845	109,549	124,096	126,015	127,097	2,646,231
China	93,800	95,000	105,000	105,000	105,000	2,203,500
Australia	1,268	7,191	10,916	13,872	17,264	97,984
Russia	1,443	2,134	2,312	3,063	2,500	34,467
Brazil	600	0	1,625	2,200	2,000	21,046
Malaysia	261	455	565	1,880	302	20,713
Burundi				0	31	31
United States	3,473	4,769	3,678	0	0	204,775
Congo, D.R.						3
India						41,980
Korea, North						13,260
Madagascar						32
South Africa						5,350
Sri Lanka						1,550
Thailand						952
Zaire						588